Eric Whaites | Nicholas Drage

ESSENTIALS OF Dental Radiography and Radiology

SIXTH EDITION



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Essentials of Dental Radiography and Radiology

SIXTH EDITION

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Preface

It is now nearly 30 years since the first edition of *Essentials* was published and nearly 6 years since the first co-authored fifth edition. This sixth edition is again co-authored with my friend and colleague Nicholas Drage and marks the last edition that I will be directly involved with, given that I am in the twilight of my career. It is reassuring to know that *Essentials* will be in Nicholas' safe hands.

I am delighted that we have been given this final opportunity to update and refresh *Essentials* together and to be able to introduce colour images throughout – we hope this has given the book a completely new and modern feel. In addition to the new photographic material, we have revised and updated nearly every chapter. We have tried to align the content and terminology more closely with the new international classifications in relation to cysts, tumours, bone lesions and diseases, caries and periodontal diseases. Many new radiographs have been added and we have placed greater emphasis on examples showing normal radiographic anatomy, working on the principle that the main reason for radiographic imaging is to be able to distinguish the difference in appearance between normal and abnormal, to determine the presence or absence of (hard tissue) disease. Another major change has been to reorder the contents of several chapters so that digital imaging is described first, recognising the switch from film-based imaging to digital imaging.

The website created with, and linked to, the previous edition proved popular with students, particularly the online self-assessment questions relating to each chapter, so these have also been reviewed and new questions added as appropriate.

Despite the various updates and revisions, the aims and objectives of this book remain the same, namely to provide a basic, but comprehensive, practical account of what we consider to be the essential subject matter of both dental radiography and radiology as required by undergraduate and postgraduate dental students. As in previous editions, some things have had to be omitted, or sometimes, over-simplified. However, the book remains first and foremost a teaching manual (albeit more colourful) rather than a comprehensive reference. We believe that the content remains sufficiently broad, detailed and up-to-date to satisfy the requirements of most undergraduate and postgraduate examinations and the needs of most general dental practitioners. Students are encouraged to build on the information included here by using the excellent and more comprehensive textbooks available.

We hope that once again the result is a clear, logical and easily understandable textbook that continues to make a positive contribution to the challenging tasks of teaching and learning dental radiology.

EW

Acknowledgements

As with previous editions, this edition has only been possible thanks to the enormous amount of help and encouragement that we have received from our various friends and colleagues in both London and Cardiff.

In particular, we would like to thank Nigel Pearson, Head of the Medical Photography Department at Guy's and St Thomas', and Sam Evans from the Dental Photography Unit, Cardiff University, who together are responsible for all the new photographic images. Special thanks to Beatrice Cicchetti for volunteering to be our adult patient model – her patience and ever-present smile made hours of photography bearable for all of us! Our thanks also to Clive and Charlene Bathurst for allowing their daughter Hayley to be our child patient model. Our thanks also to Richard Beal (Clarke Dental Limited), Paul Keeley (Henry Schein Dental) and Jay McKay (Sirona-Dentsply) for supplying some of the equipment for photography purposes.

We are very grateful to several colleagues for their help and advice with specific chapters. They include Melanie Wilson, Senior Lecturer in Oral Microbiology in Cardiff for Chapter 8 ; Dirk Bister, Consultant in Orthodontics at Guy's for Chapter 14 ; Simon Harvey, Consultant in Dental & Maxillofacial Radiology at Guy's for Chapter 18 ; Avi Banerjee, Professor of Cariology at King's College London for Chapter 21 ; Francis Hughes, Professor of Periodontology at King's College London for Chapter 22 , George Paolinelis, Consultant in Oral Surgery at Guy's for Chapter 23 and Eddy Odell, Professor of Oral Pathology, King's College London for Chapters 26 and 27 . In addition, Dental Radiology Departmental colleagues at Guy's willingly offered their

help and advice – in particular we would like to thank Jackie Brown, Bethan Thomas, John Rout, Niall O'Neill, Amanda Loughlin, Beatrice Cicchetti and Stephen Goss. We are also very grateful to Andrew Gulson, from Public Health England for his permission to allow us to reproduce parts of the 2020 Guidance Notes. Special thanks to Allisson Summerfield for co-ordinating the IT and imagery, the hours she spent photocopying and electronically correcting the proofs, and for always being on hand to ensure the job got done! Many thanks also to Elsevier's Alison Taylor, our now retired Content Strategist, Fiona Conn for masterminding the manuscript to get it ready for production, and Karthikeyan Murthy and his team for their huge effort in getting the book to final publication.

Last, but by no means least, we would once again like to thank our wives Catriona and Anji and our children Stuart, Felicity and Claudia, and Karisma and Jaimini for their love, understanding and encouragement throughout the production of this edition and for accepting the sacrifice of family time that it has involved.

EW

ND

PART I
Introduction

OUTLINE

1. The Radiographic Image

1

The Radiographic Image

Introduction

The use of X-rays is an integral part of clinical dentistry, with some form of radiographic examination necessary on the majority of patients. Radiographs are primarily taken to determine the presence or absence of underlying hard tissue disease affecting the teeth and/or bones. As a result, radiographs are often referred to as the clinician's *main diagnostic aid* . Traditional radiography enables the creation of conventional two-dimensional radiographic images, but technological advances in computer generated images – so-called *cone beam computed tomography (CBCT)* - has resulted in imaging in three dimensions and improved diagnostic capability (see Figs. 1.1 and 1.2).

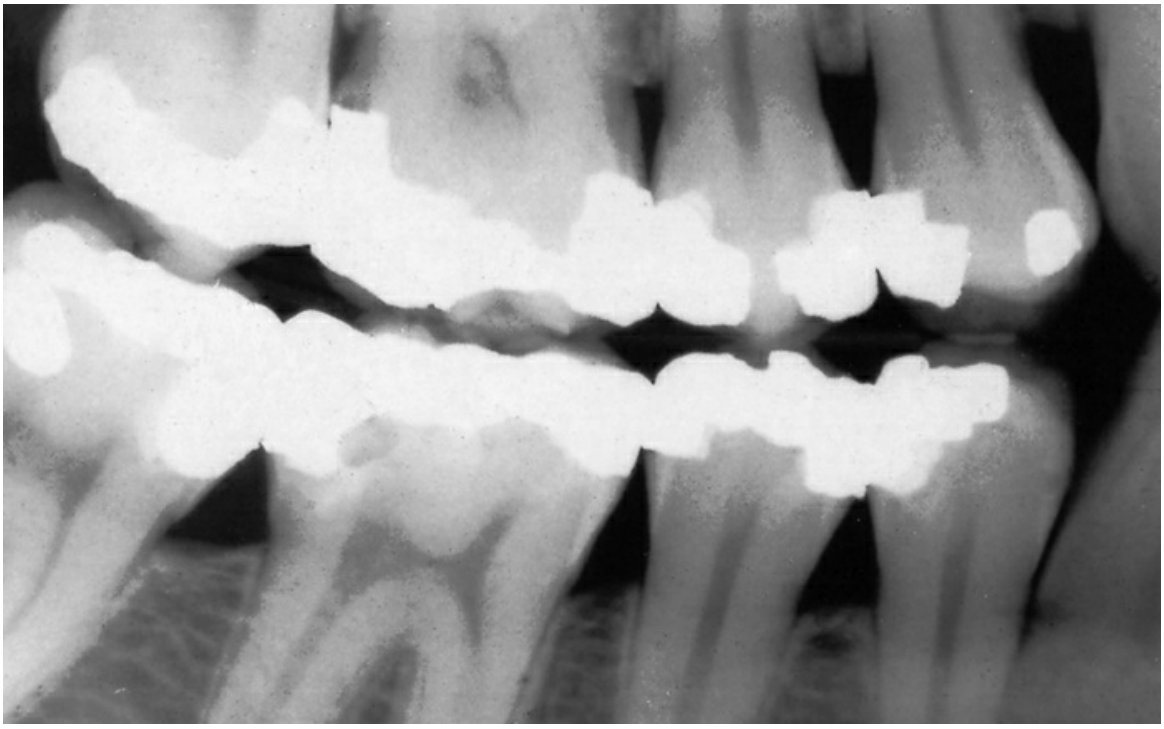


FIG. 1.1 A traditional two-dimensional dental radiograph showing the hard tissues of the teeth, containing metallic amalgam restorations, and the supporting alveolar bone.

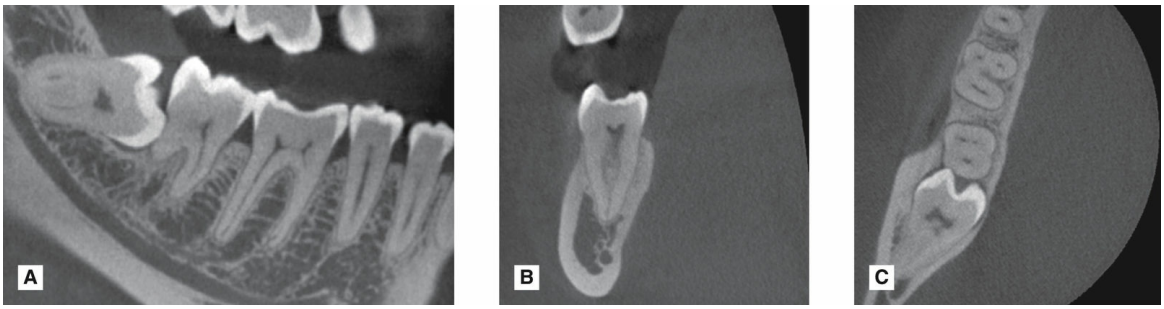


FIG. 1.2 Modern cone beam computed tomography (CBCT) radiographic images in three dimensions of the lower right molar teeth in the **(A)** sagittal, **(B)** coronal and **(C)** axial planes.

The range of knowledge of dental radiography and radiology thus required can be divided conveniently into four main sections:

- *Basic physics, X-ray equipment and image receptors* – how X-rays

are produced, their properties and how their interactions result in the formation of the various two-dimensional and three-dimensional radiographic images

- *Radiation protection* – the protection of patients and dental staff from the harmful effects of X-rays
- *Radiography* – the techniques involved in producing the various radiographic images
- *Radiology* – the interpretation of these various radiographic images, which requires a knowledge of the normal anatomy of the teeth and the jaws as well as the different appearances of underlying disease.

Understanding the different radiographic images is central to the entire subject. This chapter provides an introduction to the nature of the traditional two-dimensional image and to some of the factors that affect its quality and perception. The more complex modern CBCT images are described later in .

Nature of the Traditional Two-Dimensional Radiographic Image

The basic requirements to create a traditional two-dimensional dental radiographic image include an *X-ray generating machine* , a *patient* and an *image receptor* placed either inside the mouth (*intraoral*) or outside the mouth (*extraoral*), as shown in Fig. 1.3 . Originally the image receptor used was *film* coated with photographic emulsion that blackened when hit by X-rays. Nowadays film is being replaced more and more by a variety of *digital sensors* with the image being created in a computer and displayed on a monitor. Those parts of the digital sensor that have been hit by X-rays appear black in the computer-generated image. The extent to which the emulsion or the computer-generated image is blackened depends on the number of X-rays reaching the film or the sensor, which in turn depends on the density of the object.

However the final image is captured, it can be described as a two-dimensional picture made up of a variety of black, white and grey superimposed shadows and is thus sometimes referred to as a *shadowgraph* .

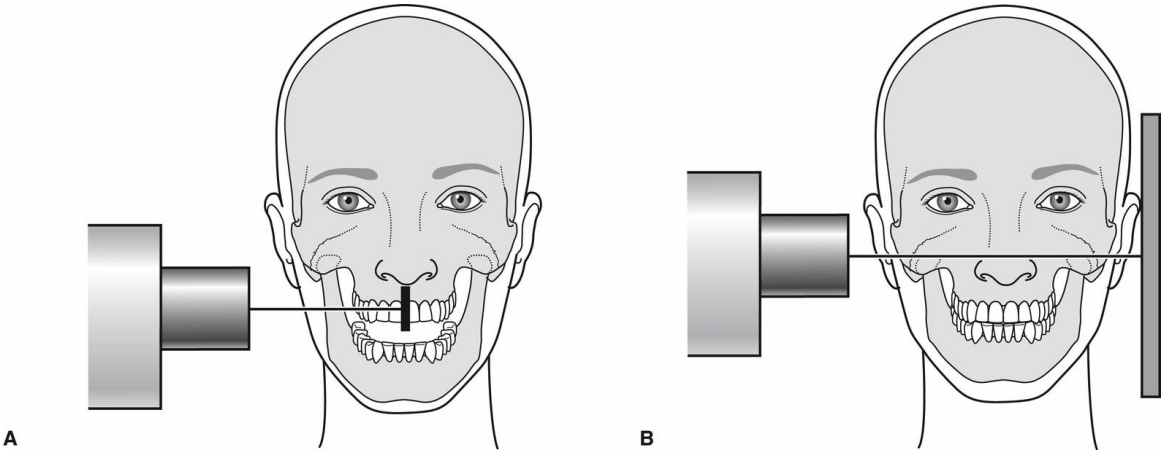


FIG. 1.3 Diagrams showing the basic requirements for two-dimensional radiography – an X-ray generating machine, a patient and an image receptor for **(A)** intraoral imaging and **(B)** extraoral imaging.

Understanding the nature of the *shadowgraph* and interpreting the information contained within it requires a knowledge of:

- The radiographic shadows
- The three-dimensional anatomical tissues
- The limitations imposed by a two-dimensional picture and superimposition.

The Radiographic Shadows

The amount the X-ray beam is stopped (attenuated) by an object determines the *radiodensity* of the shadows:

- The white or *radiopaque* shadows on an image represent the various dense structures within the object which have totally stopped the X-ray beam.

- The black or *radiolucent* shadows represent areas where the X-ray beam has passed through the object and has not been stopped at all.

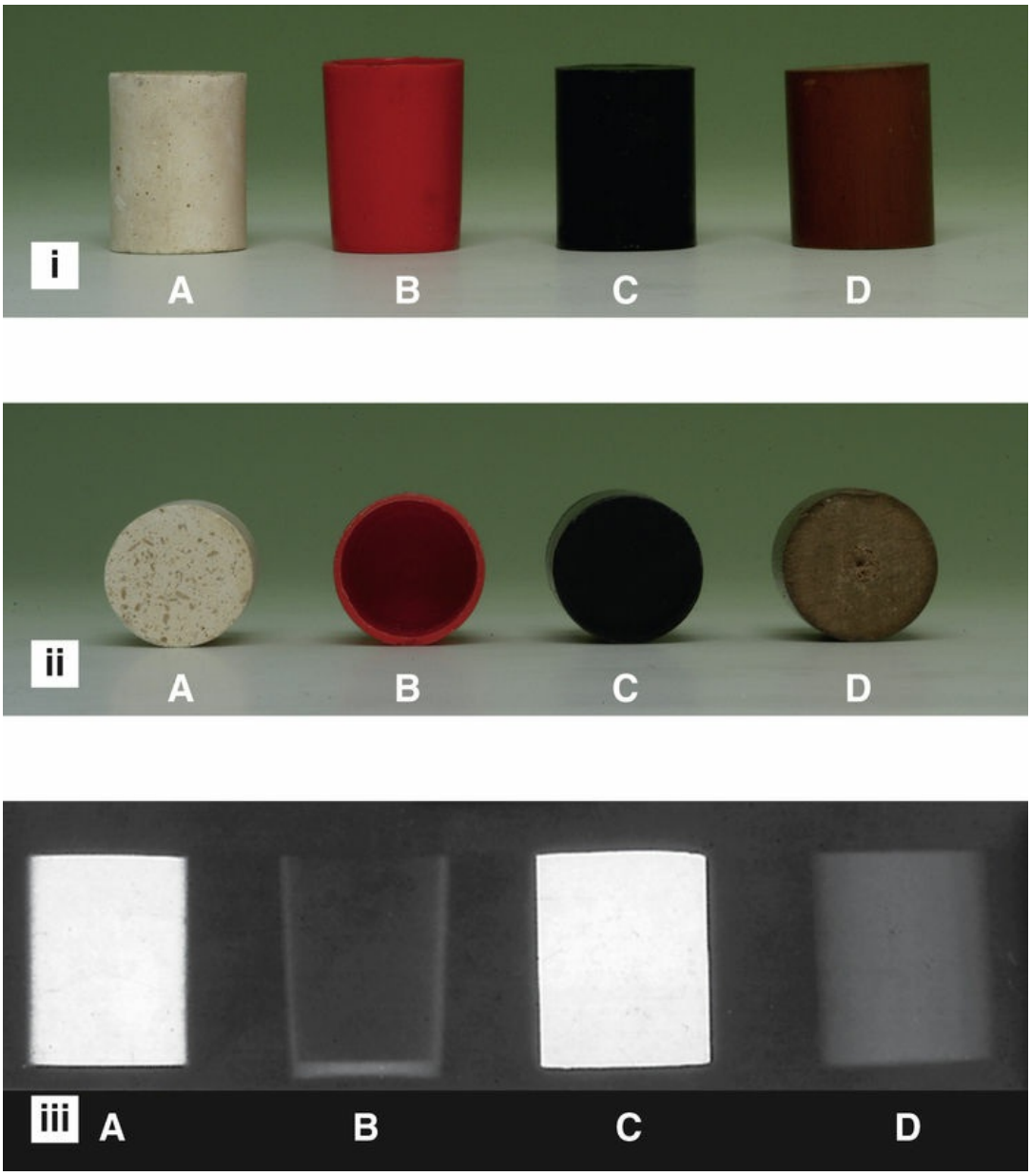


FIG. 1.4 **(i)** Front view and **(ii)** plan view of various cylinders of similar shape but made of different materials: **(A)** plaster of Paris, **(B)** hollow plastic, **(C)** metal, and **(D)** wood. **(iii)** Radiographs of the cylinders show how objects of the same shape, but of different materials, produce different radiographic images.

- The grey shadows represent areas where the X-ray beam has been stopped to a varying degree.

The final *shadow density* of any object is thus affected by:

- The specific type of material of which the object is made
- The thickness or density of the material
- The shape of the object
- The intensity of the X-ray beam used
- The position of the object in relation to the X-ray beam and image receptor
- The sensitivity and type of image receptor.

The effect of different materials, different thicknesses/densities, different shapes and different X-ray beam intensities on the radiographic image shadows are shown in Figs. 1.4 - 1.7 .

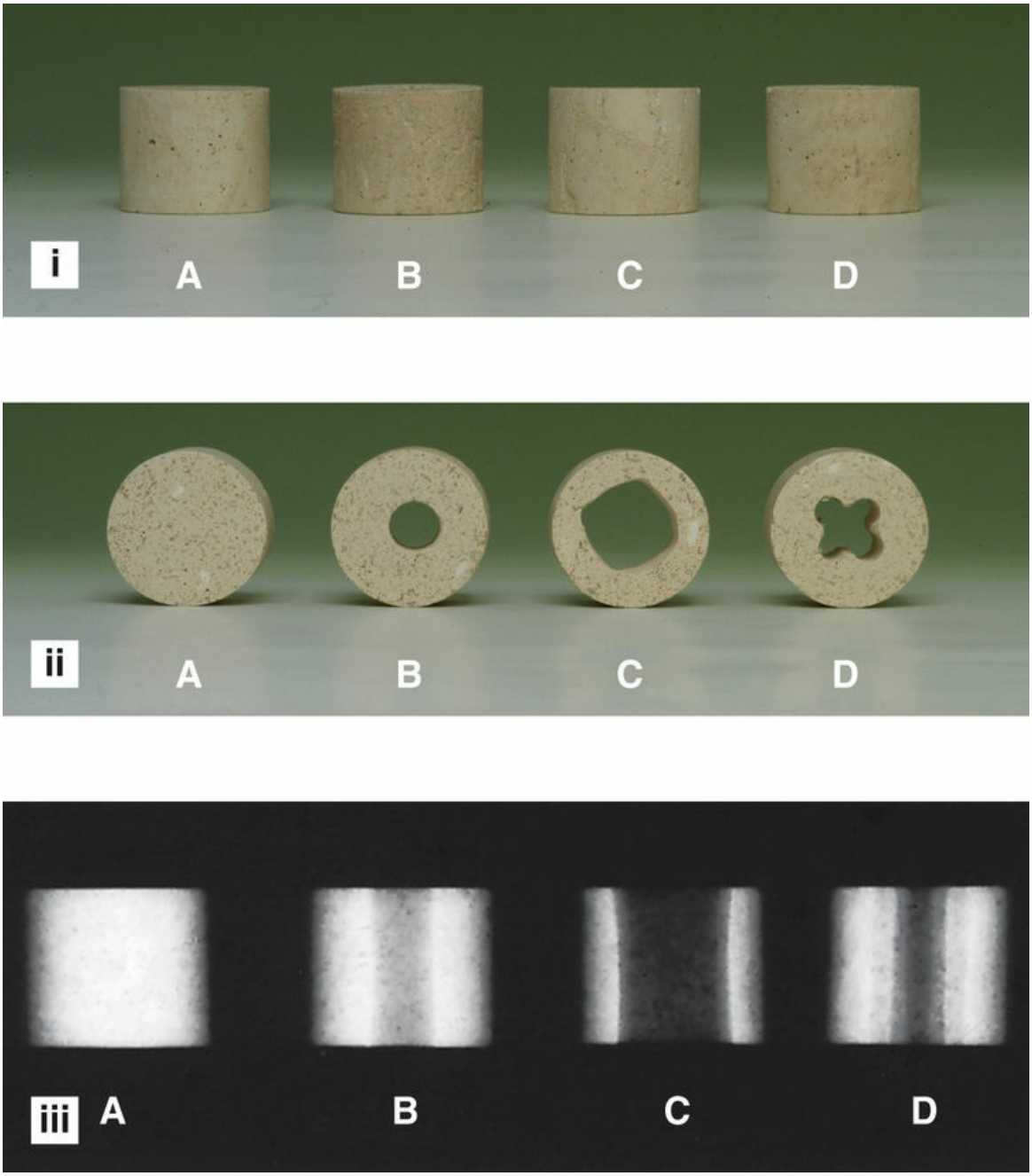


FIG. 1.5 **(i)** Front view of four apparently similar cylinders made from plaster of Paris. **(ii)** The plan view shows the cylinders have varying internal designs and thicknesses. **(iii)** Radiographs of the apparently similar cylinders show how objects of similar shape and material, but of different densities, produce different radiographic images.

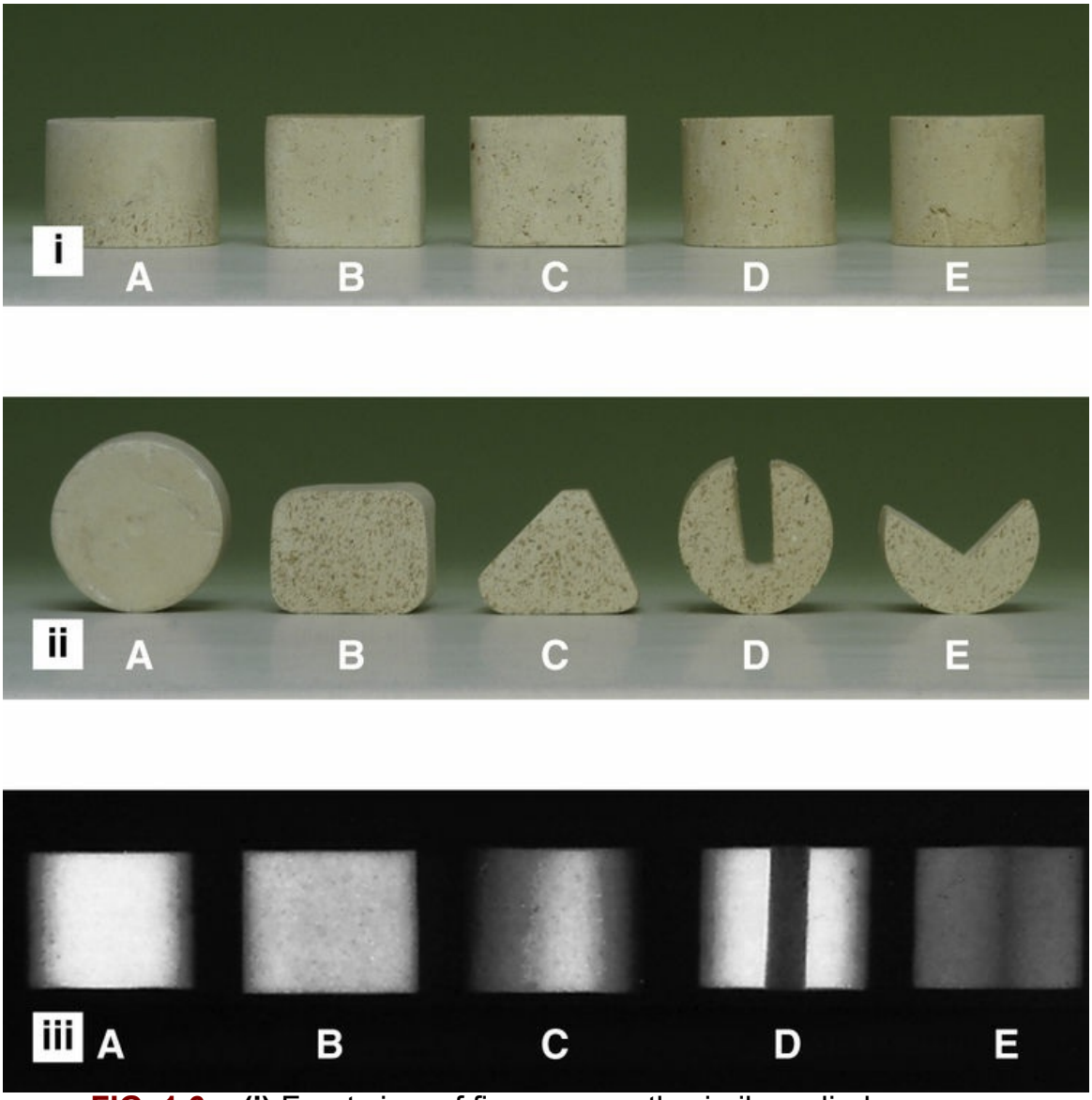


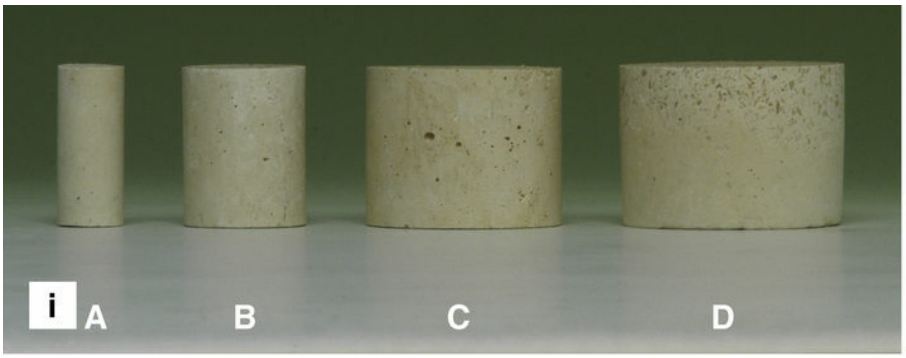
FIG. 1.6 **(i)** Front view of five apparently similar cylinders made from plaster of Paris. **(ii)** A plan view shows the objects are in fact different shapes. **(iii)** Radiographs show how objects of different shape, but made of the same material, produce different radiographic images.

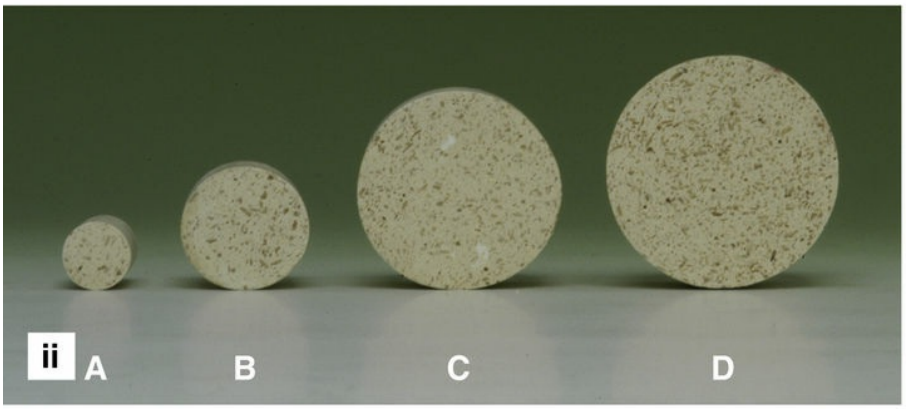
The Three-dimensional Anatomical Tissues

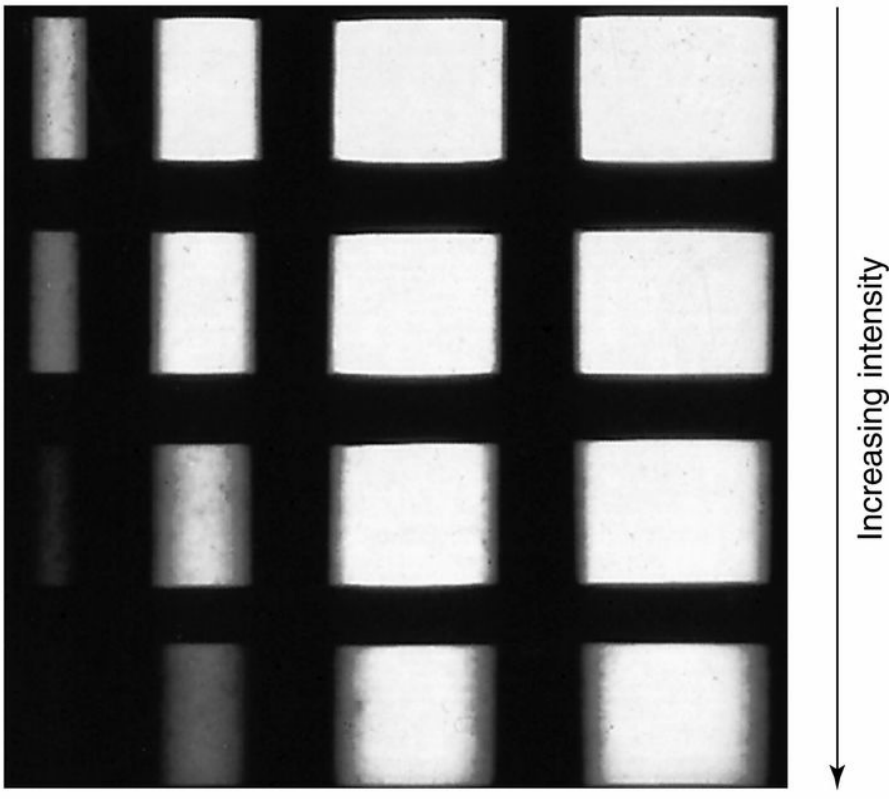
Traditional two-dimensional radiographic images depict the variable shape, density, thickness and internal structures of the patient's three-dimensional anatomical hard tissues. A sound anatomical knowledge

of the jaws and the bones of the skull is obviously a prerequisite for radiological interpretation. This knowledge not only includes the names and location of the bones, but also their shape, thickness and internal structure (see Figs. 1.8 and 1.9).

Radiological images are dramatically affected by anatomical foramina and internal cavities. In relation to the teeth and their supporting structures, examples include the mental foramina in the premolar regions of the mandible and the midline nasopalatine foramen and antral cavities in the maxilla. The various radiographic appearances of the important normal anatomical structures are illustrated and identified in subsequent chapters.



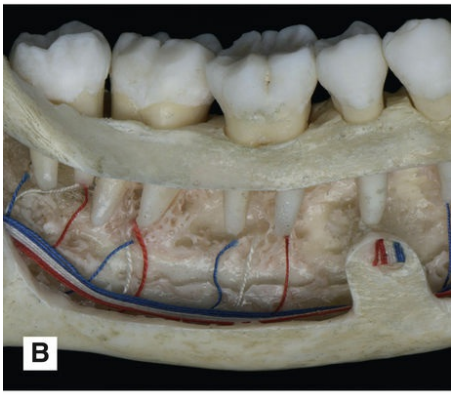




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FIG. 1.7 **(i)** Front view and **(ii)** plan view of four cylinders made from plaster of Paris but of different diameters. **(iii)** Four radiographs using different intensity X-ray beams show how increasing the intensity of the X-ray beam causes greater penetration of the object with less attenuation, hence the less radiopaque (white) shadows of the object that are produced, particularly of the smallest cylinder.


A

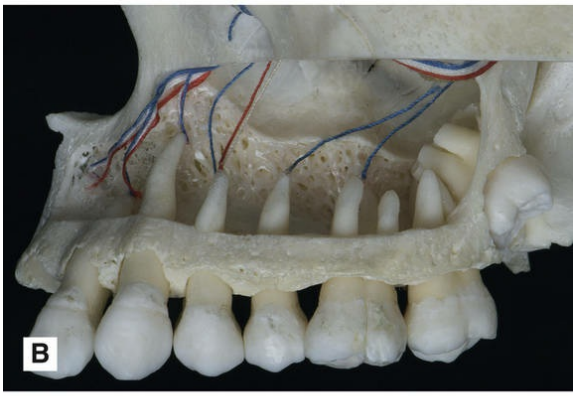

B


C


D

FIG. 1.8 Photographs showing the three-dimensional anatomy of the premolar/molar region of a dried mandible. **(A)** The external bone, **(B)** the teeth embedded in the bone and **(C)** a sagittal section showing the various internal bone structures. **(D)** Traditional two-dimensional radiographic image.


A


B


C


D

FIG. 1.9 Photographs showing the three-dimensional anatomy of the premolar/molar region of a dried maxilla. **(A)** The external bone, **(B)** the teeth embedded in the bone and **(C)** a sagittal section through the mid-line. **(D)** Traditional two-dimensional radiographic image.

The Limitations Imposed by a Two-dimensional Image and Superimposition

To visualize all aspects of any three-dimensional object, it must be viewed from several different positions. This point can be illustrated by considering an everyday object such as a *teacup* as shown in Fig. 1.10 . A photograph of the front of the cup does not allow the observer to appreciate that the teacup has a handle. A photograph from the side shows that the teacup has a handle, but a third photograph from above is also required to determine where the handle is positioned, although it provides no information as to the height of the teacup or the shape of its base.

In a traditional two-dimensional radiographic image the shadows cast by the different parts of an object are superimposed upon one another, thereby creating a more complex image than a simple two-dimensional photograph. This difference and the limitations caused by superimposition can be illustrated by X-raying the same tea cup, as shown in Fig. 1.11 . The front view radiographic image merely depicts the outline of the teacup, but does allow the observer to see the shadow of the handle. However, it gives no indication as to which side of the cup the handle is located or its shape.

All these inherent limitations of the radiographic image need to be remembered when clinically X-raying patients. Unfortunately, it is all too easy for the observer to forget that teeth and patients are three-dimensional. The superimposition of structures means that the traditional two-dimensional radiographic image can provide limited or even misleading information as to where a particular structure lies, or to its shape, as shown in Fig. 1.12A .



FIG. 1.10 Three two-dimensional photographs of a teacup. **(A)** The front view provides no information on the handle. **(B)** The side view shows the shape of the handle while **(C)** , the plan view, shows the handle is positioned in the middle of the teacup, but provides no information on the height of the teacup or the shape of its base.



FIG. 1.11 Three two-dimensional radiographs of the same teacup illustrated in Fig. 1.10 . **(A)** The front view shows only the outline of the teacup and the shadow of the handle, but gives no information as to which side of the cup the handle is located or its shape. **(B)** The side view again shows the outline of the cup and also the shape of the handle. **(C)** The plan view confirms the teacup is round and shows the position of the handle, but provides no information on the height of the teacup or the shape of its base.

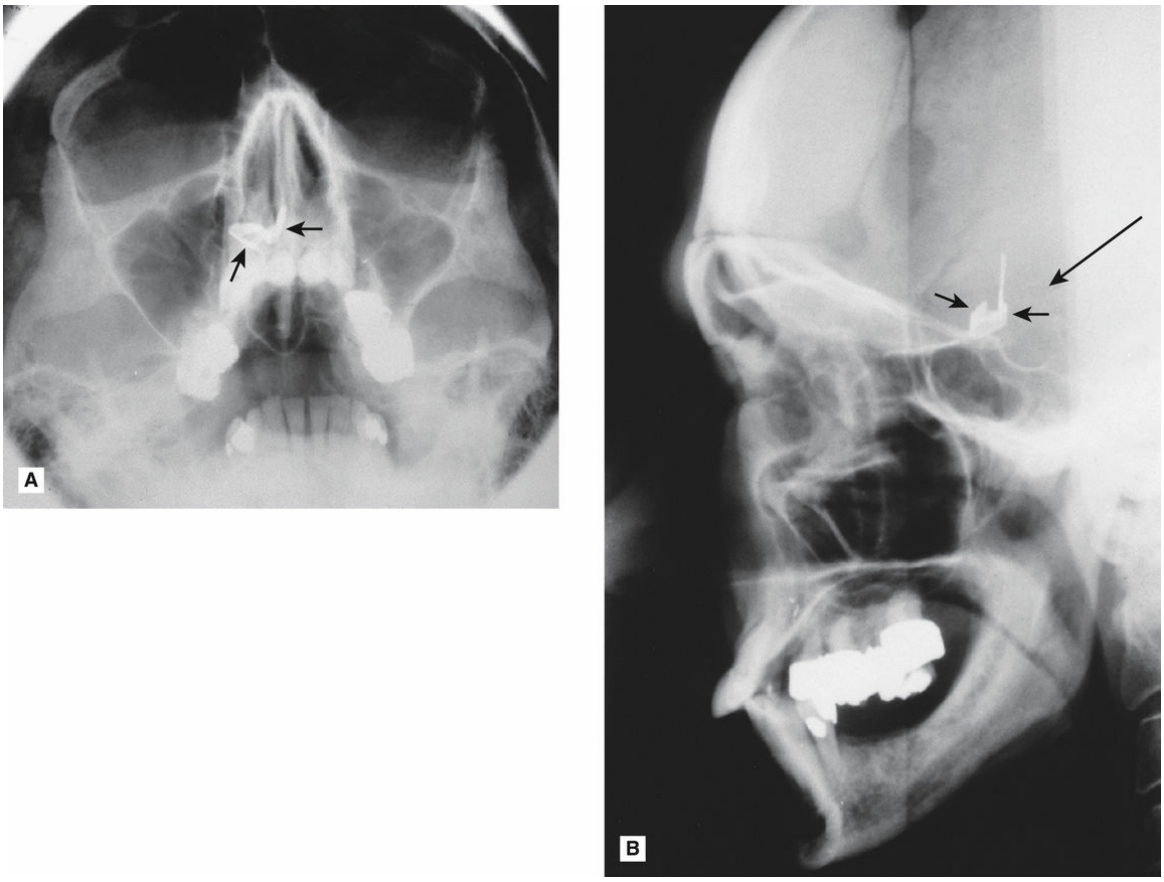


FIG. 1.12 The limitations of traditional two-dimensional skull radiographs illustrated using **(A)** An *occipitomental* (from the front) and **(B)** a *lateral skull* (from the side). A radiopaque (white) object (arrowed) is evident on both images. On the occipitomental view, it can be seen apparently in the base of the right nasal cavity. On the lateral skull, it appears intracranially just above the skull base. It is in fact a metallic aneurysm clip positioned on an artery in the Circle of Willis at the base of the brain. The long black arrow shows the direction of the X-ray beam required to produce radiograph **(A)** , illustrating how the shadow cast by the intracranial metallic clip appears in the nose on this image.

One clinical approach to try to solve these problems is to take two views, ideally at right angles to one another as shown in Fig. 1.12B . The limitation of a two-dimensional image not providing all the desired information required and the use of two views to determine the size and/or location of a lesion is illustrated diagrammatically in Fig. 1.13 .

Unfortunately, even two views may still not provide enough information for a diagnosis to be made. As shown diagrammatically in Fig. 1.14 , a dense radiopaque shadow on one side of the head may overlie the area of interest (the lesion) on the other, thus obscuring it from view.

These limitations of the conventional radiographic image have very important clinical implications and may be the underlying reason for a *negative radiographic report.* The fact that a particular feature or condition is not visible on one radiograph does not mean that the feature or condition does not exist, merely that it cannot be seen.

As mentioned, the technological advances in computer-generated images such as CBCT have enabled some of these limitations of traditional two-dimensional radiographs to be overcome in dentistry (see Chapter 16). In medical imaging, some of these limitations have been overcome by using medical computed tomography (CT) and magnetic resonance imaging (MRI) (see Chapter 18).

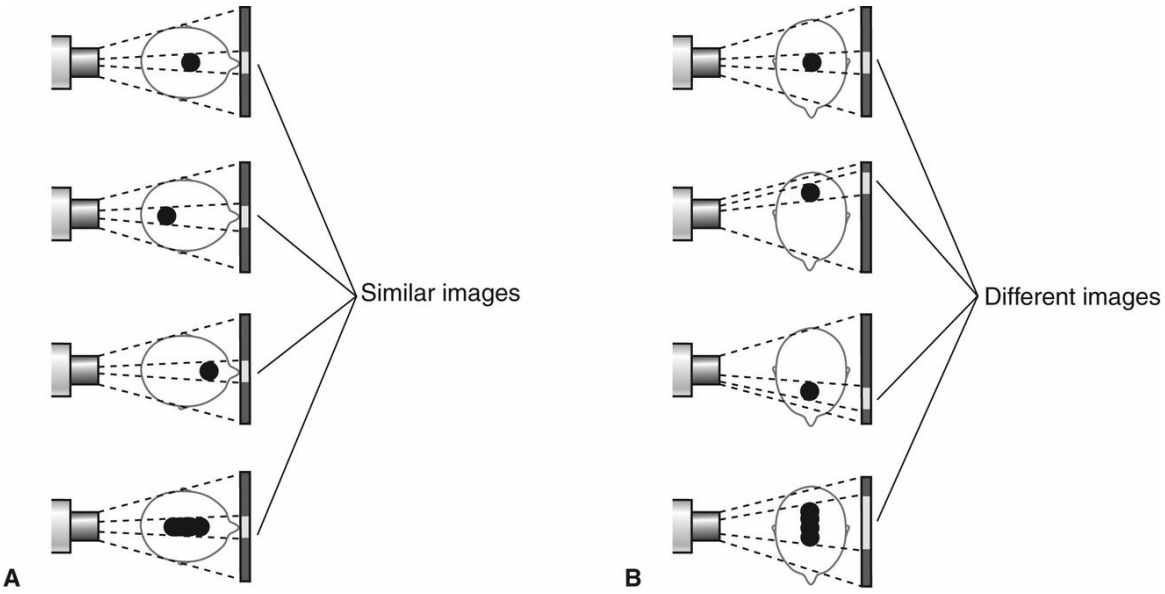


FIG. 1.13 Diagrams illustrating the limitations of a two-dimensional image. **(A)** Posteroanterior views of a head containing a variable mass. The mass appears as a similar-sized opaque image on the radiograph, providing no differentiating information on its position or shape. **(B)** The side view provides a possible solution to the problems

illustrated in **(A)** .

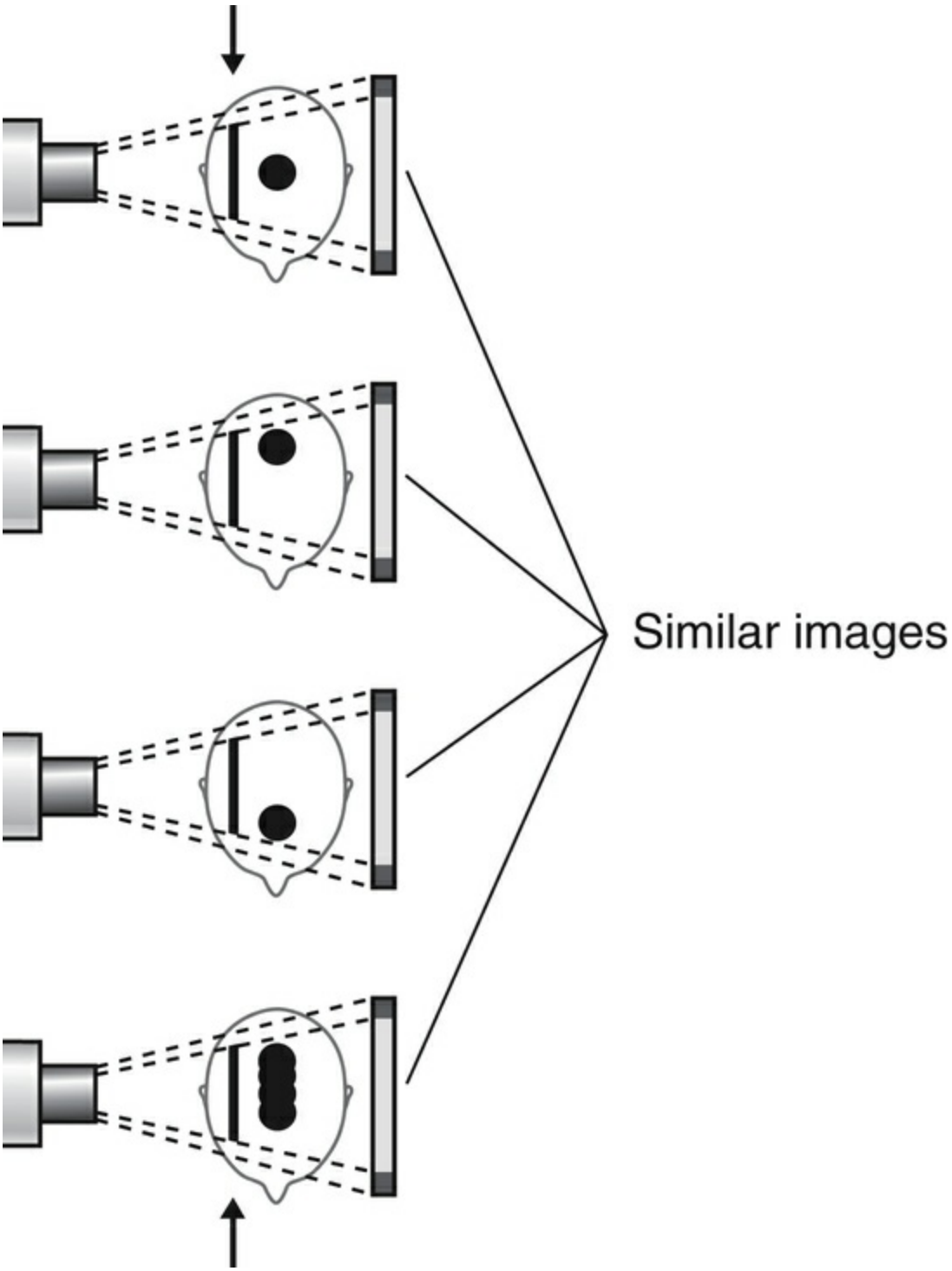


FIG. 1.14 Diagram illustrating the problems of

superimposition. Lateral views of the same masses shown in Fig. 1.10 , but with an additional radiodense object superimposed (arrowed). This view produces a similar image in each case with no evidence of the mass. The information obtained previously is now obscured and the usefulness of using two views at right angles is negated.

Quality of the Traditional Two-Dimensional Radiographic Image

Overall image quality and the amount of detail shown on a traditional two-dimensional radiograph depend on several factors, including:

- Contrast – the visual difference between the various black, white and grey shadows
- Image geometry – the relative positions of the image receptor, object and X-ray tubehead
- Characteristics of the X-ray beam
- Image sharpness and resolution.

These factors in turn depend on several variables, relating to the density of the object, the type of image receptor and the X-ray equipment. They are discussed in greater detail in Chapter 17 . However, to introduce how the geometrical accuracy and detail of the final image can be influenced, two of the main factors are considered.

Positioning of the Image Receptor, Object and X-ray Beam

The position of the X-ray beam, object and image receptor needs to satisfy certain basic geometrical requirements. These include:

- The object and the image receptor should be in contact or as close together as possible

- The object and the image receptor should be parallel to one another
- The X-ray tubehead should be positioned so that the beam meets both the object and the image receptor at right angles.

These ideal requirements are shown diagrammatically in Fig. 1.15 . The effects on the final image of varying the position of the object, image receptor or X-ray beam are shown in Fig. 1.16 .

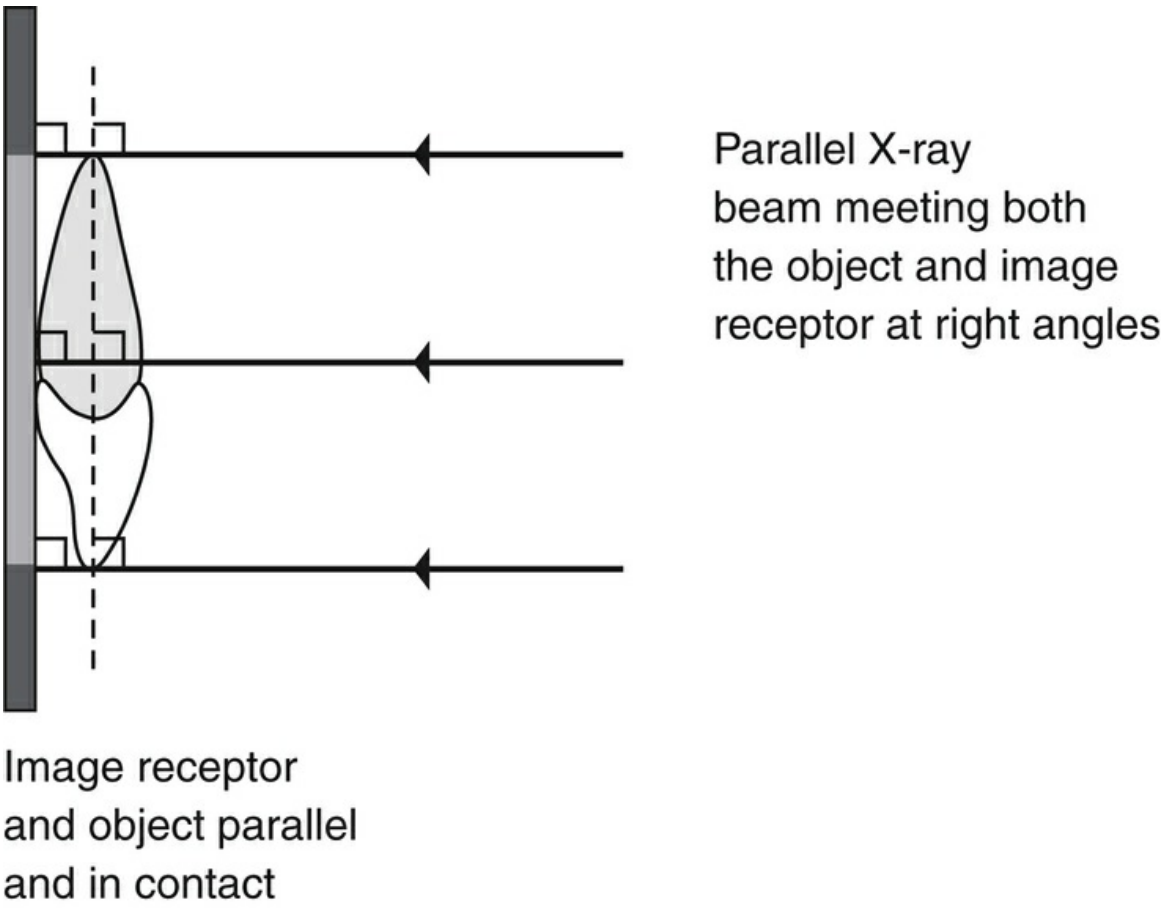


FIG. 1.15 Diagram illustrating the ideal geometrical relationship between the object, image receptor and X-ray beam.

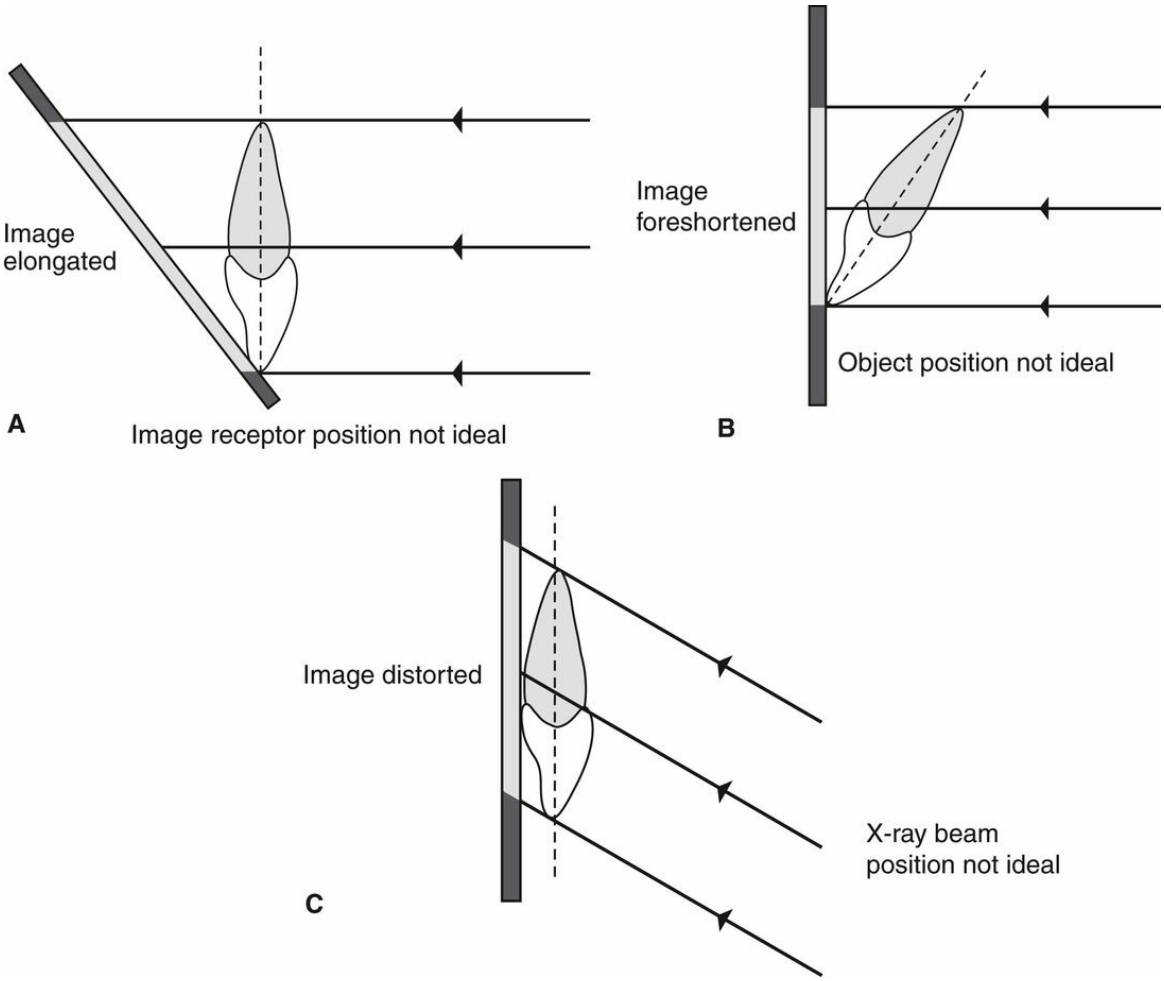


FIG. 1.16 Diagrams showing the effect on the final image of varying the position of **(A)** the image receptor, **(B)** the object and **(C)** the X-ray beam.

X-ray Beam Characteristics

The ideal X-ray beam used for imaging should be:

- Sufficiently penetrating, to pass through the patient and react with the film emulsion or digital sensor and produce good *contrast* between the different shadows (see Fig. 1.17)
- Parallel, i.e. non-diverging, to prevent magnification of the image
- Produced from a point source, to reduce blurring of the edges of the image, a phenomenon known as the *penumbra* effect.

These ideal characteristics are discussed further in Chapter 3 .

Perception of the Radiographic Image

In radiology, we use our sense of sight to perceive the information contained in the radiographic image, but, unfortunately we cannot rely completely on what we see. The apparently simple black, white and grey shadowgraph is a form of optical illusion. The main problems can be caused by the effects of:

- Partial images
- Contrast
- Context.

Effect of Partial Images

The radiographic image only provides a partial image in the form of different density shadows. To complete the picture, the clinician/observer fills in the gaps, but we do not all necessarily do this in the same way and hence may arrive at different conclusions. Three non-clinical examples are shown in Fig. 1.18 .

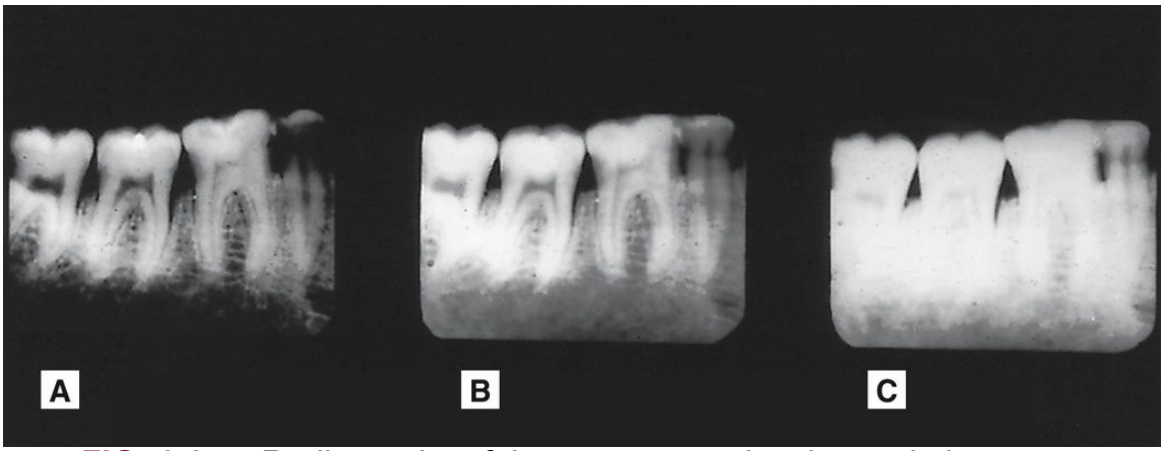


FIG. 1.17 Radiographs of the same area showing variation in contrast – the visual difference in the black, white and grey shadows owing to the penetration of the X-ray beam. **(A)**

Increased exposure (overpenetration). **(B)** Normal exposure. **(C)** Reduced exposure (underpenetration).

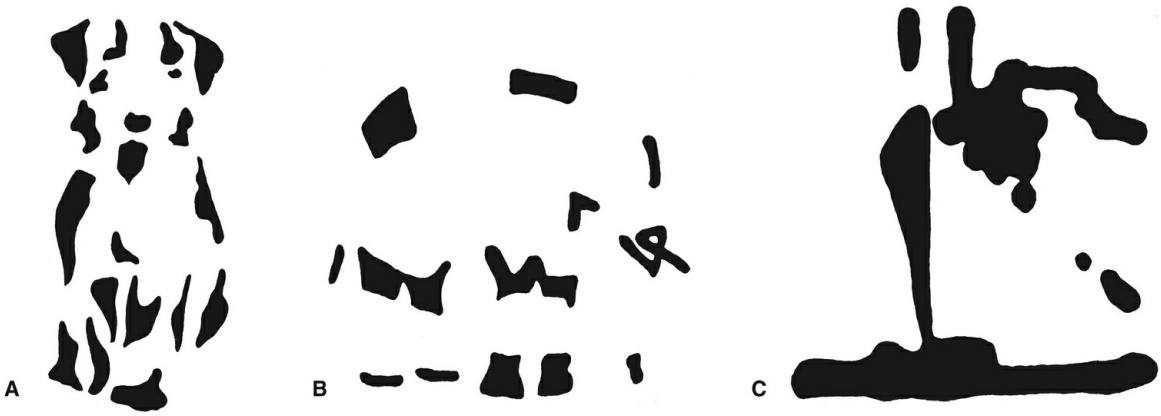


FIG. 1.18 The problem of partial images requiring the observer to fill in the missing gaps. Look at the three non-clinical pictures and what do you perceive? The objects shown are **(A)** a dog, **(B)** an elephant and **(C)** a steam ship. We all see the same partial images, but we do not necessarily *perceive* the same objects. Most people perceive the dog, some perceive the elephant while only a few perceive the ship and take some convincing that it is there.

Figures from: Coren S, Porac C, Ward LM 1979 Sensation and Perception. Harcourt Brace and Company, with permission.

Effect of Contrast

The apparent density of a particular radiographic shadow can be affected considerably by the density of the surrounding shadows. In other words, the contrast between adjacent structures can alter the perceived density of one or both of them (see Fig. 1.19). This factor is of particular importance in dentistry, where metallic restorations produce densely white radiopaque shadows that can affect the apparent density of the adjacent tooth tissue. This phenomenon is discussed in Chapter 20 in relation to caries diagnosis.

Effect of Context

The environment or context in which we see an image can affect how we interpret that image. A non-clinical example is shown in Fig. 1.20 . In dentistry, the environment that can affect our perception of radiographs is that created by the patient's description of the complaint. We can imagine that we see certain radiographic changes, because the patient has conditioned our perceptual apparatus. These various perceptual problems are included as a warning that radiographic interpretation is not as straightforward as it may at first seem.

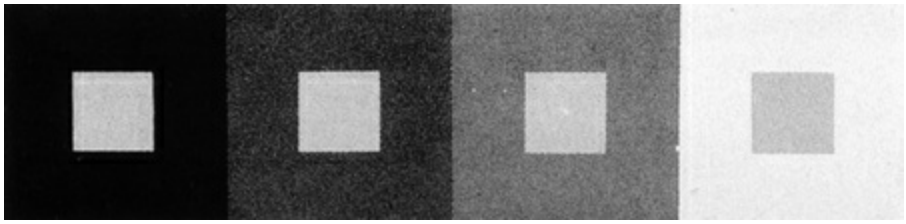


FIG. 1.19 The effect of contrast. The four small inner squares are in reality all the same grey colour, but they appear to be different because of the effect of contrast.
Figure from: Cornsweet TN 1970 Visual Perception. Harcourt Brace and Company, with permission .

Types of Traditional Dental Radiographs

As mentioned, traditional dental radiographs are divided into two main groups – *intraoral* or *extraoral* – depending on the position/location of the image receptor. The various radiographic techniques for the different projections are described in Chapters 9 – 15, which are designed to provide clinicians with the essential knowledge they require, namely:

- WHY each particular projection is taken – i.e. the main clinical indications

- HOW the projections are taken – i.e. the relative positions of the patient, image receptor and X-ray tubehead
- WHAT the resultant radiographs should look like, and which anatomical features they show.

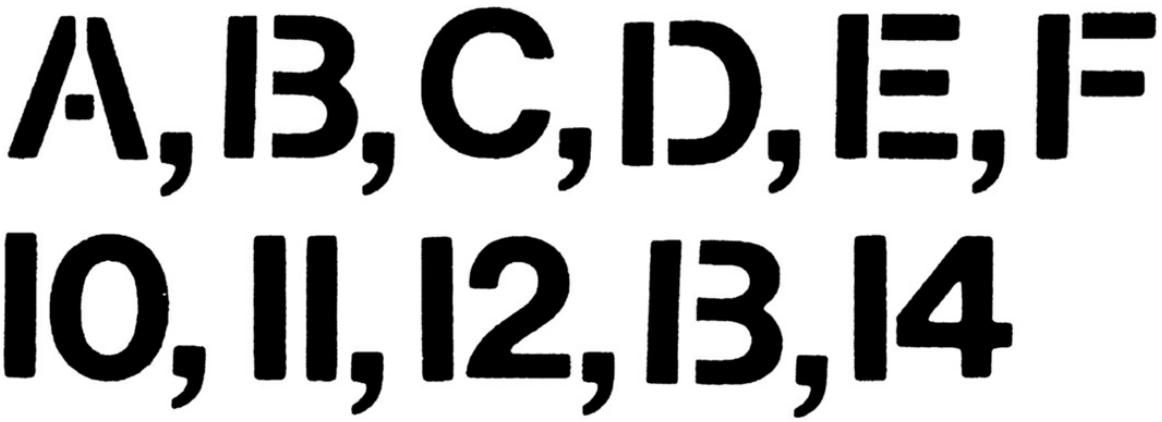


FIG. 1.20 The effect of context. If asked to read the two lines shown here most, if not all, observers would read the letters A, B, C, D, E, F and then the numbers 10, 11, 12, 13, 14. Closer examination shows the letter B and the number 13 to be identical. They are perceived as B and 13 because of the context (surrounding letters or numbers) in which they are seen.

Figures from: Coren S, Porac C, Ward LM 1979 *Sensation and Perception* . Harcourt Brace and Company, with permission.

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PART II
Radiation Physics, Equipment and Radiation Protection

OUTLINE

2. The Production, Properties and Interactions of X-rays

3. Dental X-ray Generating Equipment

4. Image Receptors

5. Image Processing

6. Radiation Dose, Dosimetry and Dose Limitation

7. The Biological Effects Associated with X-rays, Risk and Practical Radiation Protection

2

The Production, Properties and Interactions of X-rays

Introduction

X-rays and their ability to penetrate human tissues were discovered by Röentgen in 1895. He called them X-rays because their nature was then unknown. They are in fact a form of high-energy electromagnetic radiation and are part of the electromagnetic spectrum, which also includes low-energy radio waves, television and visible light as shown in Table 2.1 .

X-rays are described as consisting of *wave packets* of energy. Each packet is called a *photon* and is equivalent to one *quantum* of energy. The X-ray *beam* , as used in diagnostic radiology, is made up of millions of individual photons.

To understand the production and interactions of X-rays a basic knowledge of atomic physics is essential. The next section aims to provide a simple summary of this required background information.

Atomic Structure

Atoms are the basic building blocks of matter. They consist of minute particles – the so-called fundamental or elementary particles – held together by electric and nuclear forces. They consist of a central dense *nucleus* made up of nuclear particles – *protons* and *neutrons* – surrounded by *electrons* in specific orbits or shells (see Fig. 2.1).

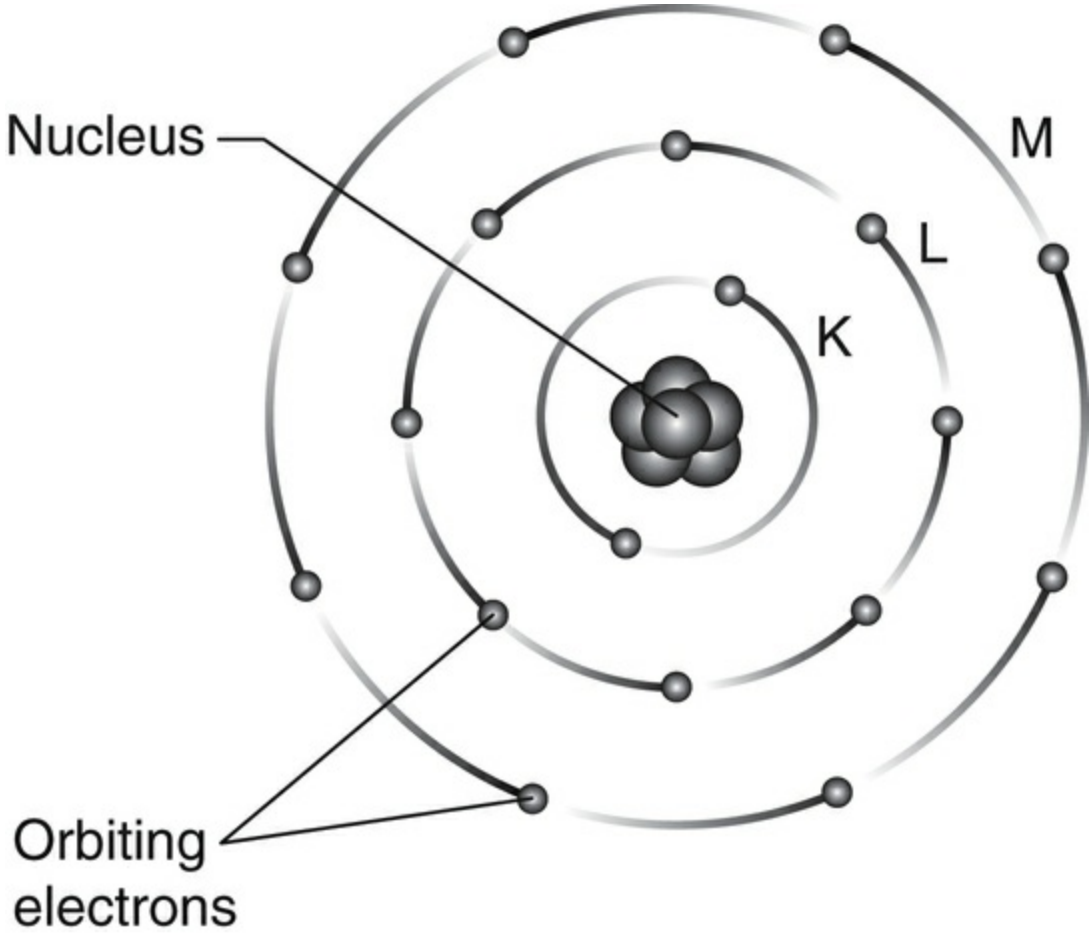


FIG. 2.1 Diagrammatic representation of atomic structure showing the central nucleus and orbiting electrons.

Table 2.1

The electromagnetic spectrum ranging from the low energy (long wavelength) radio waves to the high energy (short wavelength) X-rays and gamma rays.

Radiation	Wavelength	Photon energy
Radio, television and radar waves	$3 \times 10_{4}$ m to 100 μm	$4.1 \times 10_{-11}$ eV to $1.2 \times 10_{-2}$ eV
Infra-red	100 μm to 700 nm	$1.2 \times 10_{-2}$ eV to 1.8 eV
Visible light	700 nm to 400 nm	1.8 eV to 3.1 eV
Ultraviolet	400 nm to 10 nm	3.1 eV to 124 eV

X-rays and gamma rays	10 nm to 0.01 pm	124 eV to 124 MeV

Useful Definitions

- *Atomic number* (Z) – The number of protons in the nucleus of an atom
- *Neutron number* (N) – The number of neutrons in the nucleus of an atom
- *Atomic mass number* (A) – The sum of the number of protons and number of neutrons in an atom (A = Z + N)
- *Isotopes* – Atoms with the same atomic number (Z) but with different atomic mass numbers (A) and hence different numbers of neutrons (N)
- *Radioisotopes* – Isotopes with unstable nuclei which undergo radioactive disintegration (see Chapter 18).

Main Features of the Atomic Particles

Nuclear Particles (Nucleons)

Protons

- Mass = 1.66×10^{-27} kg
- Charge = positive: 1.6×10^{-19} coulombs

Neutrons

- Mass = 1.70×10^{-27} kg
- Charge = nil
- Neutrons act as *binding agents* within the nucleus and hold it together by counteracting the repulsive forces between the protons.

Electrons

- Mass = 1/1840 of the mass of a proton
- Charge = negative: -1.6×10^{-19} coulombs
- Electrons move in predetermined circular or elliptical shells or orbits around the nucleus
- The shells represent different *energy levels* and are labelled K,L,M,N,O outwards from the nucleus
- The shells can contain up to a maximum number of electrons per shell:

  K … 2
  L … 8
  M … 18
  N … 32
  O … 50
- Electrons can move from shell to shell but cannot exist between shells – an area known as the *forbidden zone*
- To remove an electron from the atom, additional energy is required to overcome the *binding energy* of attraction which keeps the electrons in their shells.

Summary of Important Points on Atomic Structure

- In the neutral atom, the number of orbiting electrons is equal to the number of protons in the nucleus. Because the number of electrons determines the chemical behaviour of an atom, the *atomic number* (Z) also determines this chemical behaviour. Each *element* has different chemical properties and thus each *element* has a different *atomic number.* These form the basis of the *periodic table.*
- Atoms in the ground state are electrically neutral because the number of positive charges (protons) is balanced by the number of negative charges (electrons).
- If an electron is removed, the atom is no longer neutral, but becomes positively charged and is referred to as a *positive ion.*

The process of removing an electron from an atom is called *ionization.*

- If an electron is displaced from an inner shell to an outer shell (i.e. to a higher energy level), the atom remains neutral but is in an excited state. This process is called *excitation.*
- The unit of energy in the atomic system is the electron volt (eV), 1eV = 1.6×10^{-19} joules.

X-Ray Production

X-rays are produced inside machines called *X-ray generating equipment* . Dental X-ray machines are described in more detail in Chapter 3 , but the actual X-ray generating component is referred to as the *tubehead.* Various modern dental tubeheads are shown in Fig. 2.2A and their basic components in Fig. 2.2B . They all contain a small evacuated glass container called the *X-ray tube,* shown in Fig. 2.2C and D . X-rays are produced inside the X-ray tube when energetic (high-speed) electrons bombard the target and are brought suddenly to rest.

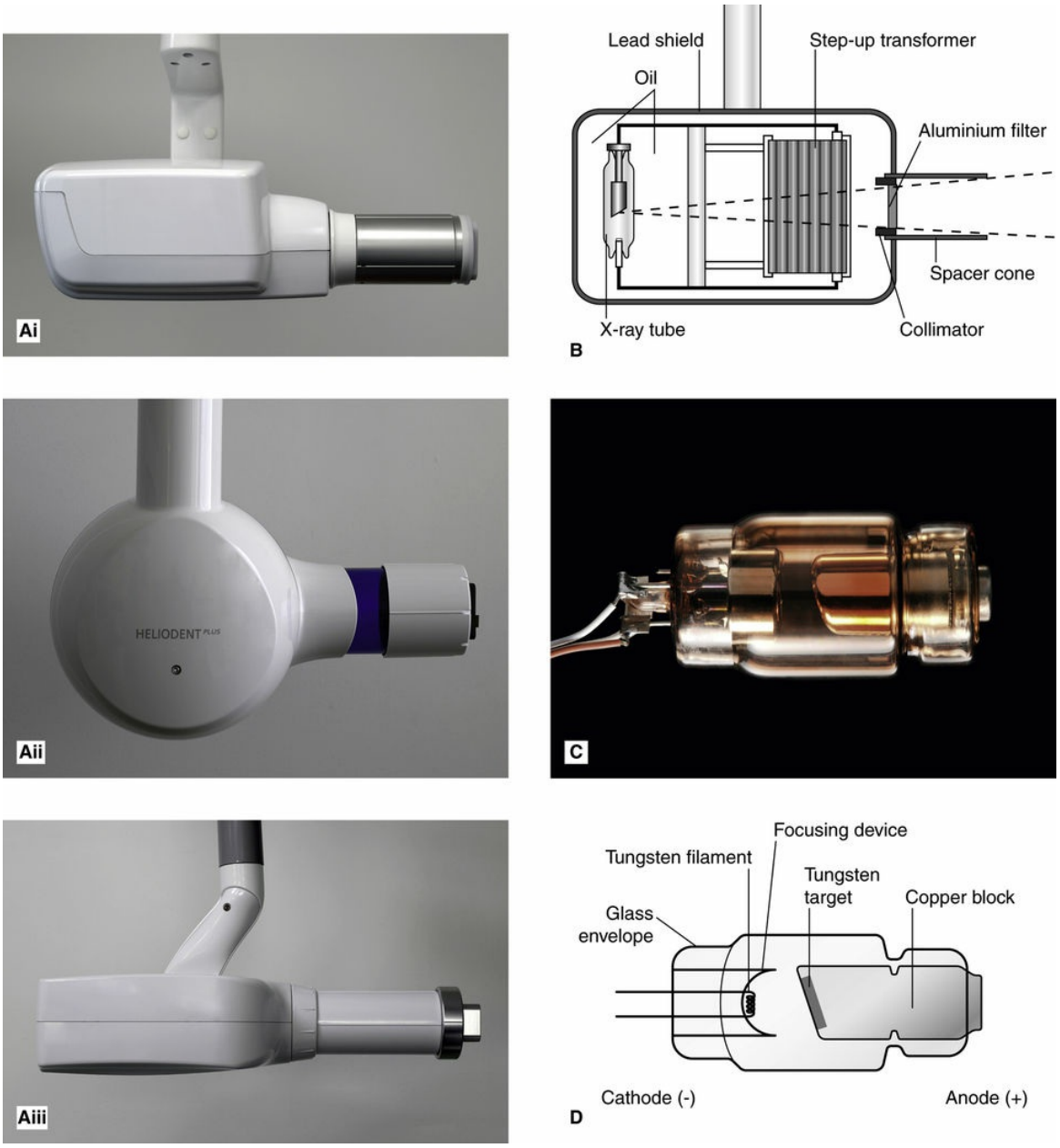


FIG. 2.2 **(A)** Examples of various modern dental X-ray tubeheads. **(i)** Belmont Belray II. **(ii)** Sirona Heliodent® Plus and **(iii)** Planmeca ProX. **(B)** Diagram of a typical tubehead showing the main components. **(C)** An actual dental X-ray tube. **(D)** Diagram of a dental X-ray tube showing the main components.

Main Features and Requirements of an X-ray Tube

- The *cathode* (negative) consists of a heated *filament* of tungsten that provides the source of electrons.
- The *anode* (positive) consists of a *target* (a small piece of tungsten) set into the angled face of a large *copper block* to allow efficient removal of heat.
- A *focusing device* aims the stream of electrons at the *focal spot* on the target.
- A high-voltage (kV) connected between the cathode and anode accelerates the electrons from the negative filament to the positive target. This is sometimes referred to as kVp or kilovoltage peak, as explained in Chapter 3 .
- A current (milliamperage) flows from the cathode to the anode. This is a measure of the quantity of electrons being accelerated.
- A surrounding *lead casing* absorbs unwanted X-rays as a radiation protection measure because X-rays are emitted in all directions.
- Surrounding *oil* facilitates the removal of heat.

Practical Considerations

The production of X-rays can be summarized as the following sequence of events:

1. The filament is electrically heated and a cloud of electrons is produced around the filament.
2. The high-voltage (potential difference) across the tube accelerates the electrons at very high speed towards the anode.
3. The focusing device aims the electron stream at the focal spot on the target.
4. The electrons bombard the target and are brought suddenly to rest.
5. The energy lost by the electrons is transferred into either *heat* (about 99%) or X-rays (about 1%).
6. The heat produced is removed and dissipated by the copper block and the surrounding oil.

7. The X-rays are emitted in all directions from the target. Those emitted through the small window in the lead casing constitute the *beam* used for diagnostic purposes.

Interactions at the Atomic Level

The high-speed electrons bombarding the target (see Fig. 2.3) are involved in two main types of *collision* with the tungsten atoms:

- Heat-producing collisions
- X-ray-producing collisions.

Heat-producing Collisions

- The incoming electron is deflected by the cloud of outer-shell tungsten electrons, with a small loss of energy, in the form of *heat* (see Fig. 2.4A).
- The incoming electron collides with an outer-shell tungsten electron, displacing it to an even more peripheral shell (excitation) or displacing it from the atom (ionization), again with a small loss of energy in the form of *heat* (see Fig. 2.4B).

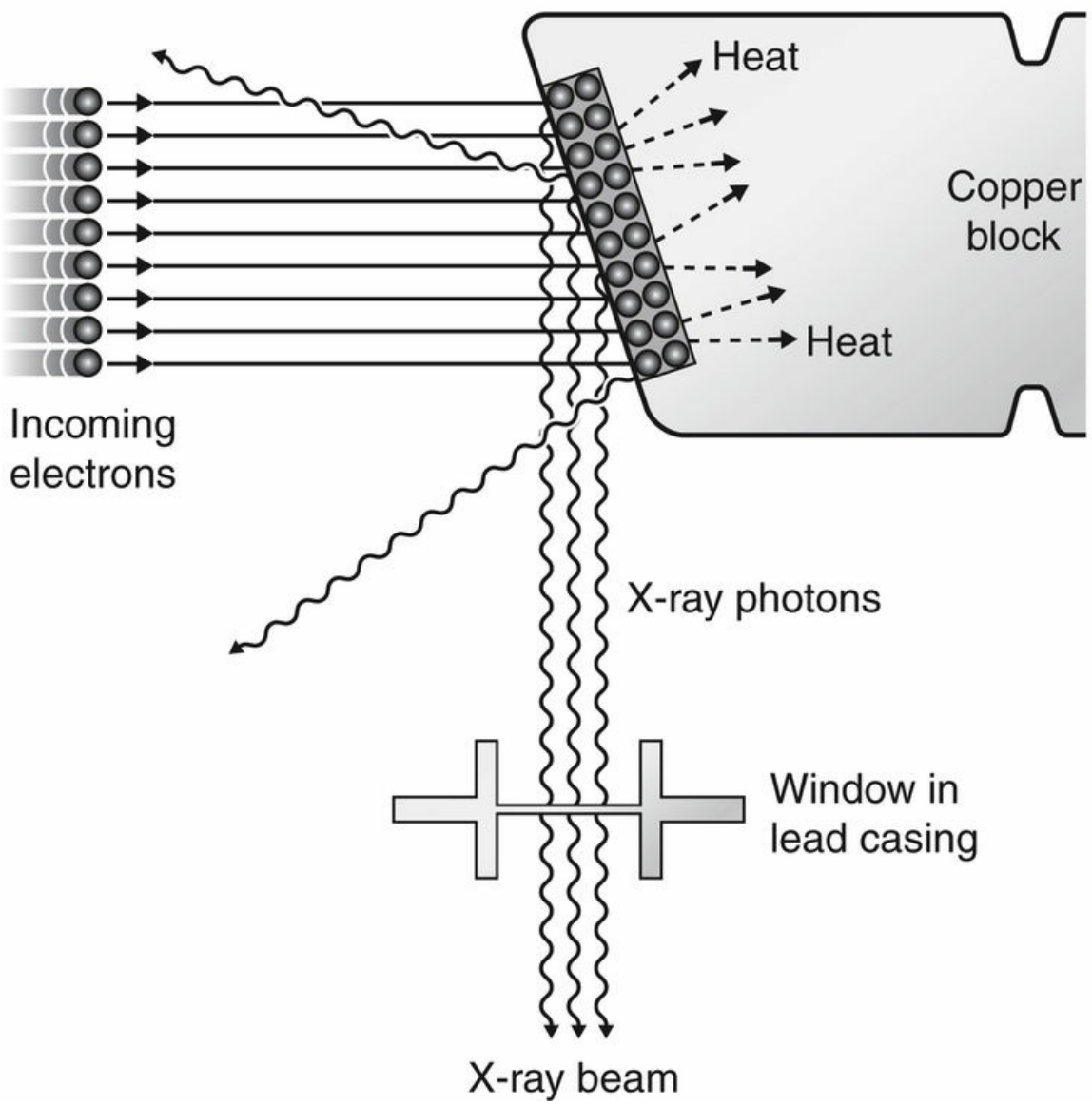


FIG. 2.3 Diagram of the anode enlarged, showing the target and summarizing the interactions at the target.

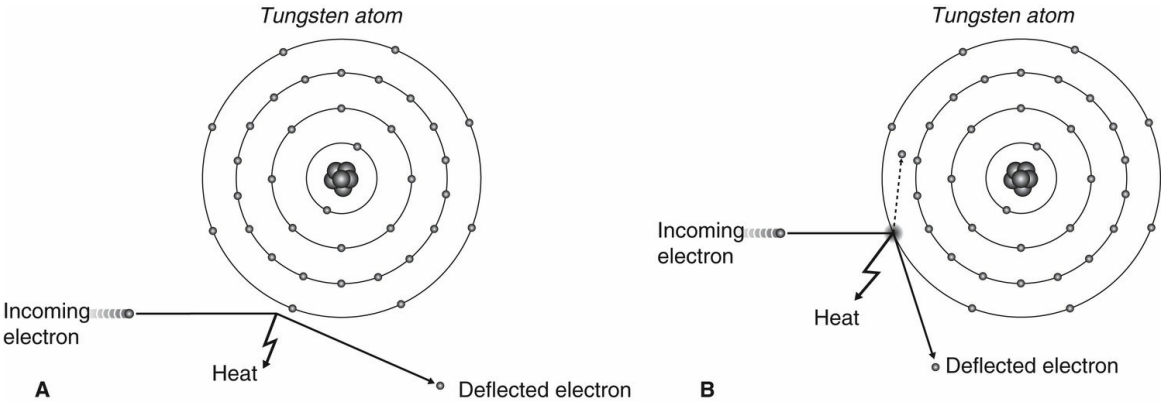


FIG. 2.4 **(A)** Heat-producing collision: the incoming electron is deflected by the outer-shell tungsten electron cloud. **(B)** Heat-producing collision: the incoming electron collides with and displaces an outer-shell tungsten electron.

Important Points to Note

- Heat-producing interactions are the most common because there are millions of incoming electrons and many outer-shell tungsten electrons with which to interact.
- Each individual bombarding electron can undergo many heat-producing collisions resulting in a considerable amount of heat at the target.
- Heat needs to be removed quickly and efficiently to prevent damage to the target. This is achieved by setting the tungsten target in the copper block, using the high thermal capacity and good conduction properties of copper.

X-ray-producing Collisions

- The incoming electron penetrates the outer electron shells and passes close to the nucleus of the tungsten atom. The incoming electron is dramatically slowed down and deflected by the nucleus with a large loss of energy, which is emitted in the form of *X-rays* (see Fig. 2.5A).
- The incoming electron collides with an inner-shell tungsten

electron, displacing it to an outer shell (excitation) or displacing it from the atom (ionization), with a large loss of energy and subsequent emission of *X-rays* (see Fig. 2.5B).

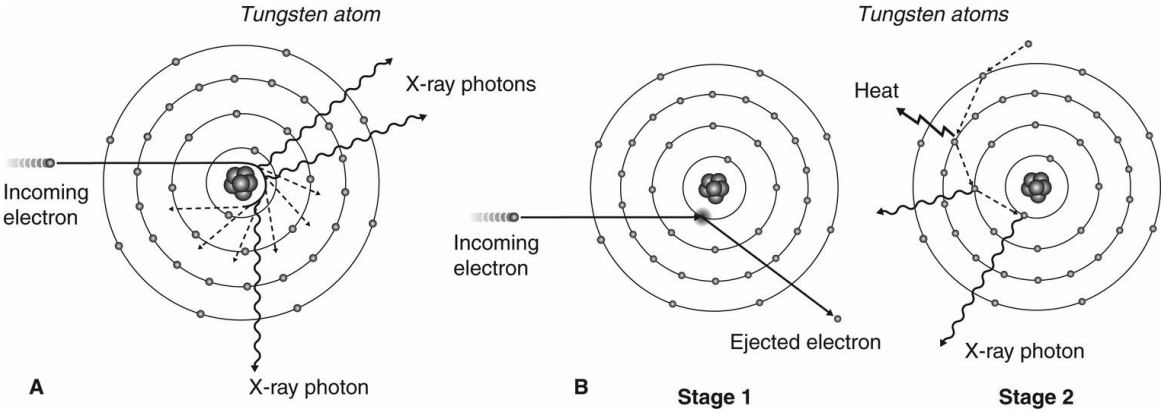


FIG. 2.5 **(A)** X-ray-producing collision: the incoming electron passes close to the tungsten nucleus and is rapidly slowed down and deflected with the emission of X-ray photons. **(B)** X-ray-producing collision: stage 1 – the incoming electron collides with an inner-shell tungsten electron and displaces it; stage 2 – outer-shell electrons drop into the inner shells with subsequent emission of X-ray photons.

X-ray Spectra

The two X-ray-producing collisions result in the production of two different types of *X-ray spectra* :

- Continuous spectrum
- Characteristic spectrum.

Continuous Spectrum

The X-ray photons emitted by the rapid deceleration of the bombarding electrons passing close to the nucleus of the tungsten atom are sometimes referred to as *bremsstrahlung* or *braking radiation* . The amount of deceleration and degree of deflection determine the

amount of energy lost by the bombarding electron and hence the energy of the resultant emitted photon. A wide range or *spectrum* of photon energies is therefore possible and is termed the *continuous spectrum* (see Fig. 2.6).

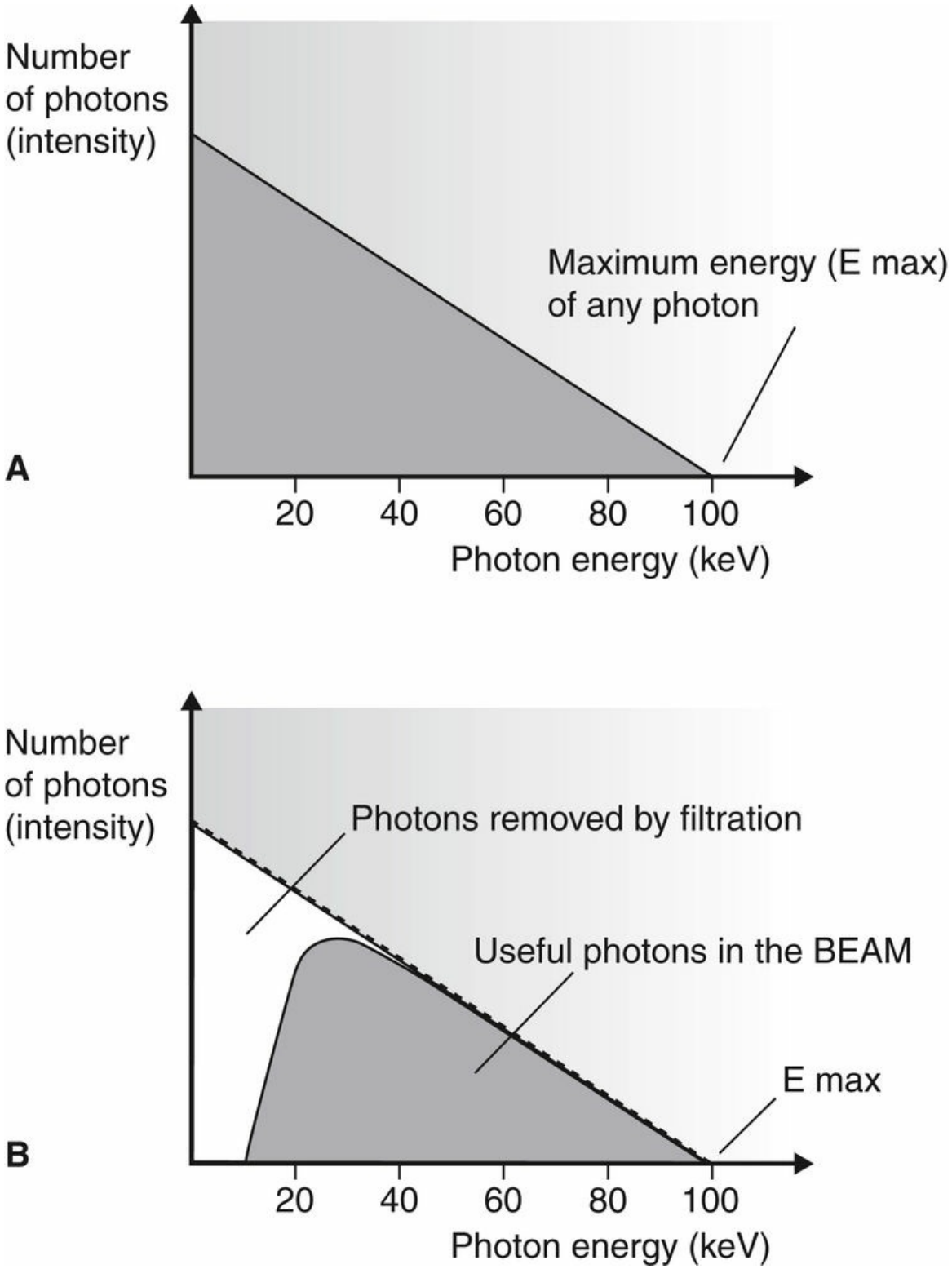


FIG. 2.6 **(A)** Graph showing the continuous X-ray spectrum at the target for an X-ray tube operating at 100 kV. **(B)** Graph showing the continuous spectrum in the emitted beam, as the result of *filtration* .

Summary of Important Points

- Small deflections of the bombarding electrons are the most common, producing many *low-energy* photons.
- Low-energy photons have little penetrating power and most will not exit from the X-ray tube itself. They will not contribute to the useful X-ray beam (see Fig. 2.6B). This removal of low-energy photons from the beam is known as *filtration* (see later).
- Large deflections are less likely to happen so there are relatively few *high-energy* photons.
- The maximum photon energy possible (E max) is directly related to the size of the potential difference (kV) across the X-ray tube.

Characteristic Spectrum

Following the ionization or excitation of the tungsten atoms by the bombarding electrons, the orbiting tungsten electrons rearrange themselves to return the atom to the neutral or ground state. This involves electron 'jumps' from one energy level (shell) to another, and results in the emission of X-ray photons with specific energies. As stated, the energy levels or shells are specific for any particular atom. The X-ray photons emitted from the target are therefore described as *characteristic of tungsten atoms* and form the *characteristic* or *line spectrum* (see Fig. 2.7). The photon lines are named K and L, depending on the shell from which they have been emitted.

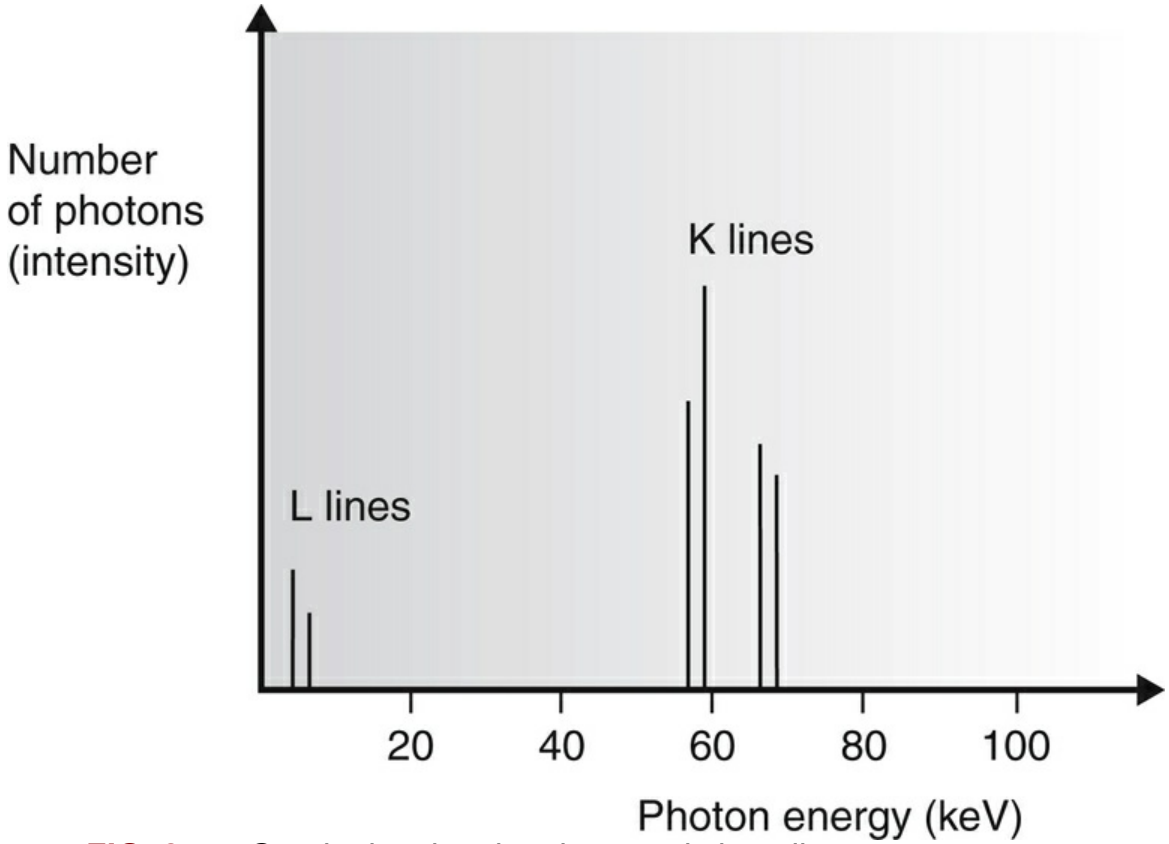


FIG. 2.7 Graph showing the characteristic or line spectrum at the target for an X-ray tube (with a tungsten target) operating at 100 kV.

Summary of Important Points

- Only the K lines are of diagnostic importance since the L lines have too little energy.
- The bombarding high-speed electron must have sufficient energy (69.5 kV) to displace a K-shell tungsten electron to produce the characteristic K line on the spectrum. (The energy of the bombarding electrons is directly related to the potential difference (kV) across the X-ray tube.)
- Characteristic K-line photons are not produced by X-ray tubes with tungsten targets operating at less than 69.5 kV – referred to as the *critical voltage.*
- Dental X-ray equipment usually operates between 60 kV and 90 kV (see Chapter 3).

Combined Spectra

In X-ray equipment operating above 69.5 kV, the final total spectrum of the useful X-ray *beam* will be the addition of the continuous and characteristic spectra (see Fig. 2.8).

Summary of the Main Properties and Characteristics of X-rays

- X-rays are *wave packets* of energy of electromagnetic radiation that originate at the atomic level.
- Each *wave packet* is equivalent to a *quantum* of energy and is called a *photon.*
- An X-ray *beam* is made up of millions of photons of different energies.
- The diagnostic X-ray beam can vary in its *intensity* and in its *quality* :
  - Intensity = the number or quantity of X-ray photons in the beam.
  - Quality = the energy carried by the X-ray photons which is a measure of their penetrating power.
- The factors that can affect the intensity and/or the quality of the beam include:
  - Size of the tube voltage (kV)
  - Size of the tube current (mA)
  - Distance from the target (d)
  - Time = length of exposure (t)
  - Filtration
  - Target material
  - Tube voltage waveform (see Chapter 3).

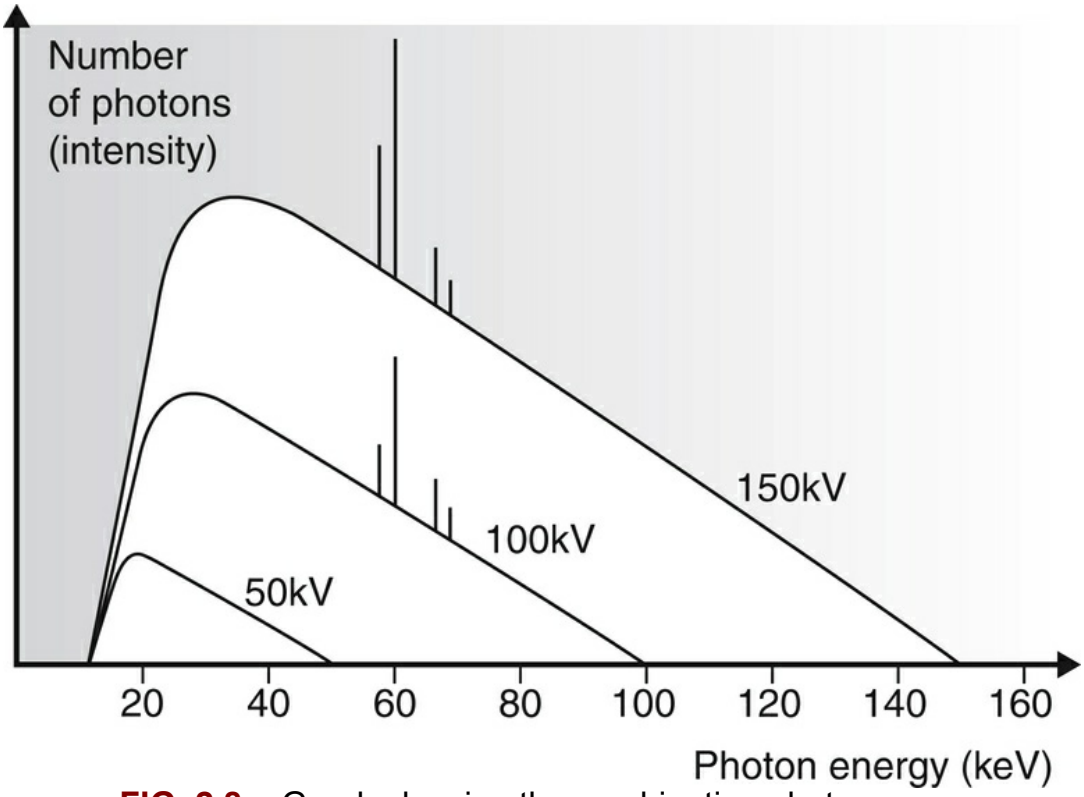


FIG. 2.8 Graph showing the combination photon energy spectra (in the final beam) for X-ray sets operating at 50 kV, 100 kV, and 150 kV.

- In free space, X-rays travel in straight lines.
- Velocity in free space = 3×10^8 m s^{-1} .
- In free space, X-rays obey the inverse square law:

$$Intensity = \frac{1}{d^2}$$

Doubling the distance from an X-ray source reduces the intensity to 1/4 (a very important principle in radiation protection, see Chapter 7).

- No medium is required for propagation.
- Shorter-wavelength X-rays possess greater energy and can

therefore penetrate a greater distance.

- Longer-wavelength X-rays, sometimes referred to as *soft X-rays* , possess less energy and have little penetrating power.
- The energy carried by X-rays can be attenuated by matter, i.e. absorbed or scattered.
- X-rays are capable of producing *ionization* (and subsequent biological damage in living tissue, see Chapter 7) and are thus referred to as *ionizing radiation.*
- X-rays are undetectable by human senses.
- X-rays can affect film emulsion to produce a visual image (the radiograph) and can cause certain salts to fluoresce and to emit light – the principle behind the use of intensifying screens in extraoral cassettes and digital sensors (see Chapter 4).

Interaction of X-Rays with Matter

When X-rays strike matter, such as a patient's tissues, the photons have four possible fates, shown diagrammatically in Fig. 2.9 . The photons may be:

- Completely scattered with no loss of energy
- Absorbed with total loss of energy
- Scattered with some absorption and loss of energy
- Transmitted unchanged.

Definition of Terms Used in X-ray Interactions

- *Scattering* – change in direction of a photon with or without a loss of energy
- *Absorption* – deposition of energy, i.e. removal of energy from the beam
- *Attenuation* – reduction in the intensity of the main X-ray beam caused by absorption and scattering

Attenuation = Absorption + Scattering

- *Ionization* – removal of an electron from a neutral atom producing a negative ion (the electron) and a positive ion (the remaining atom).

Interaction of X-rays at the Atomic Level

There are four main interactions at the atomic level, depending on the energy of the incoming photon:

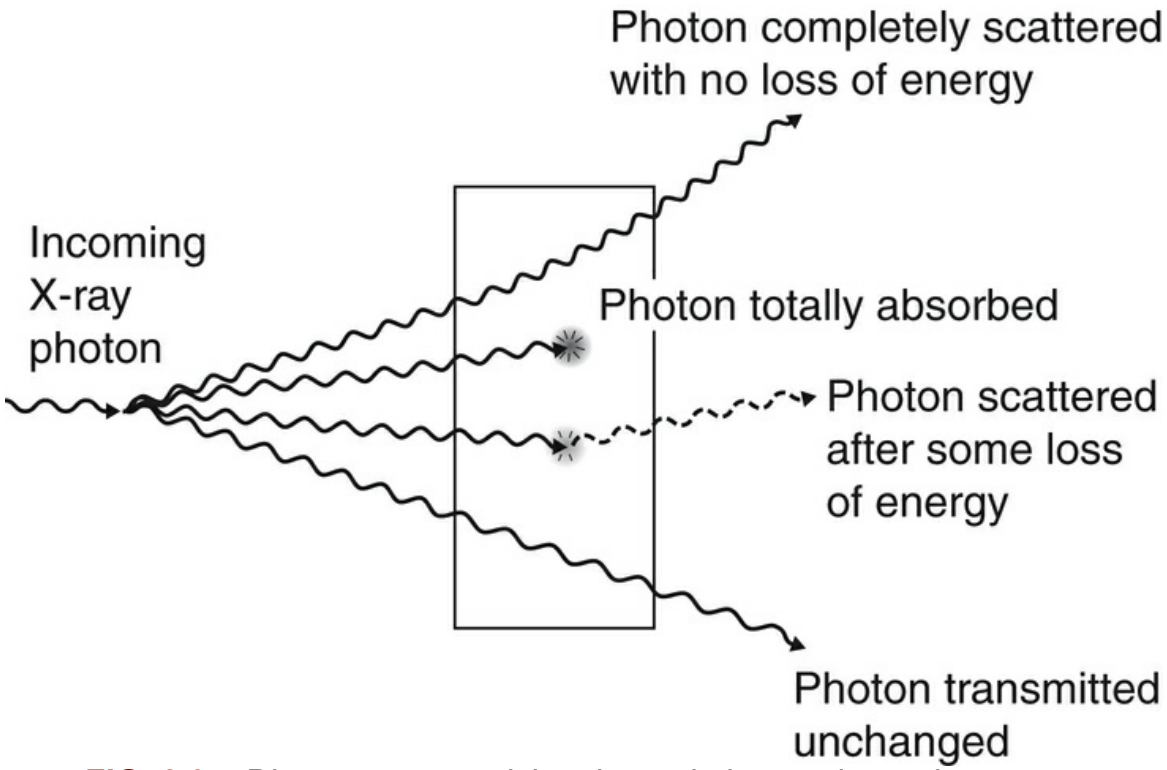


FIG. 2.9 Diagram summarizing the main interactions when X-rays interact with matter.

- Unmodified or Rayleigh scattering – pure scatter
- Photoelectric effect – pure absorption

- Compton effect – scatter and absorption
- Pair production – pure absorption.

Only two interactions are important in the X-ray energy range used in dentistry:

- Photoelectric effect
- Compton effect.

Photoelectric Effect

The photoelectric effect is a pure absorption interaction predominating with *low-energy* photons (see Fig. 2.10).

Summary of the Stages in the Photoelectric Effect

1. The incoming X-ray photon interacts with a bound inner-shell electron of the tissue atom.
2. The inner-shell electron is ejected with considerable energy (now called a *photoelectron*) into the tissues and will undergo further interactions.
3. The X-ray photon disappears having deposited all its energy; the process is therefore one of pure *absorption.*
4. The vacancy that now exists in the inner electron shell is filled by outer-shell electrons dropping from one shell to another.
5. This cascade of electrons to new energy levels results in the formation of very low energy radiation (e.g. light), which is quickly absorbed.
6. Atomic stability is finally achieved by the capture of a free electron to return the atom to its neutral state.
7. The high-energy ejected *photoelectron* behaves like the original high-energy X-ray photon, undergoing many similar interactions and ejecting other electrons as it passes through the tissues. It is these ejected high-energy electrons that are responsible for the majority of the ionization interactions within tissue, and the possible resulting damage attributable to

X-rays.

Important Points to Note

- The X-ray photon energy needs to be equal to, or just greater than, the binding energy of the inner-shell electron to be able to eject it.

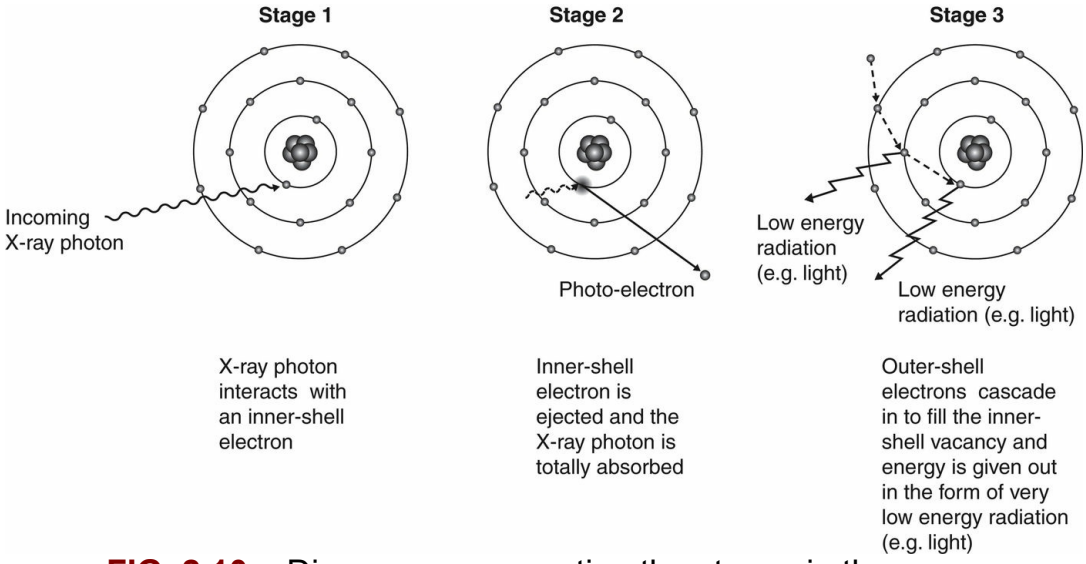


FIG. 2.10 Diagrams representing the stages in the photoelectric interaction.

- As the density (atomic number, Z) increases, the number of bound inner-shell electrons also increases. The probability of photoelectric interactions occurring is $\propto Z^3$. Lead has an atomic number of 82 and is therefore a good absorber of X-rays – hence its use in radiation protection (see Chapter 7). The approximate atomic number for soft tissue is 7 ($Z^3 = 343$) and for bone is 12 ($Z^3 = 1728$) – hence their obvious difference in radiodensity, and the *contrast* between the different tissues seen on radiographs (see Chapter 19).
- This interaction predominates with low-energy X-ray photons – the probability of photoelectric interactions occurring is $\propto$

$1/kV^3$. This explains why low kV X-ray equipment results in high absorption (dose) in the patient's tissues, but provides good contrast radiographs.

- The overall result of the interaction is *ionization* of the tissues.
- Intensifying screens, described in Chapter 4 , function by the photoelectric effect – when exposed to X-rays, the screens emit their excess energy as *light* , which subsequently affects the film emulsion.

Compton Effect

The Compton effect is an absorption *and* scattering process predominating with *higher-energy* photons (see Fig. 2.11).

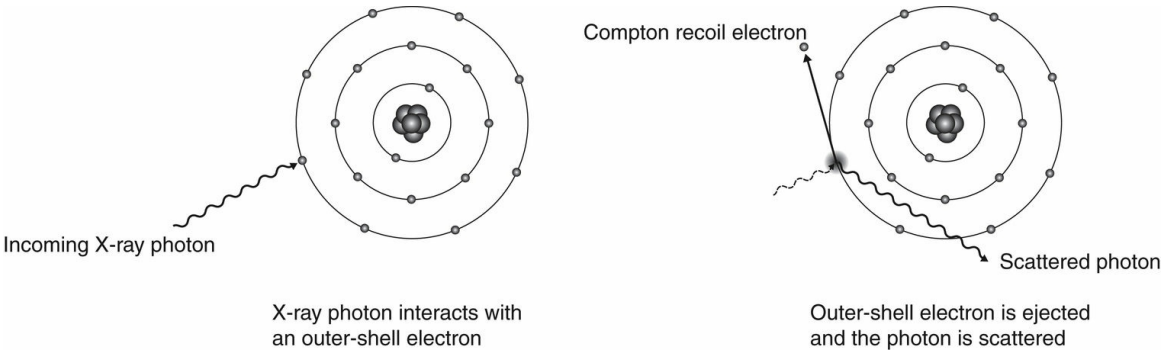


FIG. 2.11 Diagram showing the interactions of the Compton effect.

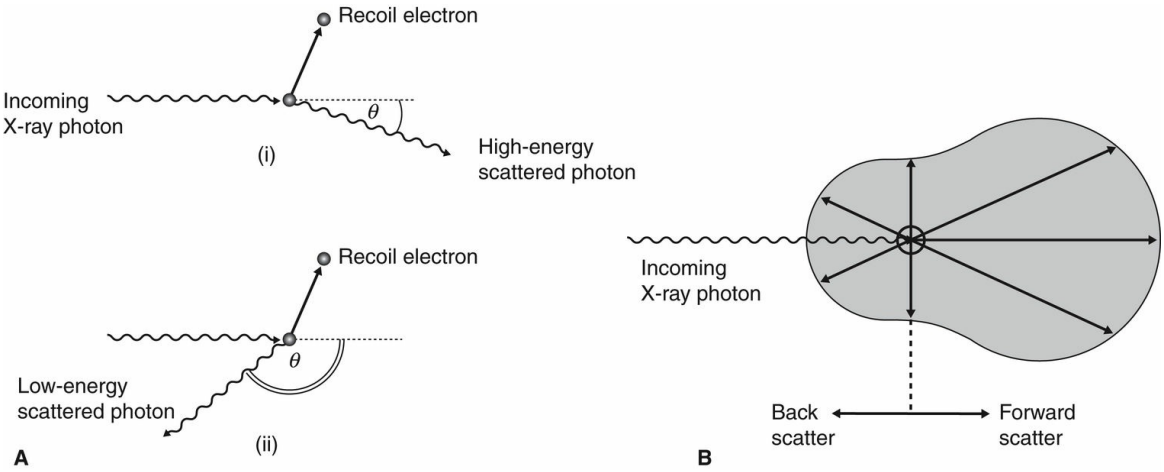


FIG. 2.12 (A) Diagram showing the angle of scatter θ with (i) high- and (ii) low-energy scattered photons. (B) Typical scatter distribution diagram of a 70 kV X-ray set. The length of any radius from the source of scatter indicates the relative amount of scatter in that direction. At this voltage, the majority of scatter is in a forward direction.

Summary of the Stages in the Compton Effect

1. The incoming X-ray photon interacts with a *free* or loosely bound outer-shell electron of the tissue atom.
2. The outer-shell electron is ejected (now called the *Compton recoil electron*) with loss of some of the energy of the incoming photon, i.e. there is some *absorption.* The ejected electron then undergoes further ionizing interactions within the tissues (as before).
3. The remainder of the incoming photon energy is deflected or *scattered* from its original path as a scattered photon.
4. The scattered photon may then:
   - Undergo further Compton interactions within the tissues
   - Undergo photoelectric interactions within the tissues
   - Escape from the tissues – it is these photons that form the *scatter radiation* of concern in the clinical environment.
5. Atomic stability is again achieved by the capture of another

free electron.

Important Points to Note

- The energy of the incoming X-ray photon is much greater than the binding energy of the outer-shell or free electron.
- The incoming X-ray photon cannot distinguish between one free electron and another – the interaction is not dependent on the atomic number (Z). Thus, this interaction provides very little diagnostic information, because there is very little discrimination between different tissues on the final radiograph.
- This interaction predominates with high X-ray photon energies. This explains why high-voltage X-ray sets result in radiographs with poor contrast.
- The energy of the scattered photon (Es) is always less than the energy of the incoming photon (E), depending on the energy given to the recoil electron (e):

$$Es = E - e$$

- Scattered photons can be deflected in any direction, but the angle of scatter (θ) depends on their energy. *High-energy* scattered photons produce *forward* scatter; *low-energy* scattered photons produce *back* scatter (see Fig. 2.12).
- Forward scatter may reach the image receptor and degrade the image.
- The overall result of the interaction is ionization of the tissues (see Chapter 7).

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3

Dental X-ray Generating Equipment

Introduction

This chapter summarizes the more important practical aspects of dental X-ray generating equipment. There are several different units available from various manufacturers. They vary in appearance, complexity and cost, but all conventional units consist of three main components:

- A tubehead
- Positioning arms
- A control panel and circuitry.

These dental units can either be fixed (wall, floor or ceiling mounted) or mobile (attached to a sturdy frame on wheels) as shown in Fig. 3.1A and B . A recent development has been the production of hand-held dental units, as shown in Fig. 3.1C , which are particularly useful for domiciliary and forensic radiology.

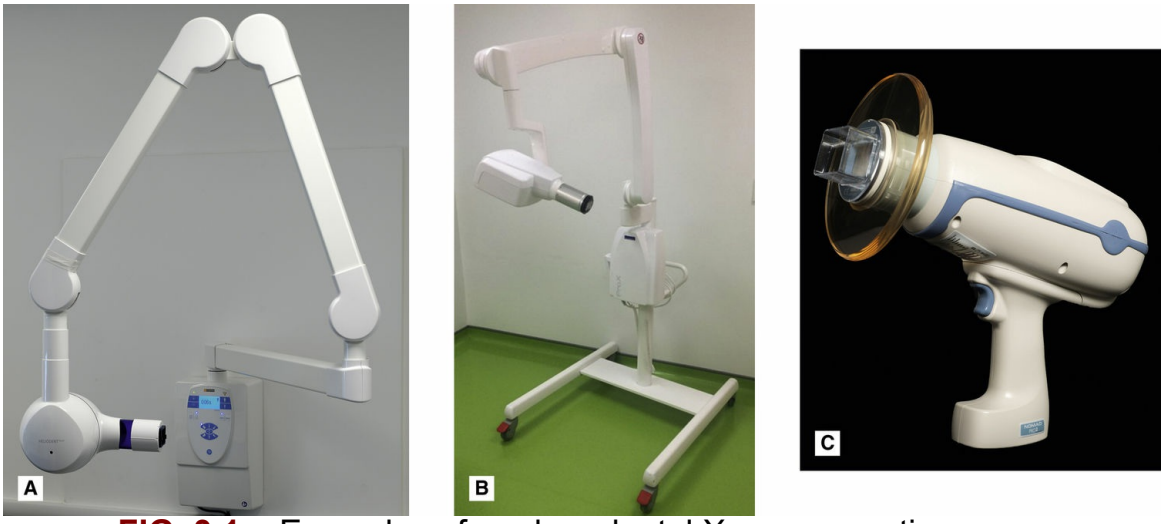


FIG. 3.1 Examples of modern dental X-ray generating equipment. **(A)** Wall-mounted Sirona Heliodent® Plus. **(B)** Mobile Planmeca ProX. **(C)** Hand-held Airbex Nomad™ .

Ideal Requirements

The equipment should be:

- Safe and accurate
- Capable of generating X-rays in the desired energy range and with adequate mechanisms for heat removal
- Small
- Easy to manoeuvre and position
- Stable, balanced and steady once the tubehead has been positioned
- Easily folded and stored
- Simple to operate and capable of both film and digital imaging
- Robust.

Main Components of the Tubehead

A diagram of a typical tubehead is shown in Fig. 3.2 . The main components include:

- The *glass X-ray tube* , including the filament, copper block and the target (see Chapter 2)
- The *step-up transformer* required to step-up the mains voltage of 240 volts to the high voltage (kV) required across the X-ray tube
- The *step-down transformer* required to step-down the mains voltage of 240 volts to the low-voltage current required to heat the filament
- A *surrounding lead shield* to minimize leakage
- *Surrounding oil* to facilitate heat removal
- *Aluminium filtration* to remove harmful low-energy (soft) X-rays (see Fig. 3.3)
- The *collimator* – a metal disc or cylinder with central aperture designed to shape and limit the beam size to a rectangle (the same size as an intraoral image receptor) or round with a maximum diameter of 6 cm (see Figs. 3.3 and 3.4)
- The *spacer cone* or *beam-indicating device* – a device for indicating the direction of the beam and setting the ideal distance from the focal spot on the target (the focus) to the skin. A long *focus-to-skin distance* (fsd) of not less than 20 cm should be employed, although *focus-to-skin distances* of 30 cm are increasingly being used.

It is the length of the *focal spot to skin distance* that is important, NOT the physical length of the spacer cone. Various designs are illustrated in Fig. 3.4 .

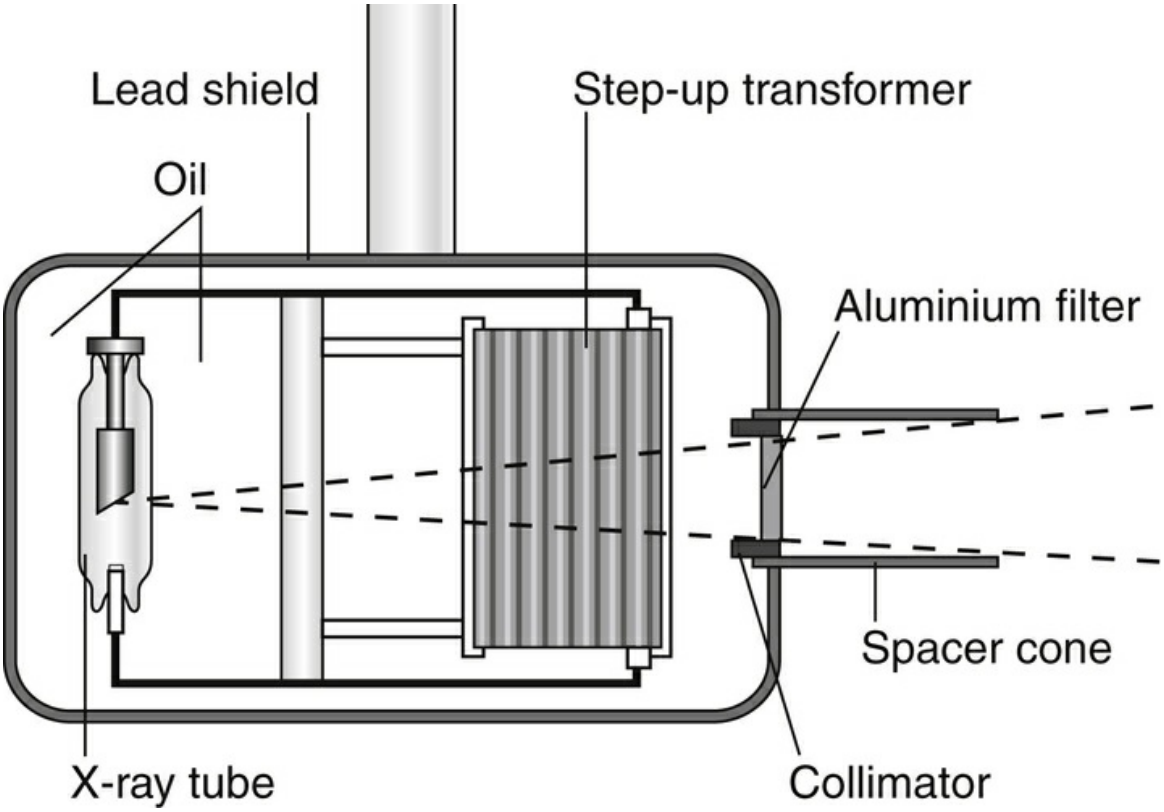
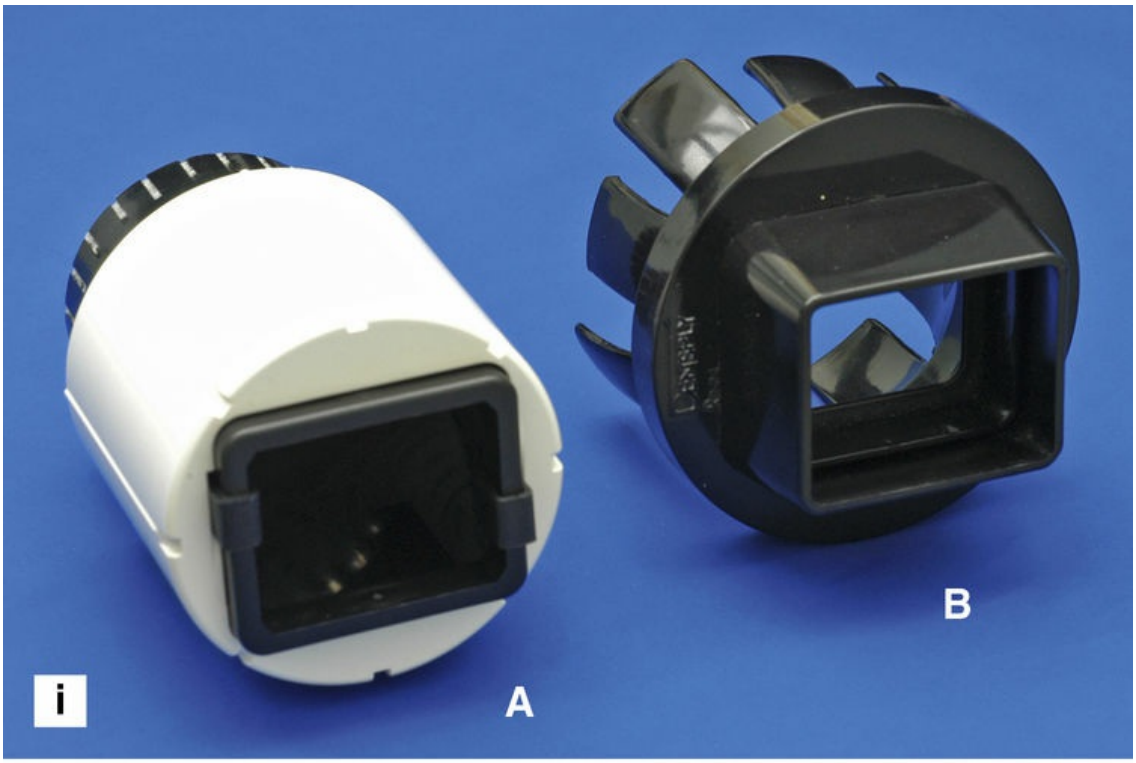


FIG. 3.2 Diagram of the tubehead of a typical dental X-ray set showing the main components.


i
A
B


ii

FIG. 3.3 **(i)** Examples of adaptors/collimators designed to change the shape of the beam from circular to rectangular. **(A)** Sirona Heliodent® DS collimator. **(B)** Dentsply's Universal collimator. **(ii)** Aluminium filter (arrowed) viewed from down the spacer cone on the Sirona Heliodent® DS.

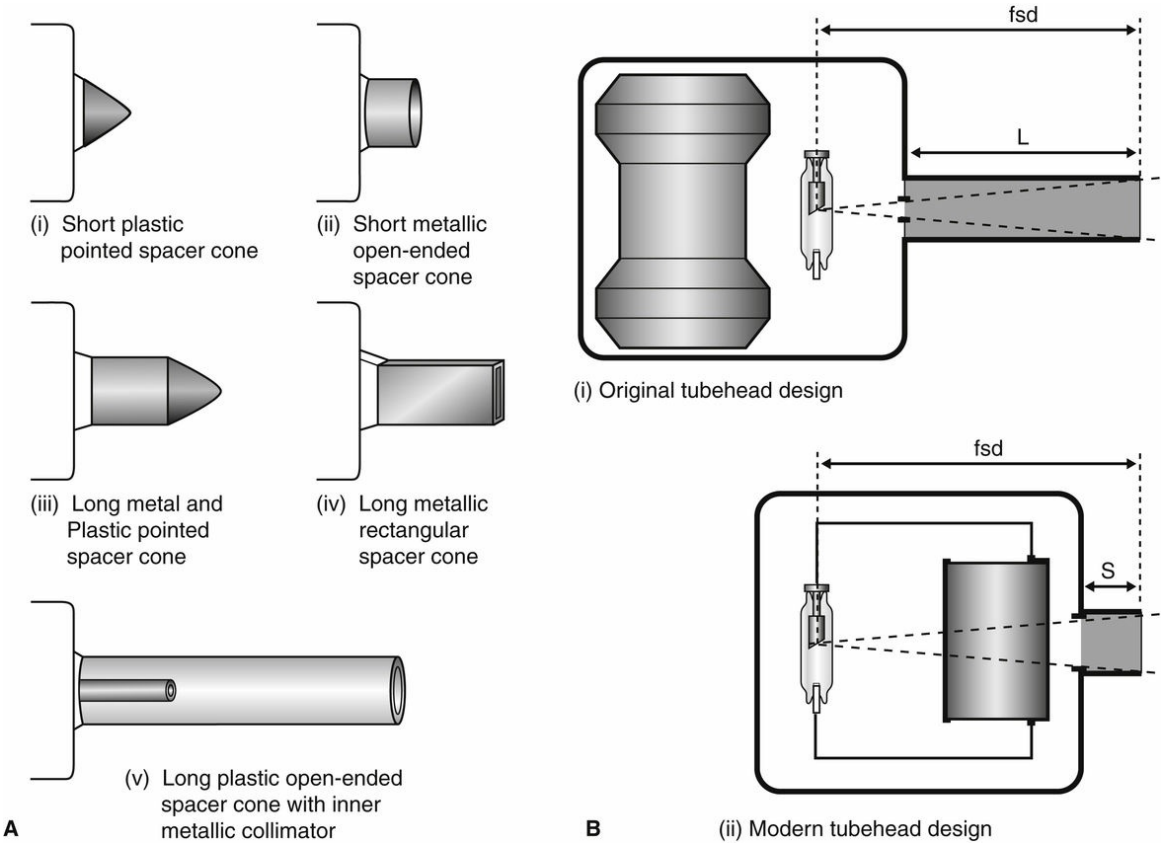


FIG. 3.4 **(A)** Diagrams showing various designs and shapes of spacer cones or beam-indicating devices. The short plastic pointed spacer cone is NOT recommended. **(B)** Diagrams showing **(i)** the original tubehead design with the X-ray tube at the **front** of the head, thus requiring a long spacer cone (L) to achieve a near-parallel X-ray beam and the correct *focus-to-skin distance* (fsd) and **(ii)** the modern tubehead design with the X-ray tube at the **back** of the head, thus requiring only a short spacer cone (S) to achieve the same *focus-to-skin distance* of 20–30 cm.

Focal Spot Size and the Principle of Line Focus

As stated inChapter 1 , the focal spot (the source of the X-rays) should be ideally a *point source* to reduce blurring of the image – the *penumbra effect* – as shown in Fig. 3.5A . However, the heat produced at the target by the bombarding electrons needs to be distributed over as large an area as possible. These two opposite requirements are satisfied by using an angled target and the principle of *line focus* , as shown in Fig. 3.5B .

Main Components of the Control Panel

Examples of four typical control panels are shown in Fig. 3.6 . The main components include:

- The *mains on/off* switch and warning light
- The *timer* , of which there are two main types:
  - electronic
  - impulse
- An *exposure time selector* mechanism, usually either:
  - numerical, time selected in seconds
  - anatomical, area of mouth selected and exposure time adjusted automatically
- *Warning lights* and *audible signals* to indicate when X-rays are being generated
- Other features can include
  - *Film speed selector*
  - *Patient size selector*
  - *Mains voltage compensator*
  - *Kilovoltage selector*
  - *Milliamperage switch*
  - *Exposure adjustment for digital imaging.*

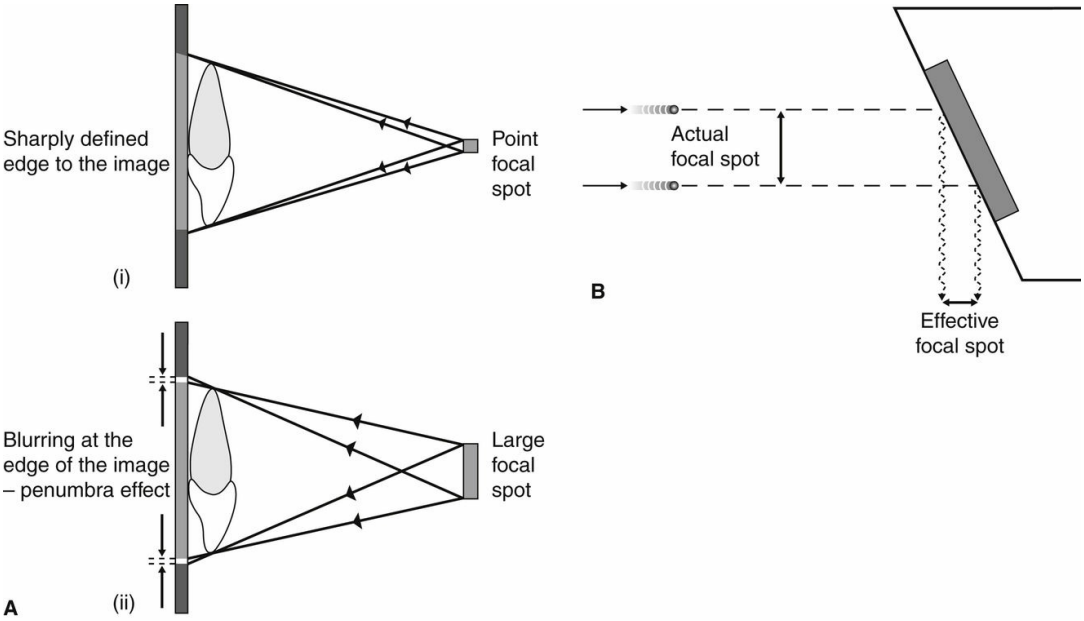


FIG. 3.5 **(A)** Diagrams showing the effect of the X-ray beam source (focal spot) size on image blurring: **(i)** a small or point source, **(ii)** a large source. **(B)** The principle of line focus; diagram of the target and focal spot showing how the angled target face allows a large *actual* focal spot but a small *effective* focal spot.

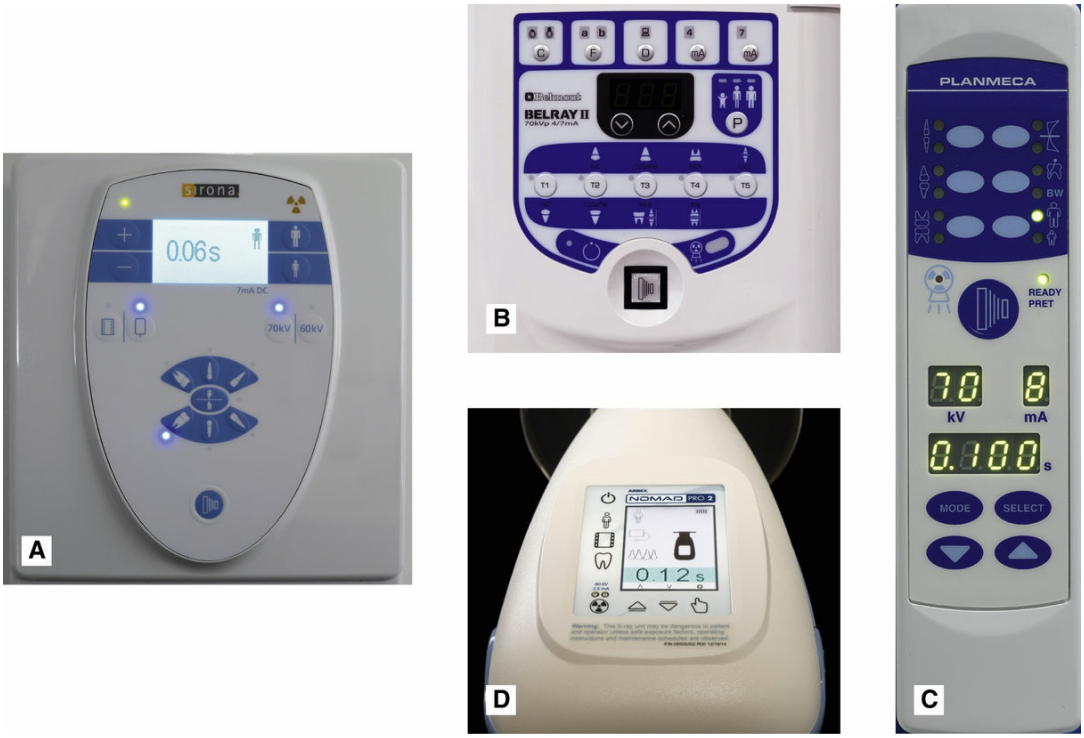


FIG. 3.6 Examples of different dental X-ray equipment control panels. **(A)** Sirona Heliodent® Plus. **(B)** Belmont Belray II. **(C)** Planmeca ProX. **(D)** Airbex hand-held Nomad™. They are all anatomical timers suitable for film and digital imaging.

Circuitry and Tube Voltage

The mains supply to the X-ray machine of 240 volts has two functions:

- To generate the high potential difference (kV) to accelerate the electrons across the X-ray tube via the step-up transformer
- To provide the low-voltage current to heat the tube filament via the step-down transformer.

However, the incoming 240 volts is an alternating current with the typical waveform shown in Fig. 3.7 . Half the cycle is positive and the other half is negative. For X-ray production, only the positive half of the cycle can be used to ensure that the electrons from the filament are always drawn towards the target. Thus, the stepped-up high voltage

applied across the X-ray tube needs to be *rectified* to eliminate the negative half of the cycle. Four types of rectified circuits are used:

- Half-wave rectified
- Single-phase, full-wave rectified
- Three-phase, full-wave rectified
- Constant potential.

The waveforms resulting from these rectified circuits, together with graphic representation of their subsequent X-ray production, are shown in Fig. 3.8 . These changing waveforms mean that equipment is only working at its optimum or peak output at the top of each cycle. The kilovoltage is therefore often described as the *kVpeak* or *kVp* . Thus, an historical 50 kVp half-wave rectified X-ray set only in fact functions at 50 kV for a tiny fraction of the total time of any exposure.

Current X-ray sets operate between 60 and 70 kV to ensure higher energy photons are produced, decreasing the skin dose to the patient. Modern designs favour constant potential circuitry, often referred to as *DC units* , which keep the kilovoltage at kVpeak throughout any exposure, thus ensuring that:

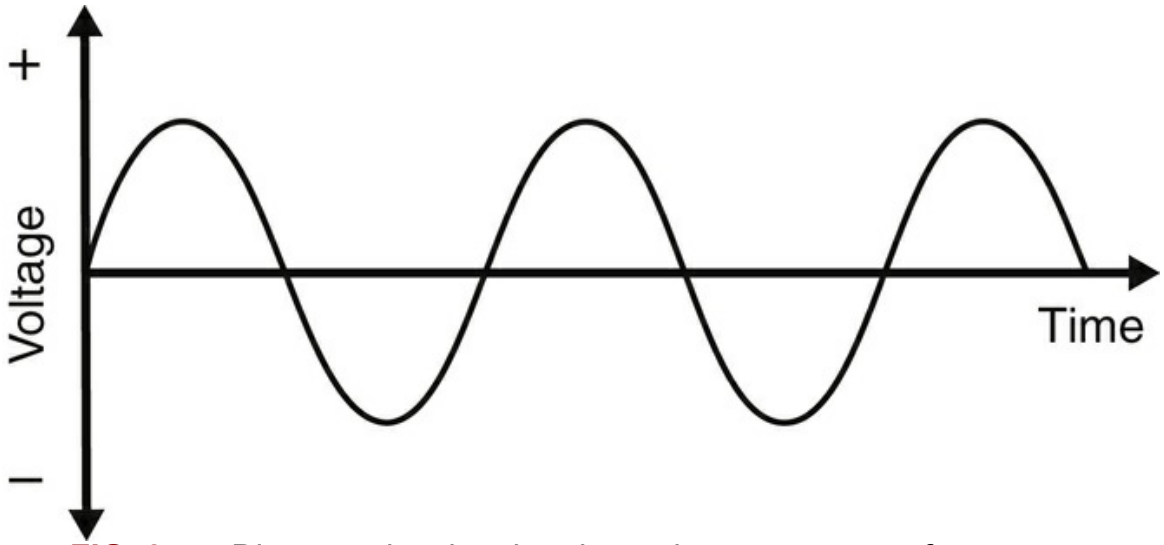


FIG. 3.7 Diagram showing the alternating current waveform.

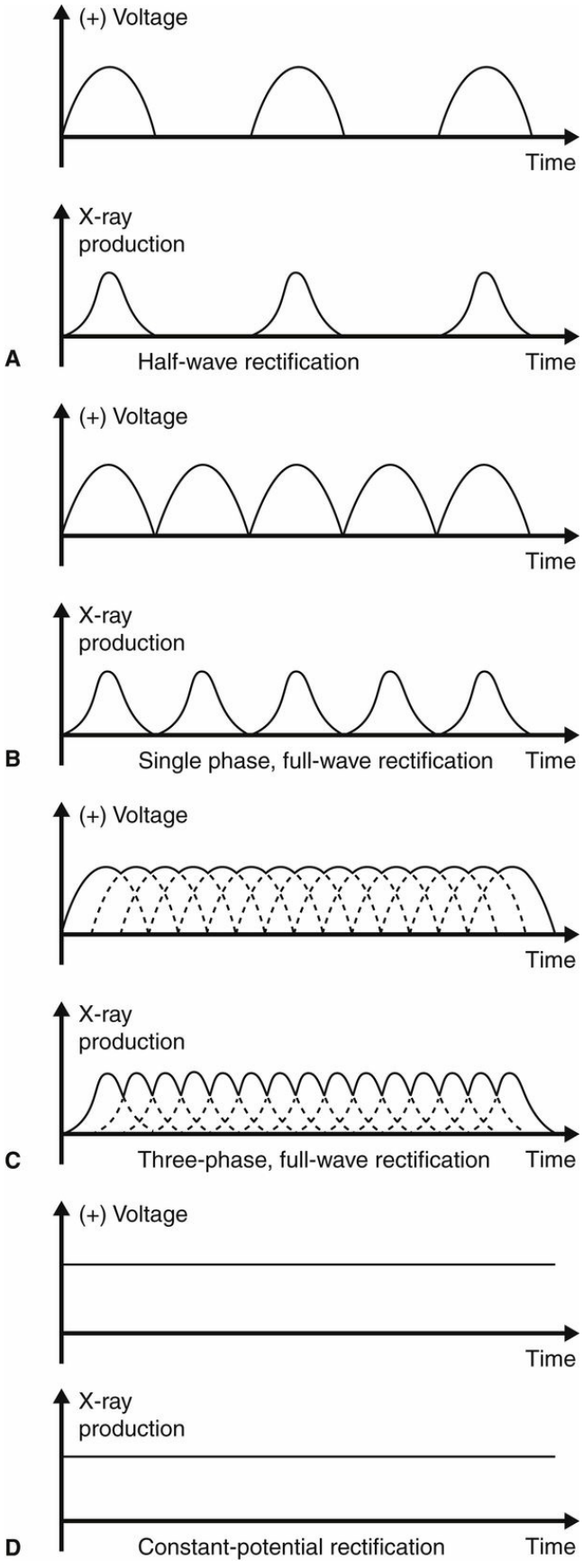

(+) Voltage
Time
X-ray production
A
Half-wave rectification
Time
(+) Voltage
Time
X-ray production
B
Single phase, full-wave rectification
Time
(+) Voltage
Time
X-ray production
C
Three-phase, full-wave rectification
Time
(+) Voltage
Time
X-ray production
D
Constant-potential rectification
Time

FIG. 3.8 Diagrams showing the waveforms and X-ray production graphs resulting from different forms of rectification.

- X-ray production per unit time is more efficient
- More high-energy, diagnostically useful photons are produced per exposure
- Fewer low-energy, harmful photons are produced
- Shorter exposure times are possible
- If using a DC unit, it may be advantageous to select 60 kV rather than 70 kV to ensure adequate radiographic contrast is maintained.

Other X-Ray Generating Apparatus

The other common X-ray generating equipment encountered in dentistry includes:

- Panoramic X-ray machines often combined with cephalometric skull equipment (see Chapters 14 and 15)
- Skull units, such as the Craniotome® (see Chapter 13)
- Cone beam computed tomography (CBCT) units (see Chapter 16).

The main features and practical components of these machines are outlined in later chapters.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

4

Image Receptors

Introduction

This chapter provides a summary of the two main types of image receptors used in dentistry, namely:

- Digital receptors
- Radiographic film.

Digital Receptors

There are two types of direct digital image receptors available:

- Solid-state sensors
- Photostimulable phosphor storage plates, often simply referred to as *PSPs* or *phosphor plates* .

Both types of sensors can be used for intraoral (periapical and bitewing radiography) and extraoral radiography, including panoramic and skull radiography. Only phosphor storage plates are available for occlusal and oblique lateral radiography because it is currently too expensive to manufacture solid-state sensors sufficiently large enough for this purpose.

Solid-state Sensors

Intraoral Sensors

The intraoral sensors consist of small, thin flat, rigid, rectangular,

cabled boxes. There are various different sized sensors available, generally similar in size to intraoral film packets. They vary in thickness from about 5–7 mm as shown in Fig. 4.1 .

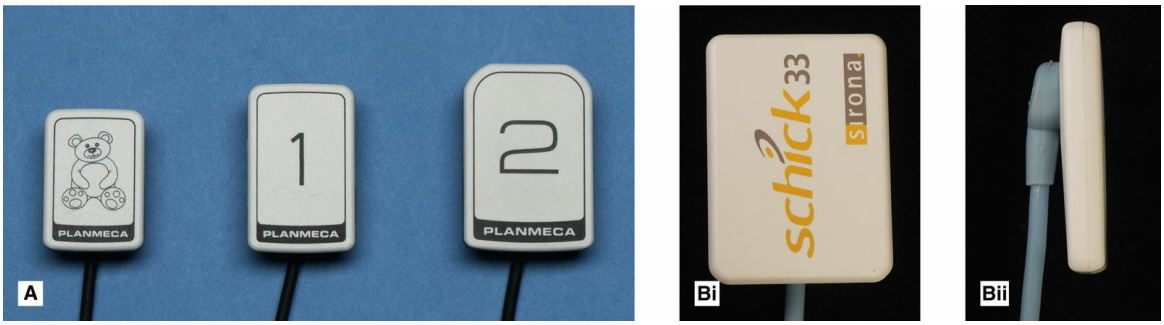


FIG. 4.1 Examples of solid-state sensors. **(A)** Planmeca's ProSensor HD size 0 (for children) and sizes 1 and 2 (for adults). **(B)** Sirona's Schick 33 sensor from the front and from the side showing the sensor's thickness.

For ease of clinical use the sensor cables are usually 1- 2 m long and plug into a remote docking station, which can conveniently be attached to the tubehead supporting arm (see Fig. 4.2). A separate cable then connects the docking station to the computer. To reduce the amount of cabling involved various *WiFi* systems are also available.

The solid-state sensors are not autoclavable. When used clinically, they all need to be placed within a protective plastic barrier envelope, covering the sensor and the first part of the cable, for infection control purposes (see Chapters 8 , 9 and 10).

Construction and Design

The sensors consist of tiny silicon chip-based pixels and their associated electronics encased in a plastic housing. Underlying technology involves either:

- Charge-coupled devices (CCD)
- Complementary metal oxide semiconductors (CMOS).

Charge-coupled devices (CCD)

Individual pixels, consisting of a sandwich of P- and N-type silicon, are arranged in rows and columns called an *array* or matrix, above which is a scintillation layer made of similar materials to the rare-earth intensifying screens. The basic design is shown in Fig. 4.3 and the complex electronic circuitry required is shown in Fig. 4.4 . The X-ray photons that hit the scintillation layer are converted to light. The light interacts via the photoelectric effect with the silicon to create a *charge packet* for each individual pixel, which is concentrated by the electrodes.

The charge pattern formed from the individual pixels in the matrix represents the latent image. The image is read by transferring each row of pixel charges from one row to the next. At the end of its row, each charge is transferred to a read-out amplifier and transmitted down the cable as an analogue voltage signal to the computer's analogue-to-digital converter, often located in the *docking station* . Each sensor consists of between 1.5 million and 2.5 million pixels and pixel sizes vary from 15 to 20 μm.


A


sirona
schick 33
sirona
B

FIG. 4.2 Examples of docking stations. **(A)** The Planmeca ProSensor plugged into the docking station on the ProX dental unit. **(B)** The Sirona Schick 33 system showing the sensor, cable and docking station.

Complementary metal oxide detectors (CMOS)

These sensors are similar in construction to CCDs and consist of an array of pixels, but they differ from CCDs in the way that the pixel charges are read. Each complementary metal oxide semiconductor pixel is isolated from its neighbour and directly connected to a transistor. The charge packet from each pixel is transferred to the transistor as a voltage enabling each individual pixel to be assessed separately.

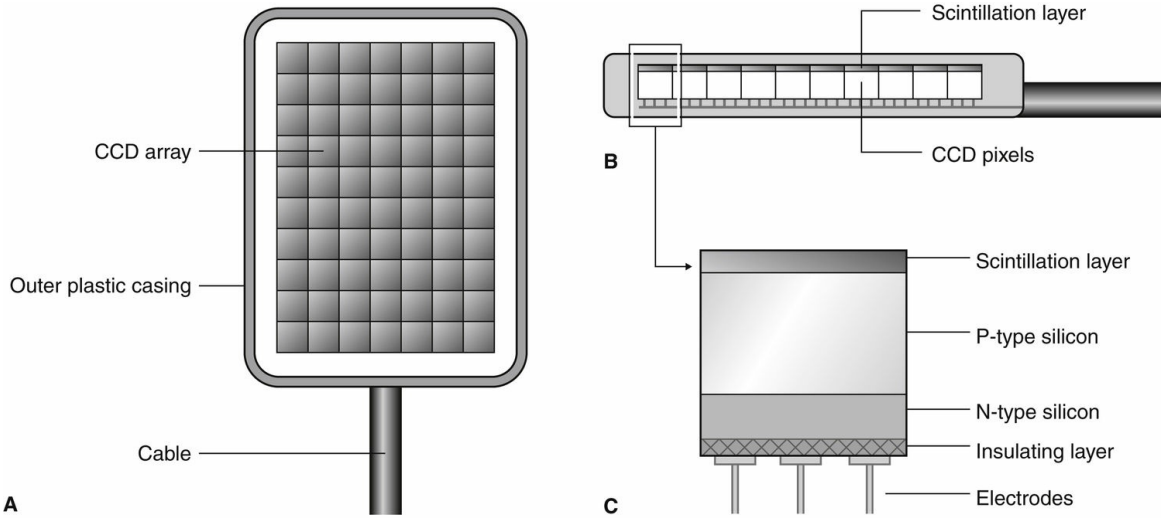


FIG. 4.3 Diagrams illustrating the basic construction of an intraoral charge-coupled device sensor. **(A)** The imaging surface showing the pixel array. **(B)** Sensor from the side showing the scintillation layer. **(C)** An individual pixel consisting of a sandwich of N- and P-type silicon.

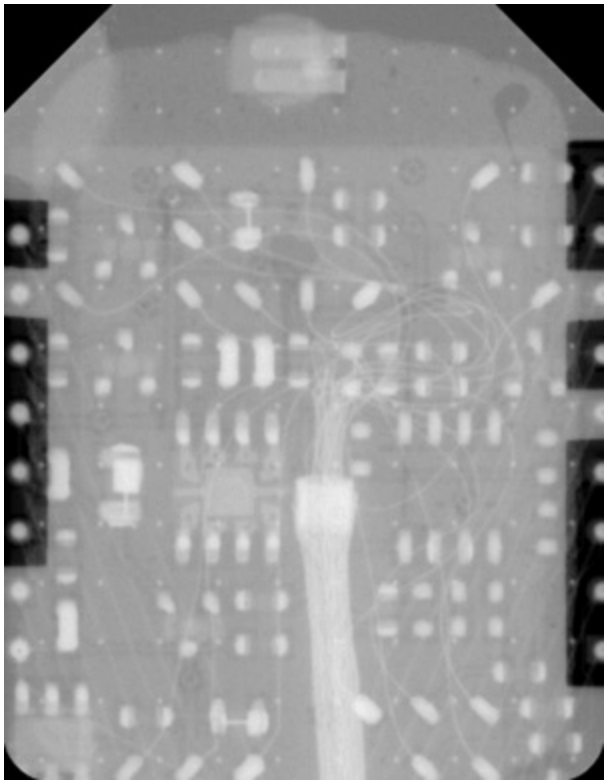


FIG. 4.4 An X-ray image of a Sirona sensor showing the complex internal electronic circuitry.

Extraoral Sensors

Extraoral sensors typically contain CCDs in long, thin linear arrays which are a few pixels wide and many pixels long. In combined panoramic/cephalometric digitals units, used for panoramic and cephalometric lateral skull radiography (see Chapter 14), the sensor consists of two long thin CCD arrays (see Fig. 4.5). The lower array is used for panoramic imaging, and both arrays are used for cephalometric radiography. The two images obtained from the two CCD arrays are *stitched* together by the computer software to create one large image. These types of sensors are used with a very narrow slit-shaped X-ray beam which is exactly aligned with the CCD array(s). To create an image the X-ray beam and sensor *move* together during the exposure so *scanning* the patient enabling the final image to be built up section by section. This movement of the equipment takes several seconds and is discussed in more details in Chapters 14 and 15

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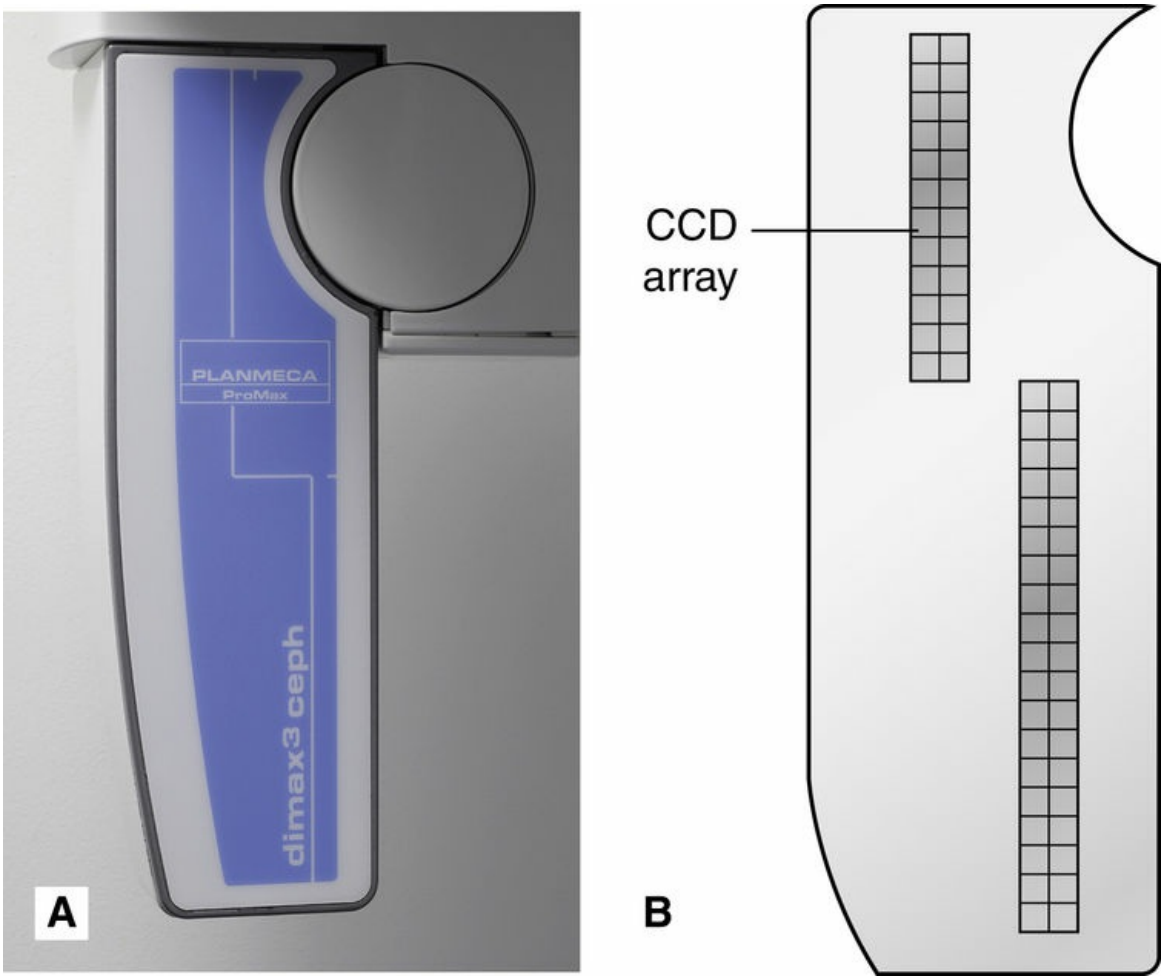


FIG. 4.5 **(A)** An example of an extraoral sensor (the Planmeca Dimax 3 sensor). The thin white lines indicating the location of the charge-coupled device array are shown on the sensor face. **(B)** Diagram showing the basic design featuring two long, thin charge-coupled device arrays.

Photostimulable Phosphor Storage Plates

These digital sensors consist of a range of imaging plates that can be used for both intraoral and extraoral radiography. The plates are not connected to the computer by a cable. Several systems are available; examples include Durr's VistaScan™, Soredex's Digora® Optime

(intraoral) and PCT (extraoral) and Planmeca's ProScanner system. A range of intraoral and extraoral plate sizes are available with these systems. The intraoral plates vary in size from one manufacturer to another as shown in Fig. 4.6 , but in general are similar in size to conventional packet film used for periapical, bitewing and occlusal radiography. As mentioned, when used clinically intraoral plates need to be inserted into protective plastic barrier envelopes for control of infection purposes (see Chapter 8). Extraoral plates are similar in size to traditional indirect action film used for panoramic and skull radiography and are used in cassettes but without intensifying screens (see later).

Plate Construction and Design

The plates typically consist of a layer of europium activated barium fluorohalide (BaFX : Eu^{2+}) phosphor on a flexible plastic backing support, as shown in Fig. 4.7 . Image production is not instantaneous with this type of image receptor. Two distinct stages are involved, namely:

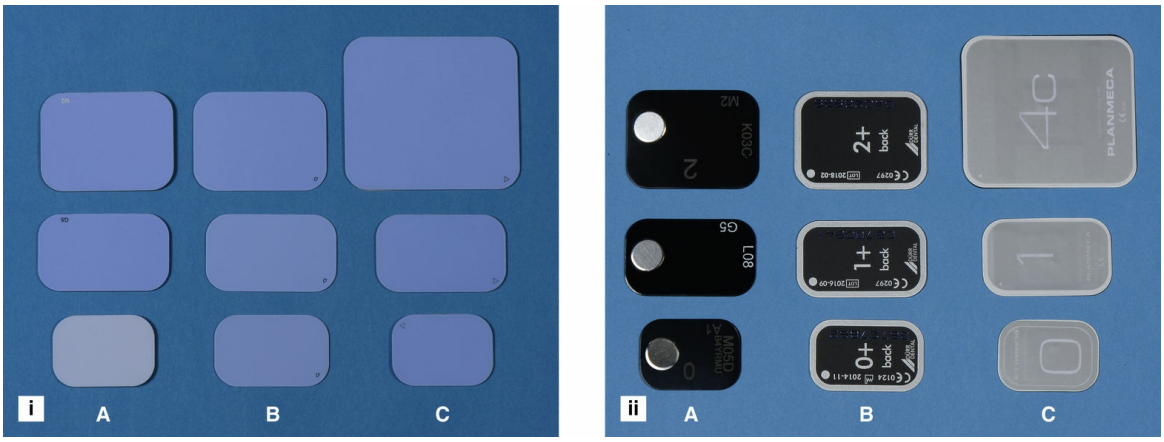


FIG. 4.6 **(i)** Examples of different sized intraoral phosphor plates manufactured by **(A)** Soredex (Digora®), **(B)** Durr (VistaScan™) and **(C)** Planmeca (ProScanner). **(ii)** The reverse side of the different plates shown in **(i)** – note the small round magnets set into the reverse of the Digora® plates.

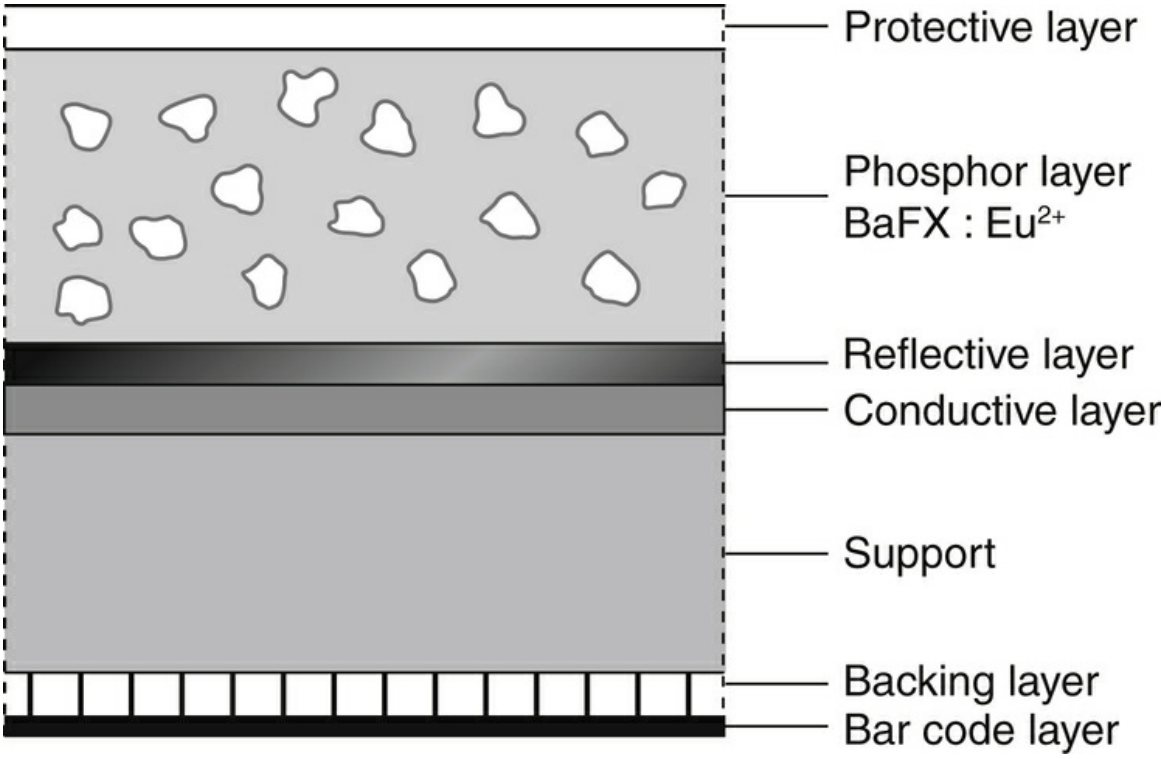


FIG. 4.7 Diagram showing the cross-sectional structure of a typical phosphor imaging plate.

- The phosphor layer absorbs and stores the X-ray energy that has not been attenuated by the patient.
- The image plate is then placed in a *reader* where it is scanned by a laser beam. The stored X-ray energy in the phosphor layer is released as light which is detected by a photo-multiplier tube and converted into a voltage, which is relayed to the computer and displayed as a digital image. This is described in greater detail in Chapter 5 .

Radiographic Film

Radiographic film has traditionally been used as the image receptor in dentistry and is still widely used. There are two basic types:

- *Direct-action* or *non-screen* film (sometimes referred to as *wrapped* or *packet* film). This type of film is sensitive primarily to X-ray photons.
- *Indirect-action* or *screen* film, so called because it is used in combination with *intensifying screens* in a *cassette* . This type of film is sensitive primarily to light photons, which are emitted by the adjacent intensifying screens. They respond to shorter exposure of X-rays, enabling a lower dose of radiation to be given to the patient.

Direct-action (Non-screen) Film

Uses

Direct-action film is used for intraoral radiography where the need for excellent image quality and fine anatomical detail are of importance.

Sizes

Various sizes of film are available, although only three are usually used routinely (see Fig. 4.8):

- 31 × 41 mm - for periapicals and bitewings
- 22 × 35 mm - for periapicals and bitewings
- 57 × 76 mm - for occlusals

The Film Packet Contents

The contents of a film packet are shown in Fig. 4.9 . It is worth noting that:

- The outer packet or wrapper is made of non-absorbent paper or plastic and is sealed to prevent the ingress of saliva
- The side of the packet that faces towards the X-ray beam has

either a pebbled or a smooth surface and is usually white

- The reverse side is usually of two colours so there is little chance of the film being placed the wrong way round in the patient's mouth and different colours represent different film speeds (see later).

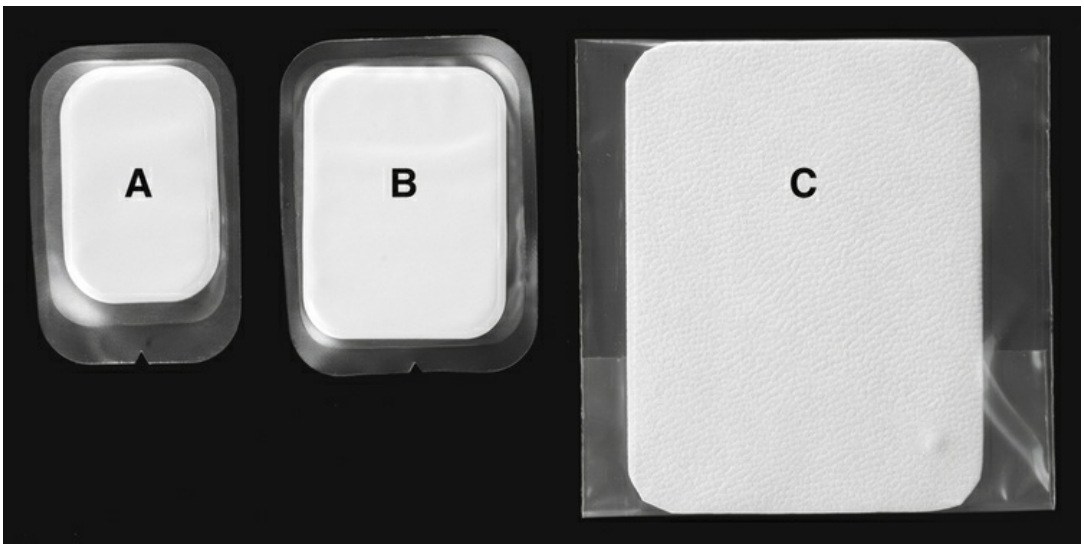


FIG. 4.8 The typical sizes of barrier-wrapped direct-action radiographic film packets available. **(A)** Small periapical/bitewing film. **(B)** Large periapical/bitewing film. **(C)** Occlusal film.

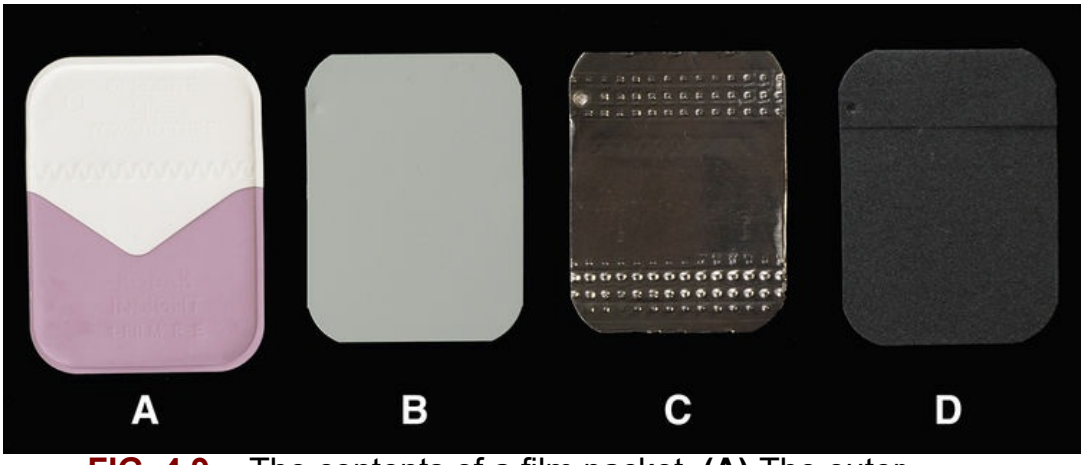


FIG. 4.9 The contents of a film packet. **(A)** The outer

wrapper. **(B)** The film. **(C)** The sheet of lead foil. **(D)** The protective black paper.

- The black paper on either side of the film is there to protect the film from:
  - Light
  - Damage by fingers while being unwrapped
  - Saliva that may leak into the film packet.
- A thin sheet of lead foil is placed behind the film to prevent:
  - Some of the residual radiation that has passed through the film from continuing on into the patient's tissues
  - Scattered secondary radiation, from X-ray photon interactions within the tissues beyond the film, scattering back on to the film and degrading the image.
- The sheet of lead foil contains an embossed pattern so that should the film packet be placed the wrong way round, the pattern will appear on the resultant radiograph. This feature enables the cause of the resultant pale film to be easily identified (see Chapter 17).

The Radiographic Film

The cross-sectional structure and components of the radiographic film are shown in Fig. 4.10 . It includes four basic components:

- A *plastic base* , made of clear, transparent cellulose acetate – acts as a support for the emulsion but does not contribute to the final image
- A thin layer of *adhesive* – fixes the emulsion to the base
- The green *emulsion* on **both** sides of the base – this consists of silver halide (usually bromide) crystals embedded in a gelatine matrix. The X-ray photons *sensitize* the silver halide crystals that they strike and these sensitized silver halide crystals are later reduced to visible black metallic silver in the

developer (see Chapter 5)

- *A protective layer* of clear gelatine to shield the emulsion from mechanical damage.

Film Orientation

The film has an embossed *dot* on one corner that is used to help with orientation. Its position is marked on the back of the packet or can be felt as a raised dot on the front. The side of the film on which the dot is raised is always placed towards the X-ray beam. When the films are mounted, this raised dot is towards the operator and the films are then arranged anatomically and viewed as if the operator were facing the patient.

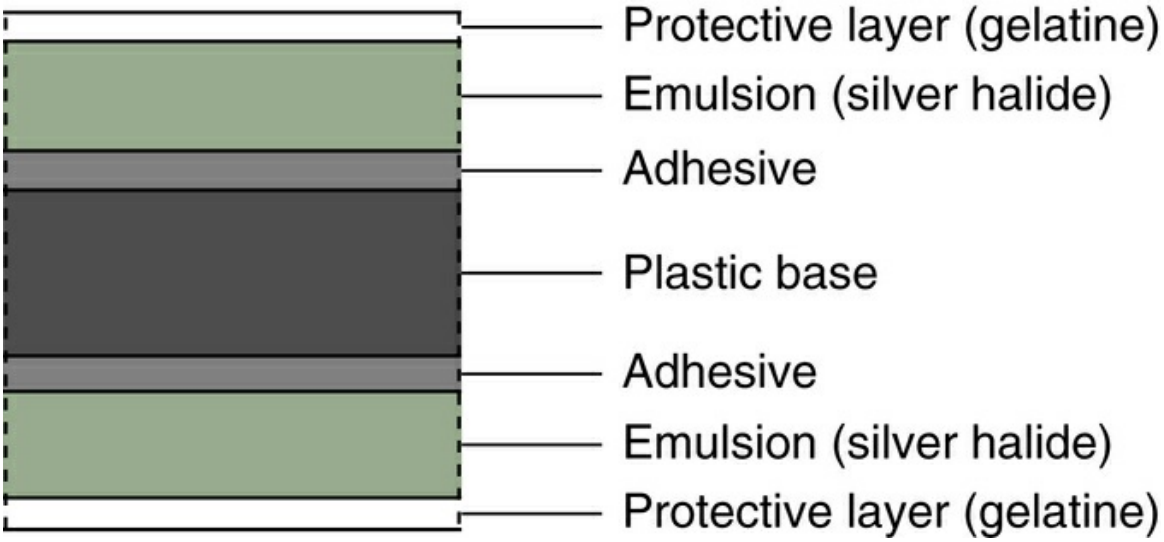


FIG. 4.10 Diagram showing the cross-sectional structure of double emulsion radiographic film.

Indirect-Action Film

Uses

Film/screen combinations are used as image detectors whenever possible because of the reduced dose of radiation to the patient

(particularly when very fine image detail is not essential). The main uses include:

- Extraoral projections, including:
  - Oblique lateral radiographs (see Chapter 12)
  - All skull radiographs (see Chapter 13)
  - Panoramic radiographs (see Chapter 15)
  - All routine medical radiography.

Indirect-action Film Construction

This type of film is similar in construction to direct-action film. However, the following important points should be noted:

- The silver halide emulsion is designed to be sensitive primarily to light rather than X-rays.
- Different emulsions are manufactured which are sensitive to the different colours of light emitted by different types of intensifying screens (see later). These include:
  - *Standard silver halide emulsion* sensitive to BLUE light
  - *Modified silver halide emulsion with ultraviolet sensitizers* sensitive to ULTRAVIOLET light
  - *Orthochromatic emulsion* sensitive to GREEN light.
  - *Panchromatic emulsion* sensitive to RED light.

The relative spectral sensitivity of these four different film emulsions is shown in Fig. 4.11 .

- It is essential that the correct combination of film and intensifying screens is used.
- There is no orientation *dot* embossed in the film so some form of additional identification is required, e.g. metal letters, **L** or **R** , placed on the outside of the cassette or electronic marking.

Characteristics of Radiographic Film

This section summarizes the more important theoretical terms and definitions used to describe how radiographic film responds to exposure to X-rays.

Optical Density (OD)

$$\text{OD} = \log \frac{\text{Incident light intensity}}{\text{Transmitted light intensity}}$$

Optical density (OD) is the term used for describing the degree of film blackening and can be measured directly using a densitometer. In diagnostic radiology the range of optical densities is usually 0.25–2.50. There are no units for optical density.

Characteristic Curve

The characteristic curve is a graph showing the variation in optical density (degree of blackening) with different exposures. Typical characteristic curves for direct-action (non-screen) and indirect-action (screen) film are shown in Fig. 4.12 . This curve describes several of the film's properties.

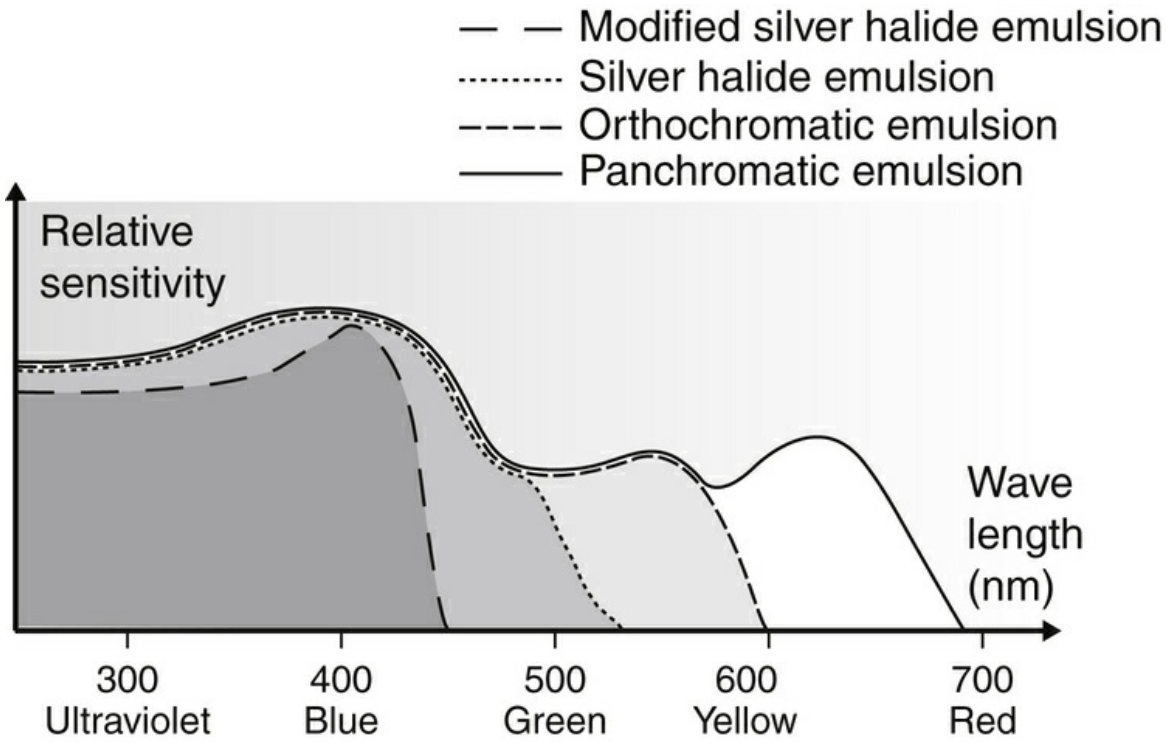


FIG. 4.11 Graph showing the relative spectral sensitivity of standard silver halide (BLUE), modified silver halide (ULTRAVIOLET), orthochromatic (GREEN) and panchromatic (RED) film emulsions.

Background Fog Density

Background fog density is the small degree of blackening evident even with zero exposure. This is due to:

- The colour/density of the plastic base
- The development of some unexposed silver halide crystals.

If the film has been stored correctly, this background fog density should be less than 0.2 (see Fig. 4.12).

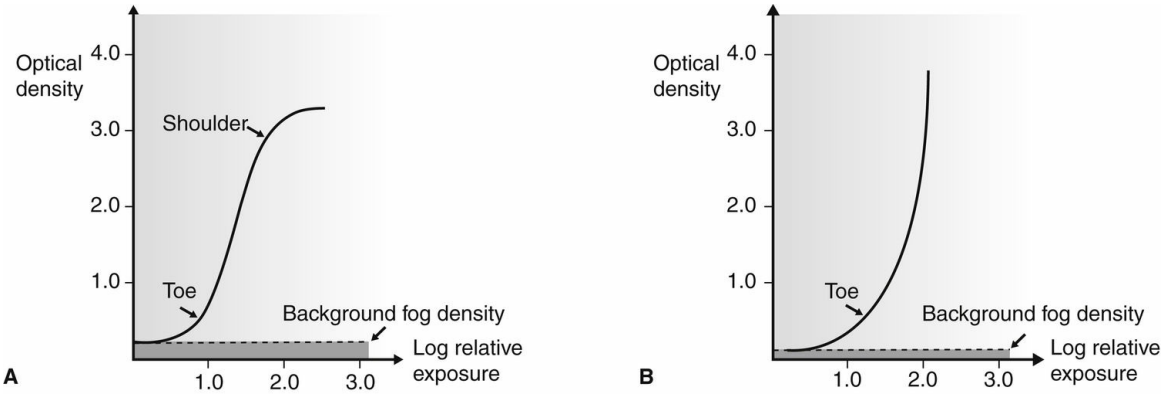


FIG. 4.12 **(A)** A typical characteristic curve of indirect-action radiographic film, showing the main regions of the curve including *background fog density*, *toe* and *shoulder* . **(B)** A typical characteristic curve for direct-action film.

Film Speed

Film speed is the exposure required to produce an optical density of 1.0 above background fog (see Fig. 4.13). Thus, the faster the film, the less the exposure required for a given film blackening and the lower the radiation dose to the patient. Film speed is a function of the number and size of the silver halide crystals in the emulsion. The larger the crystals, the faster the film but the poorer the image quality. In clinical practice, the fastest films consistent with adequate diagnostic results, either D-speed or more usually nowadays the faster E or F-speed, should be used (see Fig. 4.14).

Film Sensitivity

Film sensitivity is the reciprocal of the exposure required to produce an optical density of 1.0 above background fog. Thus, a fast film has a high sensitivity.

Film Latitude

This is a measure of the range of exposures that produces distinguishable differences in optical density, i.e. the linear portion of the characteristic curve (see Fig. 4.15). The wider the film latitude, the

greater the range of object densities that may be seen.

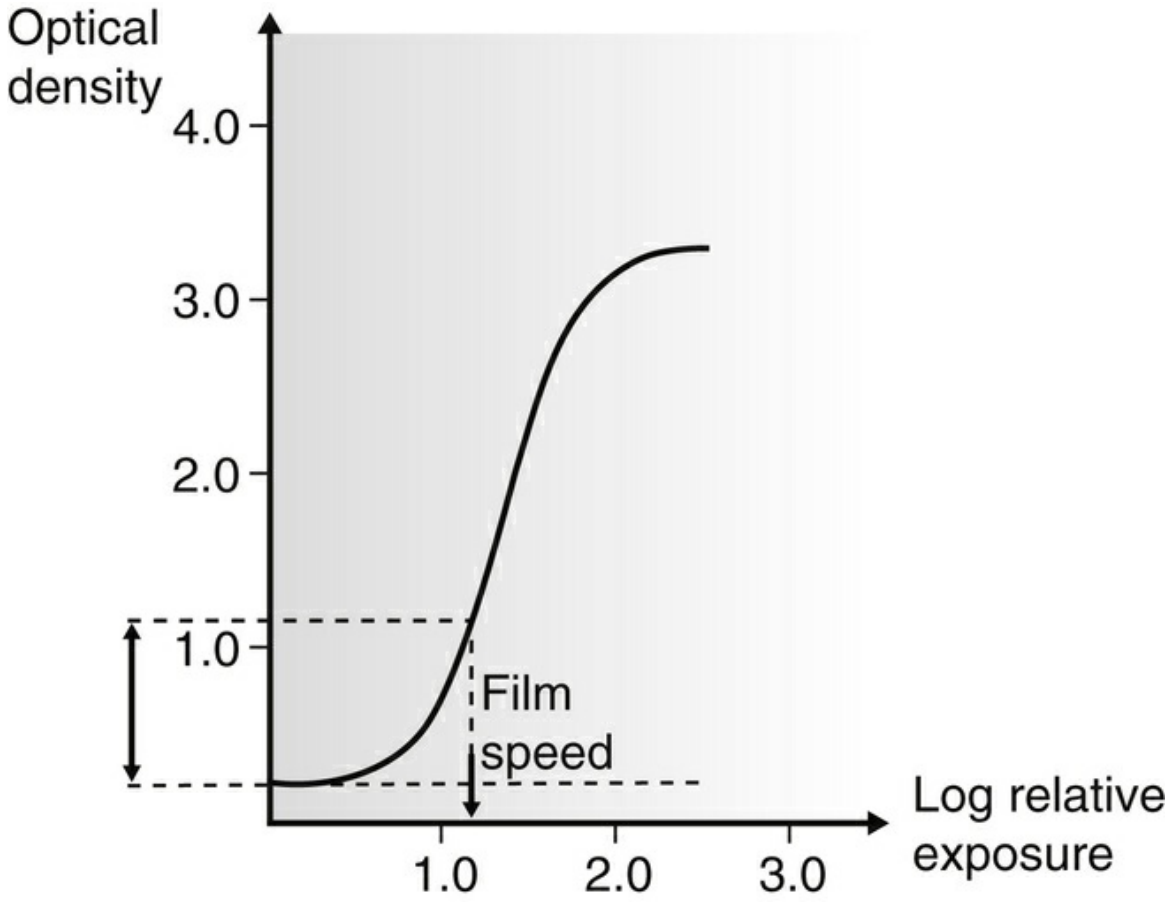


FIG. 4.13 The characteristic curve of an indirect-action (screen) film showing the *film speed* – the exposure required to produce an optical density of 1.0 above background fog.

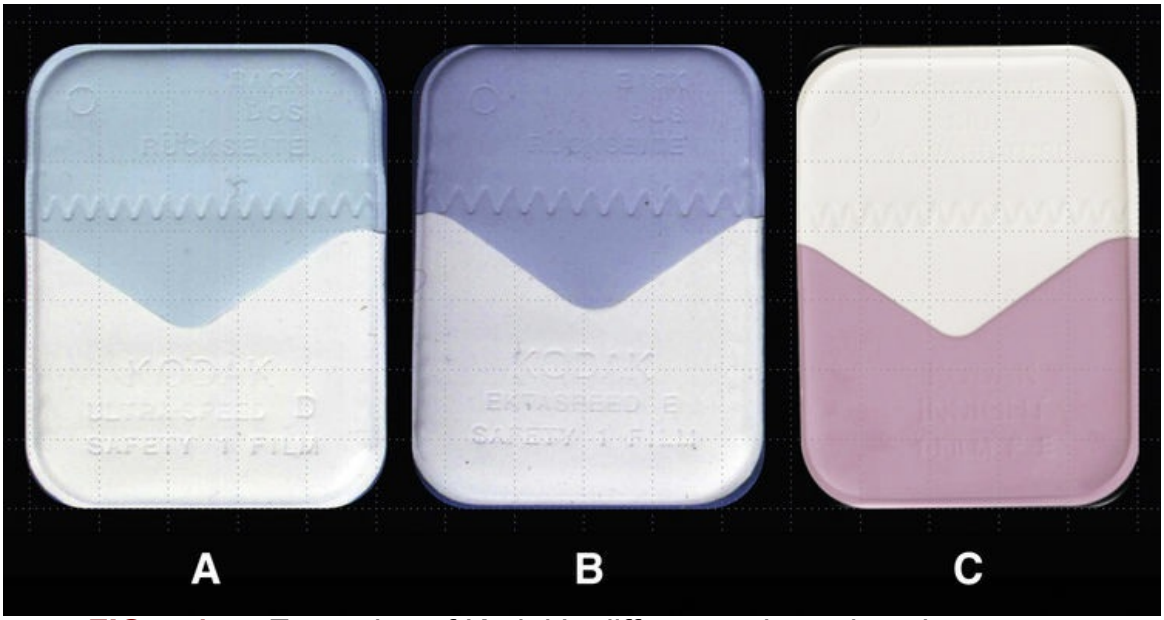


FIG. 4.14 Examples of Kodak's different coloured packets containing films of different speeds. **(A)** D-speed film. **(B)** E-speed film. **(C)** F-speed film.

Film Contrast

Film contrast is the difference in optical density between two points on a film that have received different exposures (see Fig. 4.15).

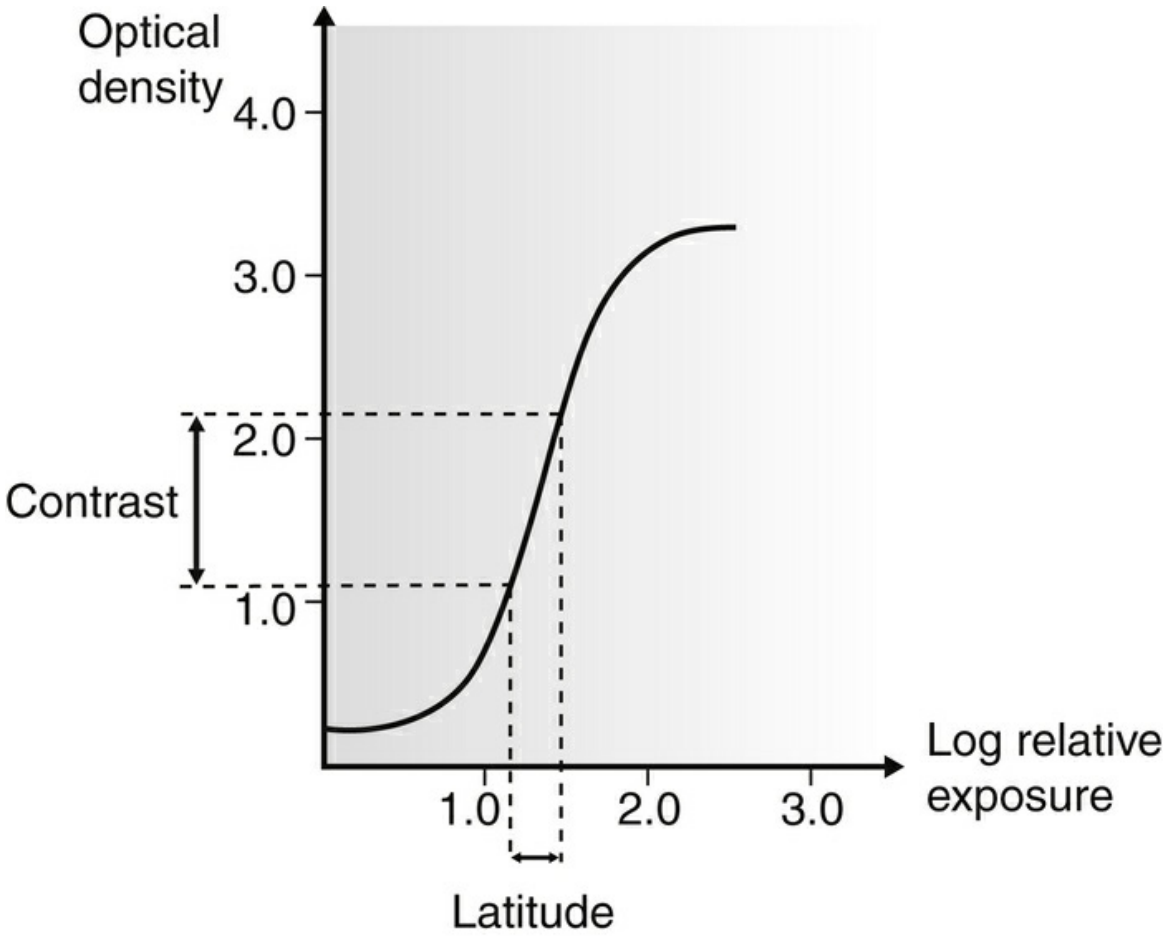


FIG. 4.15 The characteristic curve of an indirect-action film showing film *contrast* and *latitude* .

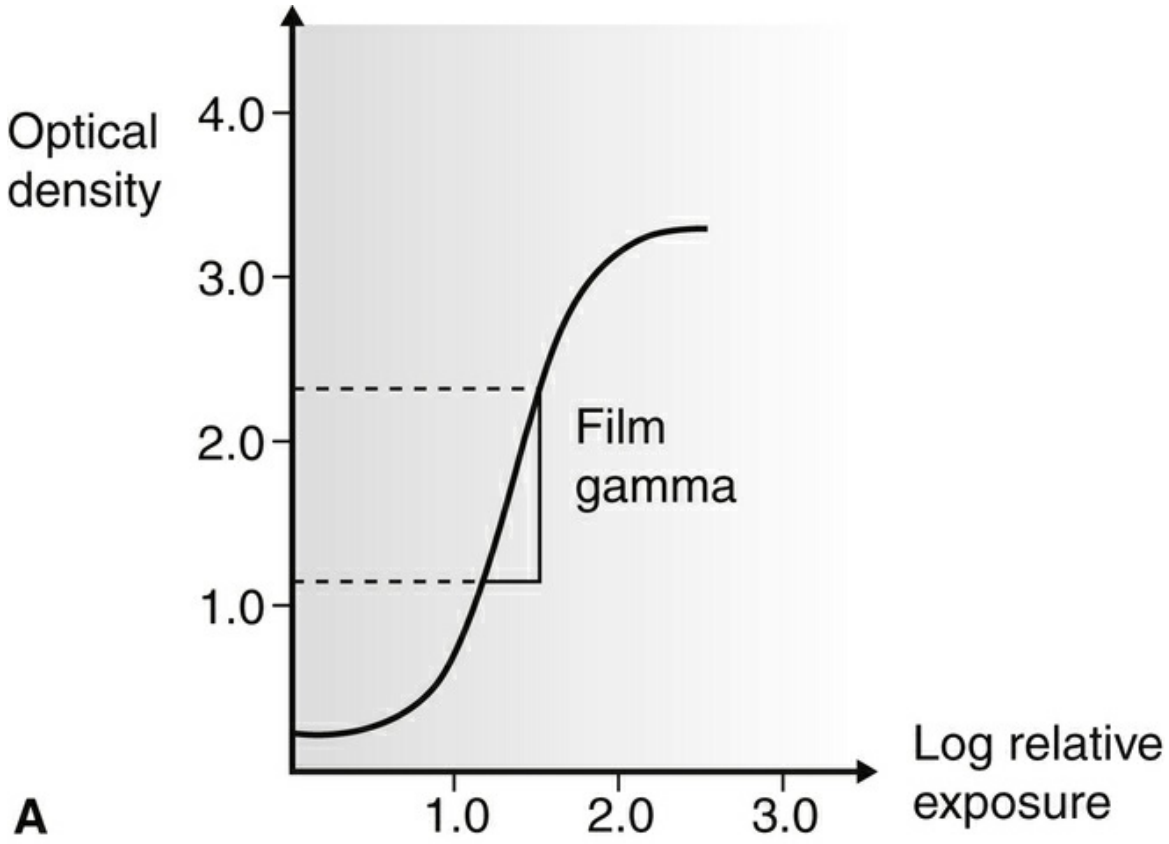
Film Gamma and Average Gradient

Film gamma is the *maximum* gradient or slope of the linear portion of the characteristic curve. This term is often quoted, but is of little value in radiology because the maximum slope (steepest) portion of the characteristic curve is usually very short. The average gradient is a more useful measurement and is usually calculated between density 0.25 and 2.0 above background fog (see Fig. 4.16).

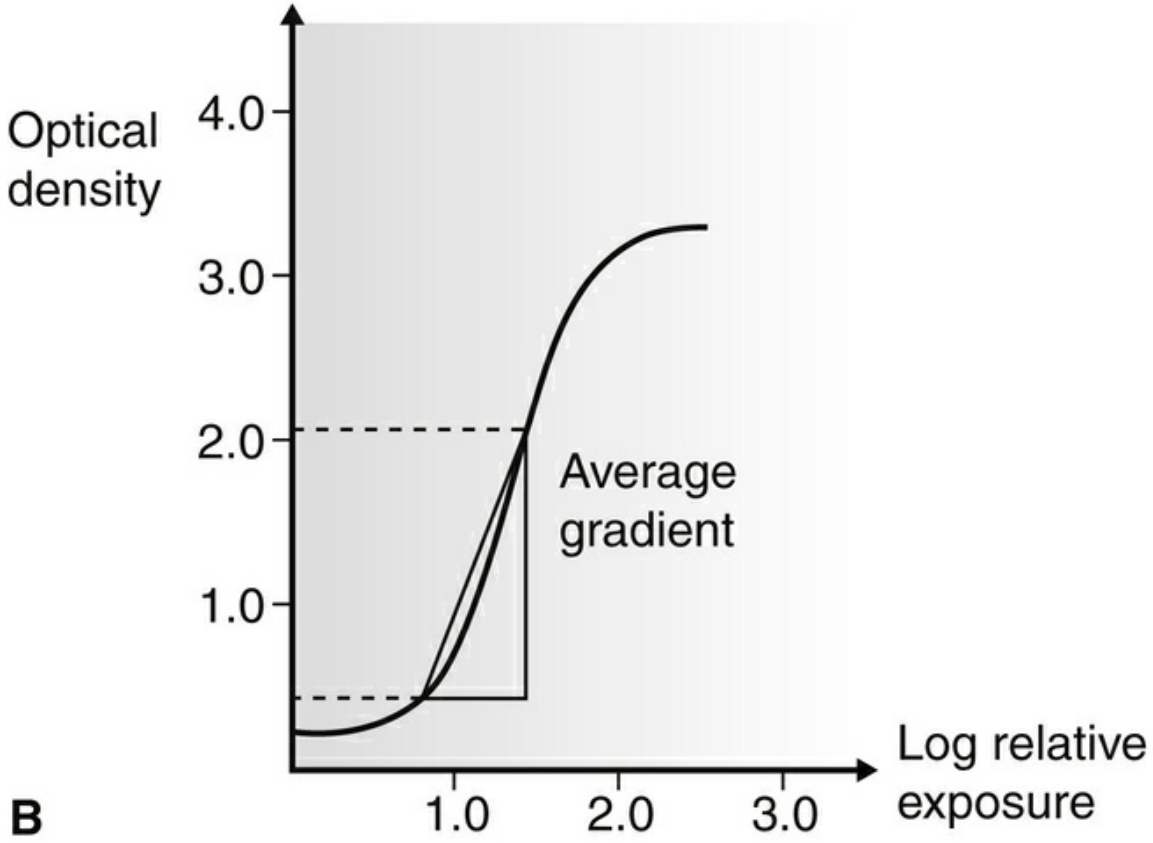
Thus, the film *gamma* or *average gradient* measurement determines both *film latitude* and *film contrast* as follows:

- If the gamma or average gradient is **high** (i.e. a steep gradient), that film will show good contrast, but will have less latitude.

- If the film gamma or average gradient is **low** (i.e. a shallow gradient), that film will show poor contrast but will have wider latitude.


Optical density
4.0
3.0
2.0
1.0
Film gamma
Log relative exposure
1.0
2.0
3.0

A


Optical density
4.0
3.0
2.0
1.0
Average gradient
Log relative exposure
1.0
2.0
3.0

B

FIG. 4.16 Characteristic curves showing **(A)** *film gamma* and **(B)** *average gradient* of an indirect-action (screen) film.

Resolution

Resolution, or resolving power, is a measure of the radiograph's ability to differentiate between different structures that are close together. Factors that can affect resolution include penumbra effect (image sharpness), silver halide crystal size and contrast. It is measured in line pairs per millimetre. Direct-action film has a resolution of approximately 10 line pairs per millimetre and indirect-action film a resolution of about 5 line pairs per millimetre.

Intensifying Screens

Intensifying screens consist of *fluorescent phosphors* , which emit light when excited by X-rays, embedded in a plastic matrix. The basic construction and components of an intensifying screen are shown in Fig. 4.17 .

Action

Two intensifying screens are used – one in front of the film and the other at the back. The front screen absorbs the low-energy X-ray photons and the back screen absorbs the high-energy photons. The two screens are therefore efficient at stopping the transmitted X-ray beam, which they convert into visible light by the *photoelectric effect* (described inChapter 2). One X-ray photon will produce many light photons, which will affect a relatively large area of film emulsion. Thus, the amount of radiation needed to expose the film is reduced but at the cost of fine detail; *resolution* is decreased. The ultraviolet system was developed to improve *resolution* by reducing light diffusion and having virtually no light crossover through the plastic film base (see Fig. 4.18).

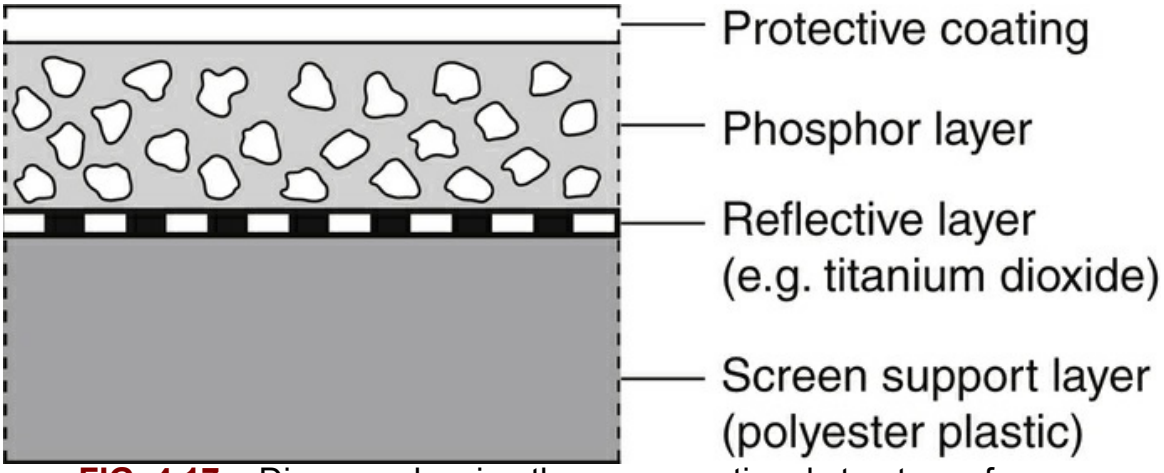


FIG. 4.17 Diagram showing the cross-sectional structure of a typical intensifying screen.

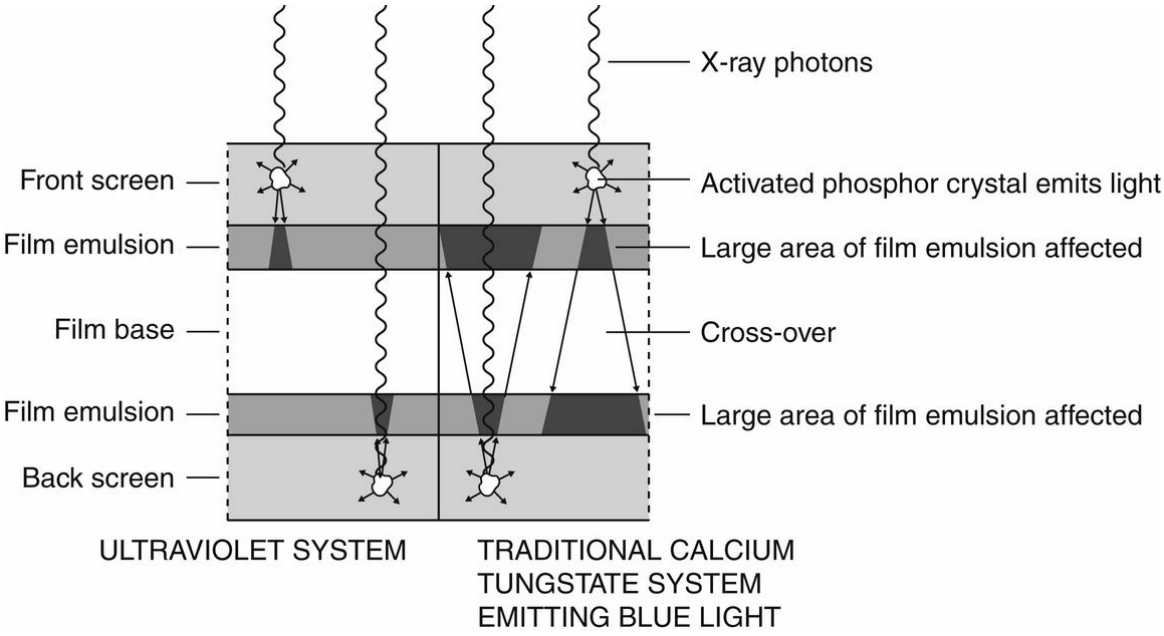


FIG. 4.18 Diagram showing the action of traditional calcium tungstate and ultraviolet systems. Note the small cone of ultraviolet light with no cross-over through the film base, compared with the large cone of blue light and marked cross-over from the calcium tungstate phosphors. These differences result in better resolution and image sharpness with ultraviolet systems.

Useful Definitions

The following terms are used to describe intensifying screens:

- *Conversion efficiency* – the efficiency with which the phosphor converts X-rays into light
- *Absorption efficiency* – the ability of the phosphor material to absorb X-rays
- *Screen efficiency* – the ability of the light emitted by the phosphor to escape from the screen and expose the film
- *Intensification factor* (IF)

$$\text{IF} = \frac{\text{Exposure required when screens are } \textit{not} \text{ used}}{\text{Exposure required with screens}}$$

- *Screen speed* – the time taken for the screen to emit light following exposure to X-rays. The faster the screen, the lower the radiation dose to the patient
- *Packing density* – the ability of the phosphor to pack closely together resulting in thin screens and less light divergence.

Fluorescent Materials

Three main phosphor materials are, or have been, used in intensifying screens:

- Rare earth phosphors including gadolinium and lanthanum
- Yttrium (a non-rare earth phosphor but having similar properties)
- Calcium tungstate ($CaWO_4$).

Rare Earth and Related Screens

Modern screens use these phosphors that produce very fast screen speeds, enabling a substantial decrease in radiation dose to patients, without excessive loss of image detail. The main points can be summarized as follows:

- The rare earth group of elements includes:
  - Lanthanum (Z = 57)
  - Gadolinium (Z = 64)
  - Terbium (Z = 65)
  - Thulium (Z = 69).
- The term *rare earth* is used because it is difficult and expensive to separate these elements from earth and from each other, not because the elements are scarce.
- These phosphors only fluoresce properly when they contain impurities of other phosphors, e.g. gadolinium plus 0.3% terbium. Typical screens include:
  - Terbium-activated gadolinium oxysulphide ($Gd_2 O_1 S$: Tb)
  - Thulium-activated lanthanum oxybromide (LaOBr : Tm).
- Terbium-activated screens emit GREEN light, and thulium-activated screens emit BLUE light (see Fig. 4.19).
- Yttrium (Z = 39), the rare earth related phosphor, in the form of pure yttrium tantalate ($YTaO_4$) emits ULTRAVIOLET light (see Fig. 4.19).
- Rare earth and related screens are approximately five times faster than calcium tungstate screens. The amount of radiation required to produce an image is therefore considerably decreased, but they are relatively expensive.
- Several different screens of each phosphor, each producing a different *image system speed*, are available:

Screen type	**Image system speed**
Detail or fine	100
Fast detail or medium	200

Rapid or fast	400
Super rapid	800

- It is important to use the appropriate films with their correctly matched screens.

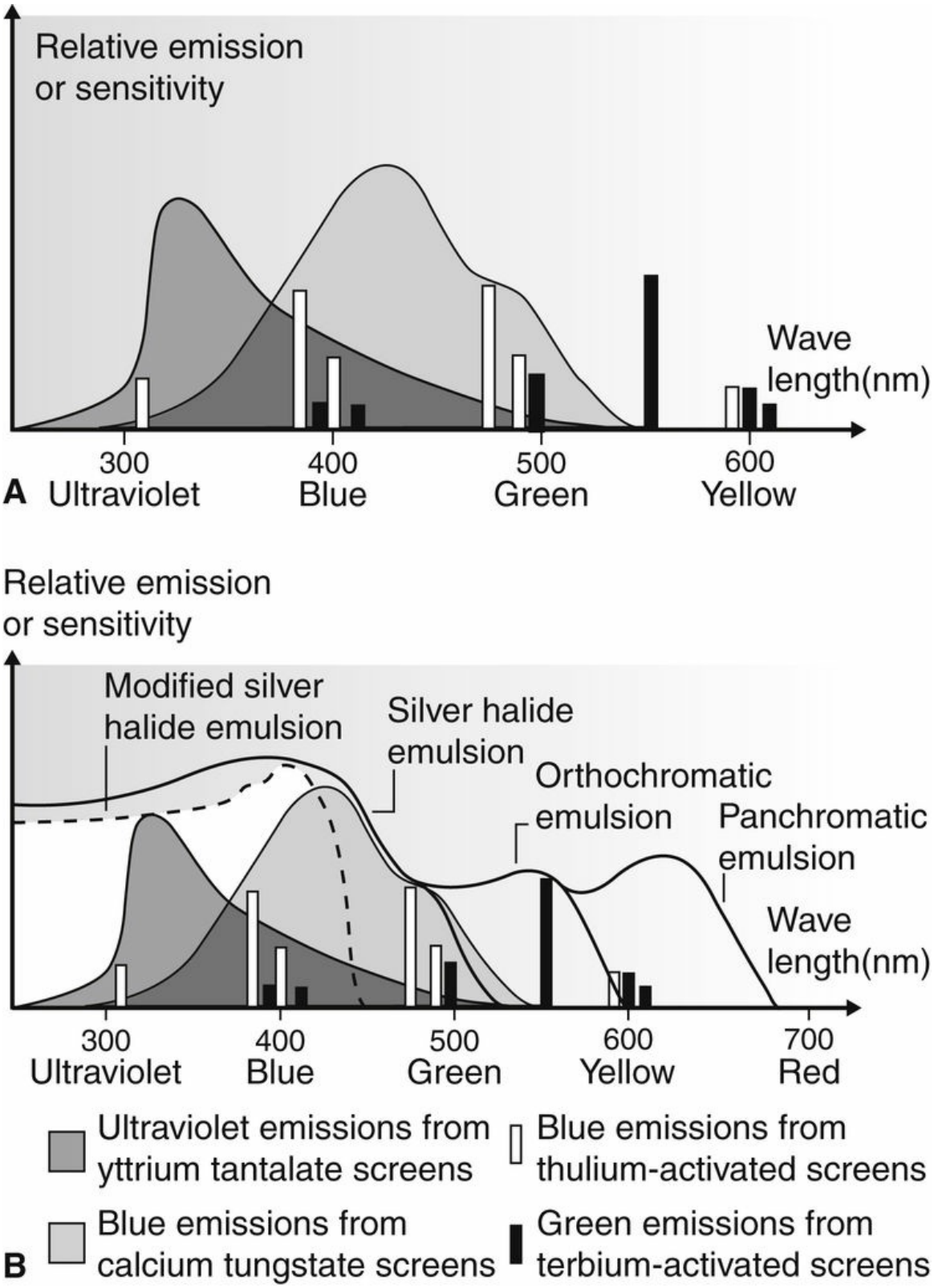


FIG. 4.19 **(A)** Graph showing the relative spectral emissions of different types of intensifying screens. **(B)** Graph showing the spectral sensitivity of different types of film combined with

the relative spectral emissions of different types of intensifying screens.

Calcium Tungstate Screens

Calcium tungstate was the original material used but it is no longer recommended. The main points can be summarized as follows:

- The speed of these screens depends on:
  - The thickness of the phosphor layer
  - The size of the phosphor crystals
  - The presence or absence of light-absorbing dyes within the screen
  - The *conversion efficiency* of the crystals
- The faster the screen, the lower the radiation dose to the patient but the less the detail of the final image
- All calcium tungstate screens emit BLUE light and must be used with blue light–sensitive monochromatic radiographic film (see Fig. 4.19).
- Slower than rare earth screens.

Cassettes

Types

Cassettes are made in a variety of shapes and sizes for different projections. A selection is shown in Fig. 4.20 .

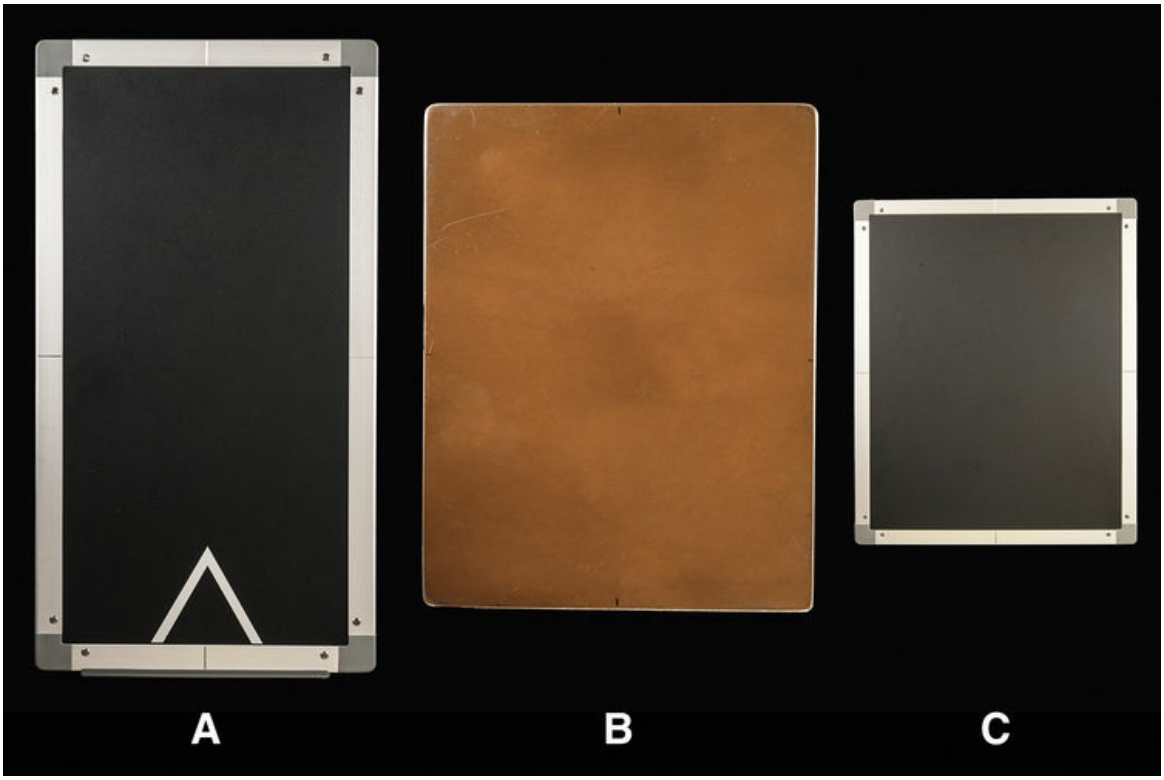


FIG. 4.20 Various sizes of cassettes used for different radiographic projections. **(A)** Panoramic cassette (see Chapter 15). **(B)** Skull cassette (see Chapter 13). **(C)** Oblique lateral cassette (see Chapter 12).

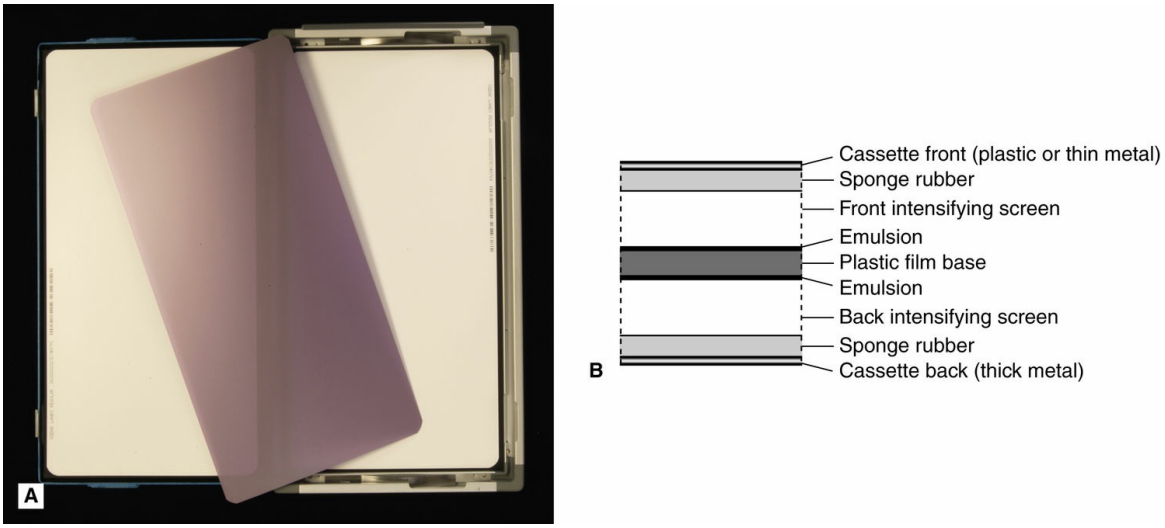


FIG. 4.21 **(A)** A panoramic cassette opened up showing the white intensifying screens and the film. **(B)** Diagram showing

the cross-sectional components in a cassette.

Construction

Despite their different shapes, the construction of the cassettes is very similar. They usually consist of a light-tight aluminium or carbon fibre container with the radiographic film sandwiched tightly between two intensifying screens (see Fig. 4.21). Any loss in film/screen contact will result in degradation of the final image.

Important Practical Points to Note

Film Storage

All radiographic film deteriorates with time and manufacturers state expiry dates on film boxes as a guide. However, this does not mean that the film automatically becomes unusable after this date. Storage conditions can have a dramatic effect on the deterioration rate. Ideally, films should be stored:

- In a refrigerator in cool, dry conditions
- Away from all sources of ionizing radiation
- Away from chemical fumes including mercury and mercury-containing compounds
- With boxes placed on their edges, to prevent pressure artefacts.

Screen Maintenance

Intensifying screens should last for many years if looked after correctly. Maintenance should include:

- Regular cleaning with a proprietary cleaning agent
- Careful handling to avoid scratching or damaging the surface
- Regular checks for loss of film/screen contact.

These aspects are discussed further in Chapter 17 .

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

5

Image Processing

Processing is the general term used to describe the sequence of events required to convert the invisible latent image, contained in the solid-state or phosphor layer of digital sensors, or in the sensitized emulsion of traditional film, into the visible black, white and grey radiographic digital or film image. This chapter summarizes the two main methods involved, namely:

- Computer digital processing
- Chemical film processing.

Computer Digital Processing

Digital Image

The digital image is captured in pixels (tiny squares), by two different types of sensors – solid-state or photostimulable phosphor plates described in Chapter 4 . However captured, the digital image is similar to a film-captured image, in that both are two-dimensional representations of a three-dimensional object. In digital imaging, each two-dimensional pixel represents a three-dimensional cuboid or *voxel* of the patient. This is shown diagrammatically in Fig. 5.1 **.** The depth o the cuboid depends on the thickness of the part of the body being X-rayed. Each pixel measures the total X-ray absorption throughout the whole of each voxel. This two-dimensional limitation has been overcome with the development of *cone beam computed tomography* (CBCT) (see Chapter 16).

Computer Input

Solid-state Sensors

As explained in Chapter 4 , solid-state sensors input the information from each pixel directly (usually down the cable) to the computer's analogue-to-digital converter as an analogue voltage signal.

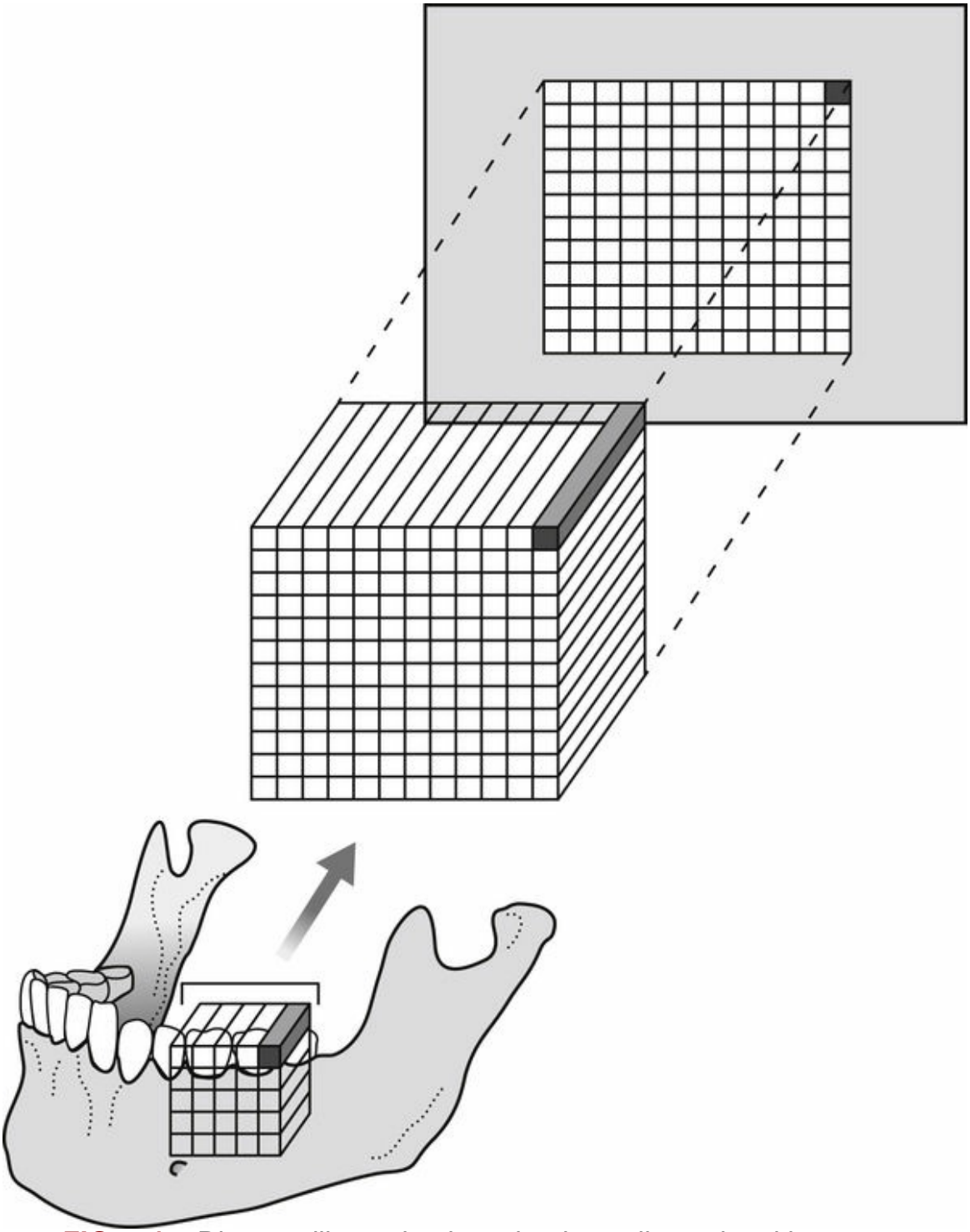


FIG. 5.1 Diagram illustrating how the three-dimensional jaw is represented as a digital image made up of a grid or matrix of two-dimensional pixels.

Phosphor Plates

Phosphor plates are **not** directly connected to the computer and therefore an intermediary stage is required when the plate is *read*. The time taken to read the plate depends on the particular system being used, and the size of the plate, but typically varies between 5–100 seconds. Several dental systems are available including Soredex's Digora® Optime (intraoral) and PCT (extraoral) and Durr's VistaScan™. Although different in design, they all work on the same principle as shown in Fig. 5.2 , namely:

- During the radiographic procedure the phosphor layer on the plate absorbs and stores the X-ray energy that has not been attenuated by the patient.
- The plate is then placed in the reader.
- The plate is scanned by a laser beam and the stored X-ray energy is released as light.
- The light is detected by a photomultiplier tube and converted into an electrical signal (voltage) and input to the connected computer's analogue-to-digital converter.
- The plate is cleared (erased) ready for reuse.

Computer Processing Theory

Computers deal with numbers, hence the need for the *analogue* voltage from each pixel to be changed by the analogue-to-digital converter into a discrete *numerical* digital signal. Each pixel has an x and a y coordinate and is allocated a number. Typically using the greyscale there are 256 numbers to select. These range from 0, when the voltage received is at its maximum (no X-ray attenuation in the patient), to 255 when there is no voltage (total X-ray attenuation in the patient). The computer finally allocates an appropriate colour from the greyscale (256 shades of grey from black through to white) to each pixel (0 = black, 255 = white) to create the visual image on the monitor. This concept is illustrated simply in Fig. 5.3 using just eight numbers and eight shades of grey.

The number and size of the pixels, together with the number of shades of grey available, determine the amount of information in an image, the size of the image file and the resolution of the final image (see Fig. 5.4). Pixel sizes vary from 20 to 70 μm, producing resolution between 7 and 25 line pairs per millimetre.

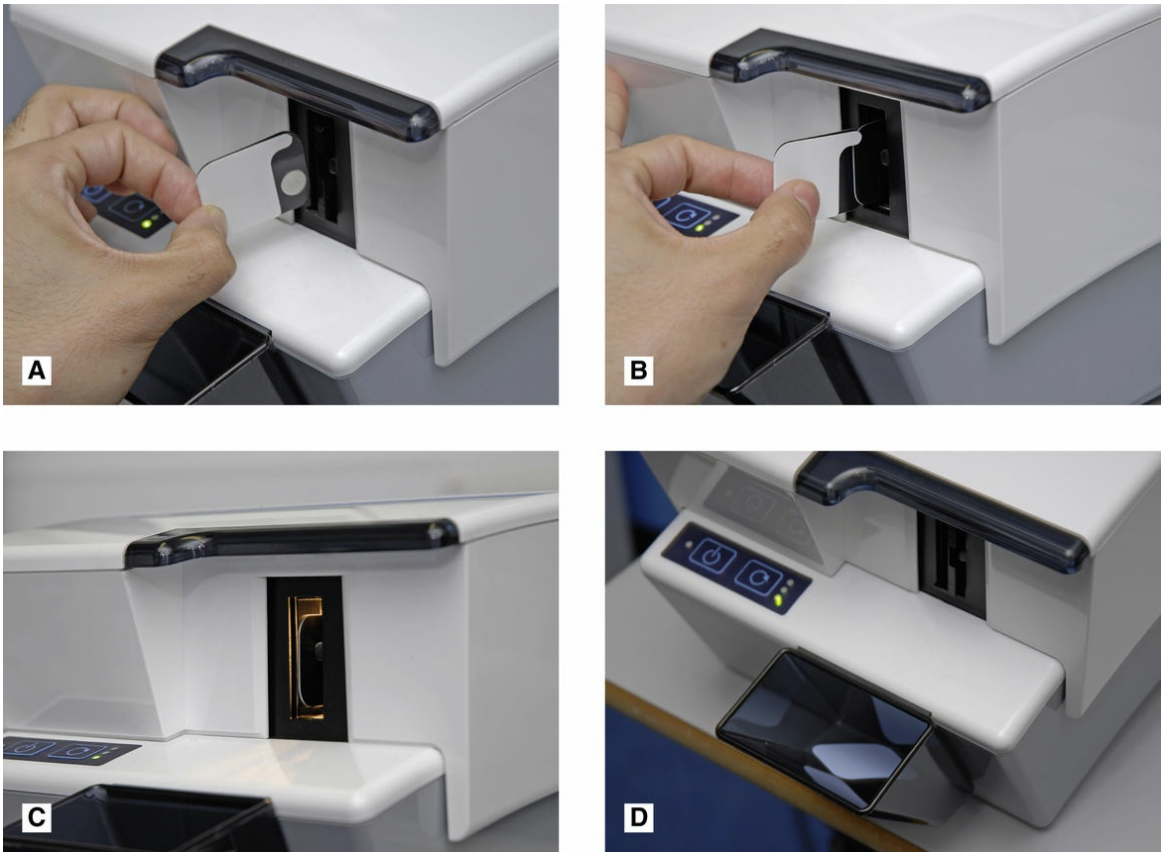


FIG. 5.2 Phosphor plate processing using the Digora® Optime reader. **(A)** Plate presented to the reader magnet end first. **(B)** Plate pulled into the reader for scanning. **(C)** Plate is automatically ejected from the reader and cleared (erased) by exposure to white light. **(D)** Plate drops into the collection box for subsequent repackaging ready for reuse.

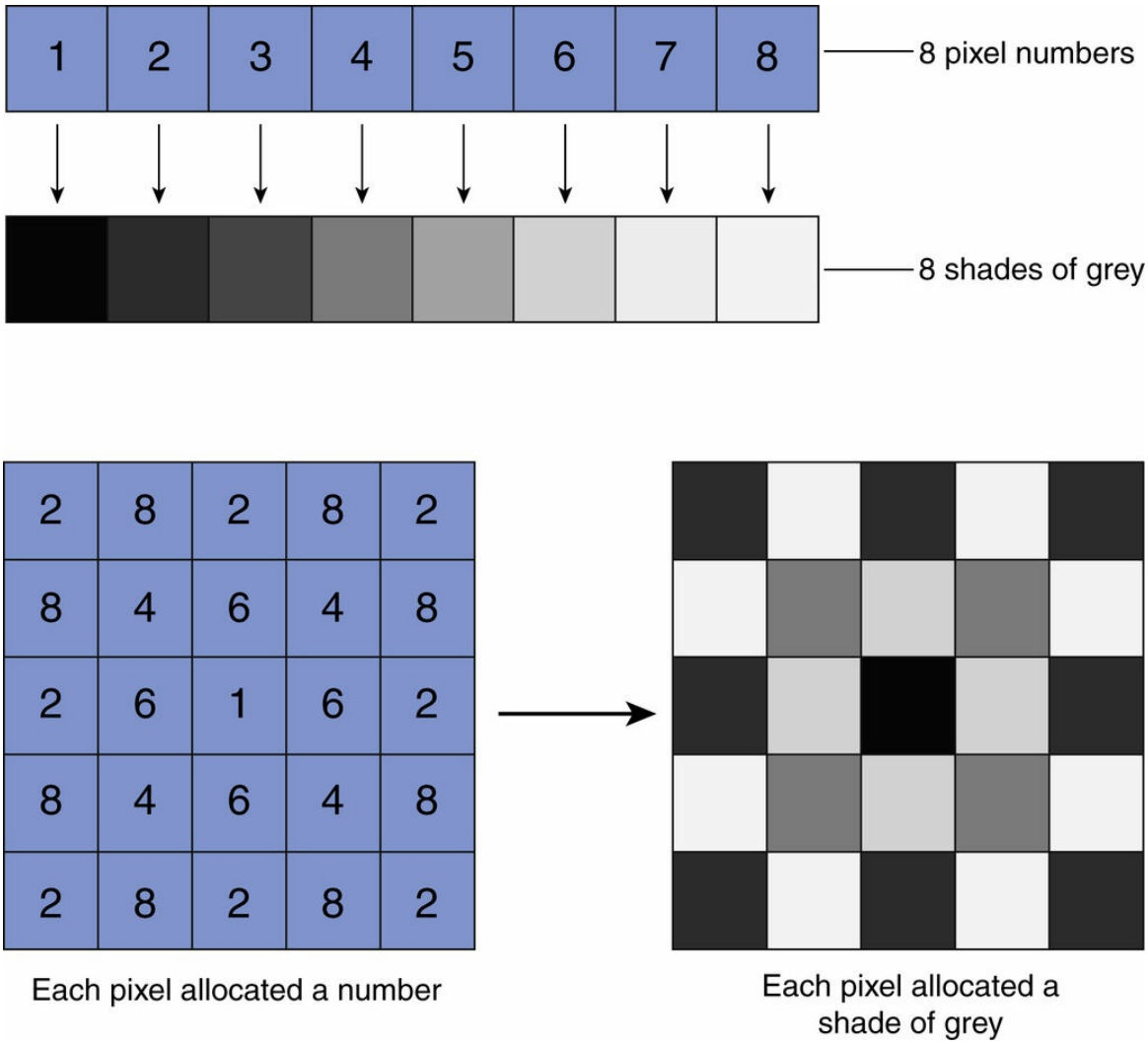


FIG. 5.3 Illustration of a simple digital image creation using eight pixel numbers corresponding with eight shades of grey. Each pixel is allocated a number (depending of the size of the input voltage) and then allocated a shade of grey to create the visual image.

Image Manipulation

Digital images can be changed by giving the pixels different numbers so altering the shades of grey. Different colours can be used. The coordinates of pixels may be changed or swapped, allowing different parts of the image to be moved around. These variables are the basis for image manipulation and enhancement. Software packages allow several enhancement techniques, some of which are shown in Fig. 5.5 .

These can include:

- Alteration in contrast
- Alteration in brightness
- Inversion (reversed)
- Embossing or pseudo three-dimensional imaging
- Magnification
- Automated measurement
- Pseudocolourization.

The two most frequently used enhancement functions are altering *brightness* and *contrast*.

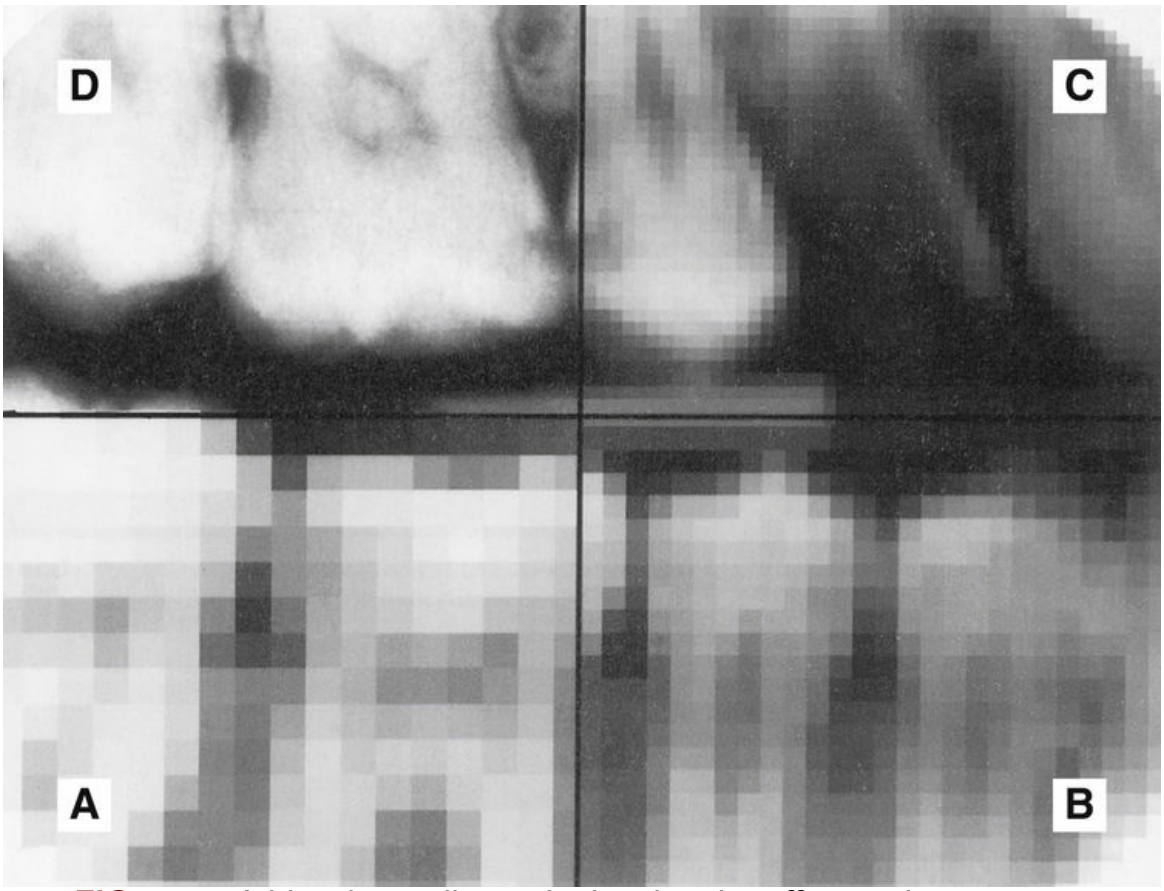


FIG. 5.4 A bitewing radiograph showing the effect on image quality and resolution of different sized pixels gradually reducing from **(A)** to **(D)** .

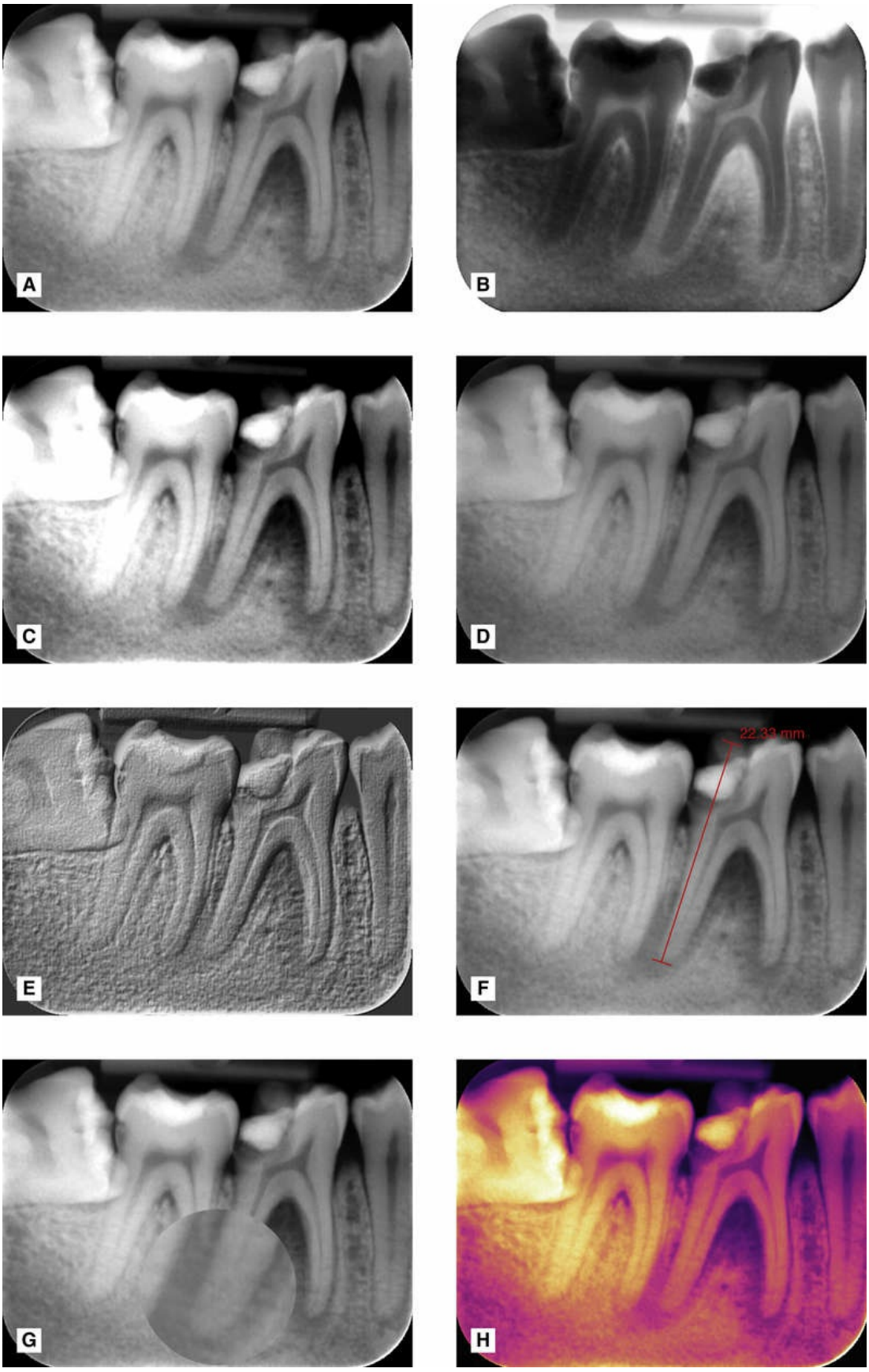

A
B
C
D
E
F
22.33 mm
G
H

FIG. 5.5 Digital image enhancement. **(A)** Original image. **(B)** Inverted. **(C)** High contrast. **(D)** Low contrast. **(E)** Embossed. **(F)** Automated measurement. **(G)** Magnified. **(H)** Pseudocoloured.

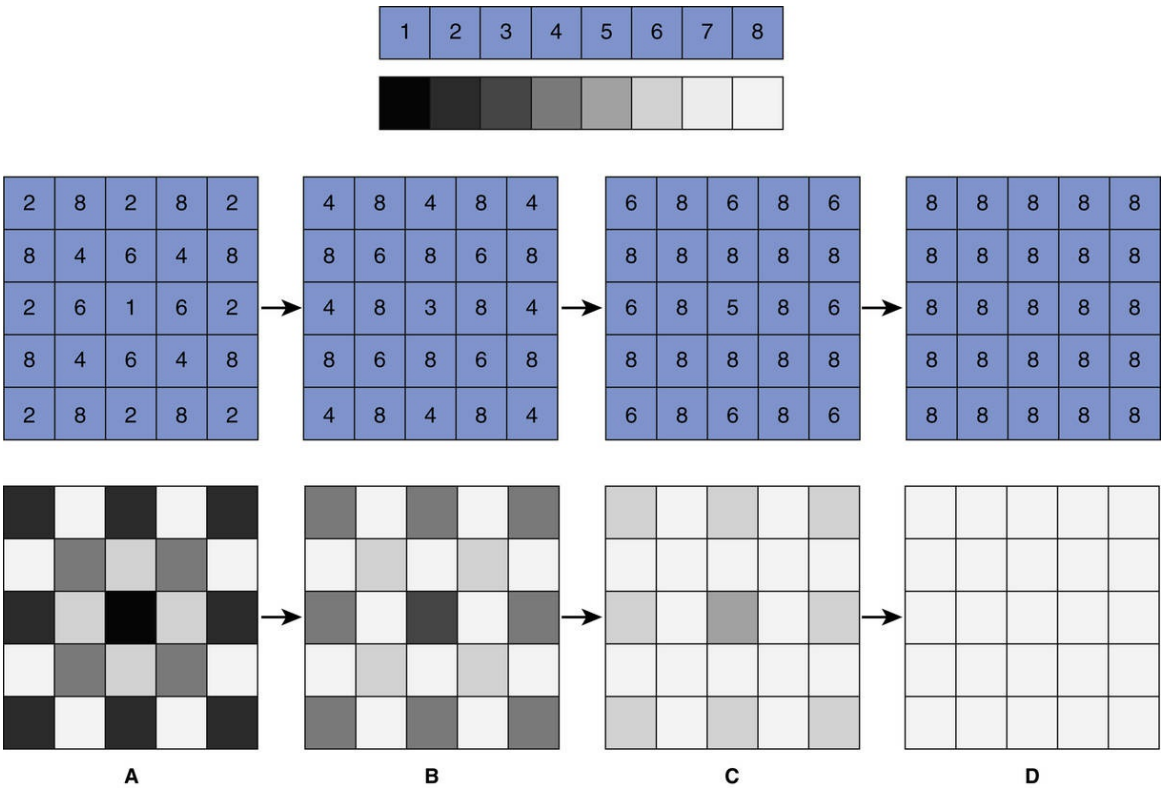


FIG. 5.6 Illustration showing the effect of increasing brightness. **(A)** The original numbers allocated to the pixels and the original black/white and grey image. **(B)** Pixel values increased by two and the resultant grey/white image. **(C)** Pixel values increased by four and the resultant brighter image. **(D)** Pixel values increased by seven (i.e. to the extreme end of the brightness scale) and the resultant totally white image.

Brightness

Brightness can be regarded as equivalent to the *degree of blackening* of a film-captured image. Increasing brightness decreases the degree of blackening and makes the image lighter. This is done by increasing

the numerical value of each pixel in the image and allocating it a lighter shade of grey. Taken to the extreme, every pixel would be allocated the highest number and the image would be totally white. The concept of altering brightness is illustrated in Fig. 5.6 , using the same simple model of eight numbers and eight shades of grey. Conversely, decreasing brightness increases the degree of blackening and makes the image darker.

Contrast

Contrast is the visual difference between black and white. Increasing contrast increases this difference. This is done by decreasing the pixel numbers in the darker half of the greyscale and increasing the pixel numbers in the lighter half. Taken to the extreme, every pixel would be allocated either the lowest number available or the highest and the image would be black and white only, containing no shades of grey. The concept of altering contrast is illustrated in Fig. 5.7 using the same simple model of eight shades of grey. Conversely, decreasing contrast results in a grey image with little visual difference between the pixels.

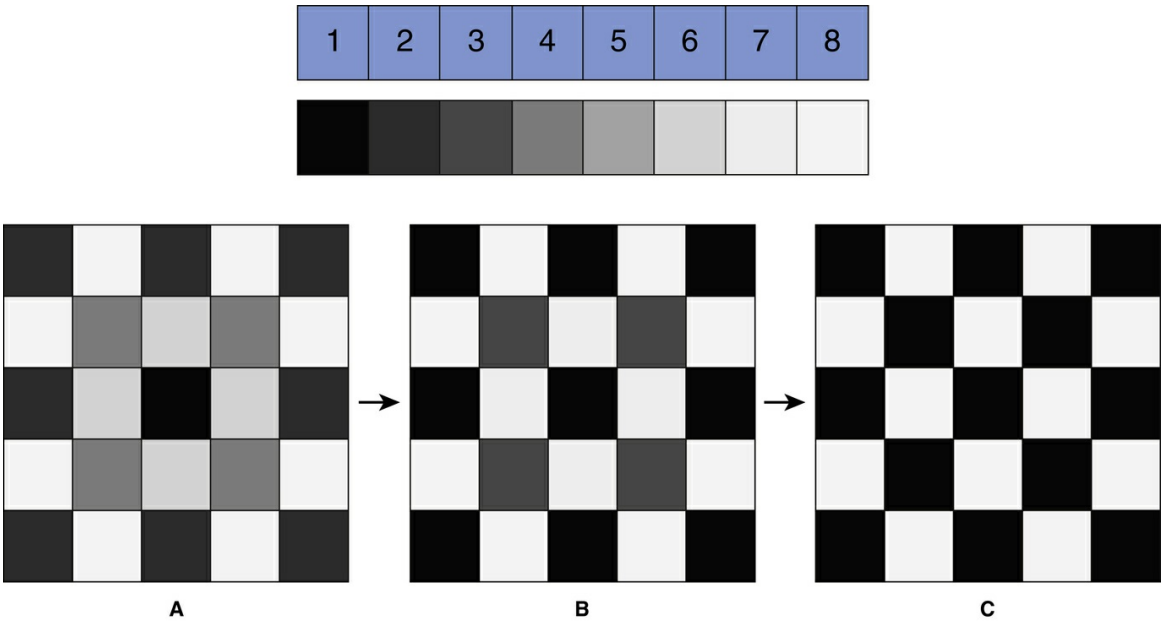


FIG. 5.7 Illustration showing the effect of increasing contrast. **(A)** The original black/white and grey image. **(B)**

Increased contrast – less visible grey. **(C)** Complete contrast – the image is only black and white.

Note: Despite being able to alter the final image, the computer cannot provide any additional information to that contained in the original image. It should be remembered that, although manipulation and enhancement may make images look aesthetically more pleasing, they also may cause clinical information to be lost and diagnosis compromised.

Hard Copy Printed Images

Hard printed copies of digital images can be obtained on glossy photographic paper by using thermal, laser or ink-jet printers. However, image quality is considerably compromised because of the printer's inability to reproduce 256 shades of grey. It is possible to produce excellent quality hard copy images using expensive heat sublimation printers. These print the digital image back onto film and can reproduce all the shades of grey. The quality is comparable with film-captured images.

Advantages of Digital Imaging

- No need for chemical processing, thus avoiding all conventional processing faults (see Chapter 17) and the hazards associated with handling chemical solutions.
- Easy storage and archiving of patient information and incorporation into patient records.
- Easy transfer of images electronically.
- Image enhancement and manipulation.
- Phosphor plates have a wide latitude, producing an acceptable image whether underexposed or overexposed.

Disadvantages of Digital Imaging

- Large pixels result in poor resolution and structures may not be represented accurately, as shown in Figs. 5.8 and 5.9 .
- Conventional PC screens/monitors reduce or limit image quality. Diagnostic image quality screens/monitors are required for optimal viewing.
- Images need to be backed up to a separate storage area remote from the image-capture computer in case this computer fails.
- Over-exposure and overloading of CCD sensors creating the phenomenon of *blooming* (see Chapter 17).
- Loss of image quality and resolution on hard copy print-outs when using thermal, laser or ink-jet printers.

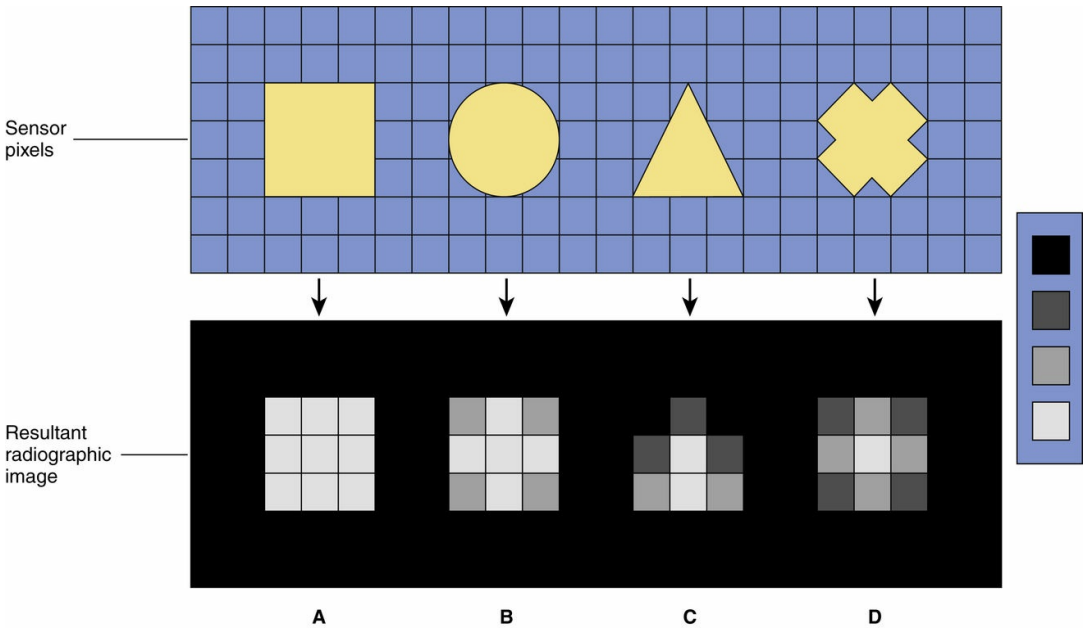


FIG. 5.8 Illustration showing how objects may not be represented accurately on a digital image if pixel size is large, using five shades of grey. **(A)** The square covers *exactly* and fills the sensor pixels and is therefore represented exactly radiographically. The outlines of **(B)** the circle, **(C)** the triangle and **(D)** the cross do not exactly cover and fill whole sensor pixels. The number and hence shade of grey allocated to an individual radiographic pixel represents the average of the total X-ray absorption within the whole pixel. Hence, the outlines and shapes of the objects are not represented

accurately.

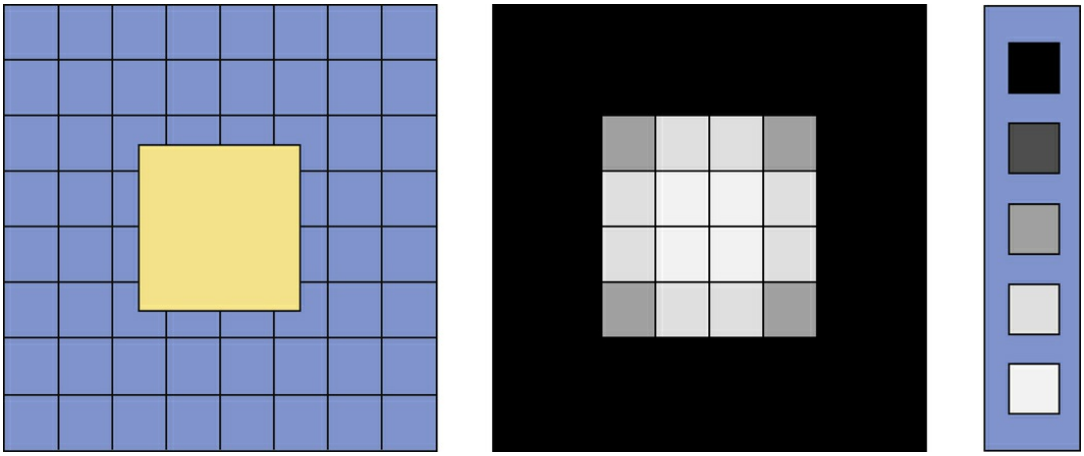


FIG. 5.9 Another illustration showing how an object may not be represented accurately on a digital image if pixel size is large, using five shades of grey. The square from Fig. 5.8 is positioned so that it does not cover *exactly* and fill the sensor pixels. As a result it is now not accurately represented.

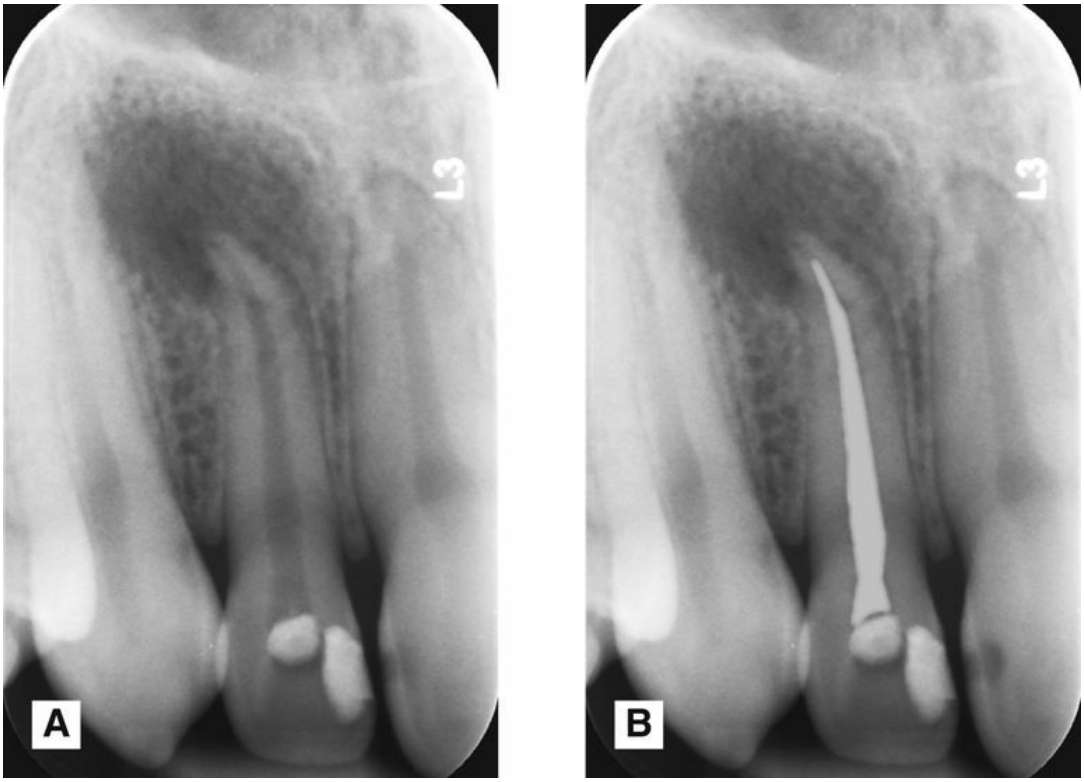


FIG. 5.10 An example of image alteration using third-party software. **(A)** Original image. Note the 2 is not root filled, the large area of apical radiolucency and the small carious lesion 1 distally. **(B)** After image manipulation. Note the 2 now seems to have been root filled, although the large area of apical radiolucency is still evident and the carious lesion in 1 seems to have enlarged.

- Image enhancement and manipulation:
  - Operators need to understand how the image is created and being altered to avoid being misled
  - Time consuming
  - Magnification is achieved by enlarging the pixels, but resolution is lost.
- Although manufacturers provide safeguards to prevent any tampering with original images within their own software, it is relatively easy to access these images using inexpensive third-party software and then to change them, as shown in Fig. 5.10 .

Chemical Processing

It is crucial that the stages involved in chemical processing using *developer* and *fixer* solutions are performed under controlled, standardized conditions with careful attention to detail. Strict quality assurance procedures must be applied (see Chapter 17). Unfortunately, all too often in dental practice poor chemical processing is the cause of radiographic films being of inadequate diagnostic quality, irrespective of how reliable and expensive the X-ray equipment or how accurate the operator's radiographic techniques.

Theory

A detailed knowledge of the chemistry involved in processing is not essential. However, a working knowledge and understanding of the theory of processing is necessary so that processing faults can be identified and corrected. A simplified approach to the stages involved in converting the green film emulsion into the black/white/grey radiograph is outlined below and shown in Fig. 5.11 .

Stage 1: Development

The **sensitized** silver halide crystals in the emulsion are converted by the *developer* to black metallic silver to produce the *black/grey* parts of the image.

Stage 2: Washing

The film is washed in water to remove residual developer solution.

Stage 3: Fixation

The **unsensitized** silver halide crystals in the emulsion are removed by the *fixer* to reveal the *transparent or white* parts of the image and the emulsion is hardened.

Stage 4: Washing

The film is washed thoroughly in running water to remove residual fixer solution.

Stage 5: Drying

The resultant *black/white/grey* radiograph is dried.

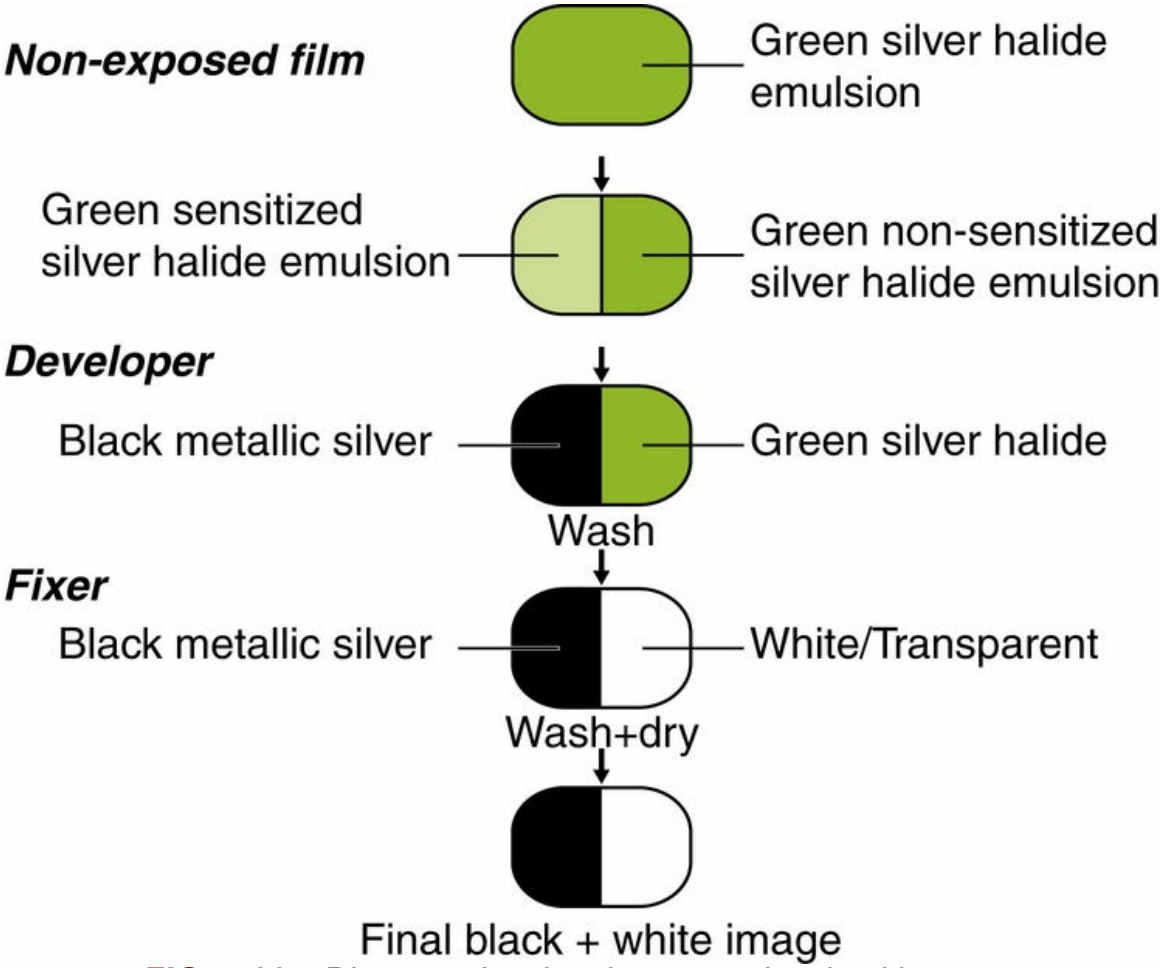


FIG. 5.11 Diagram showing the stages involved in processing, to convert the green film emulsion to the final black and white radiograph

courtesy of Mrs J.E. Brown.

Practical Methods

There are three practical chemical processing methods available:

- Manual or wet processing
- Automatic processing
- Using self-developing films.

Manual Processing

Manual processing is traditionally carried out in a *darkroom,* the general requirements of which should include:

- Absolute light-tightness
- Adequate working space
- Adequate ventilation
- Adequate washing facilities
- Adequate film storage facilities
- Safelights – positioned 1.2 m from the work surfaces with 25W bulbs and filters suitable for the type of film being used (see Chapter 17)
- Processing equipment as shown in Fig. 5.12 :
  - – Tanks containing the various solutions
  - – Thermometer
  - – Immersion heater
  - – An accurate timer
  - – Film hangers.

Manual processing cycle

1. The exposed film packet is unwrapped and the film clipped on to a hanger.
2. The film is immersed in *developer* and agitated several times in the solution to remove air bubbles and left for about 5 minutes at 20°C.
3. The residual developer is rinsed off in water for about 10

seconds.

4. The film is immersed in *fixer* for about 8–10 minutes.
5. The film is washed in running water for about 10–20 minutes to remove any residual fixer.
6. The film is allowed to dry in a dust-free atmosphere.



FIG. 5.12 The basic traditional requirements for manual processing including a series of chemical solution tanks, thermometer, timer and film hanger.

Processing solutions

As mentioned two different processing solutions are required, the *developer* and the *fixer*. The typical constituents of these solutions are shown in Tables 5.1 and 5.2 .

Important Points to Note Regarding Development

- The alkaline developer solution should be made up to the concentration recommended in the manufacturer's instructions.
- The developer solution is oxidized by air and its effectiveness decreased. Solutions should be used for no more than 10–14 days, irrespective of the number of films processed during that time.
- If the development process is allowed to continue for too long, more silver will be deposited than was intended and the radiograph will be too dark. Conversely, if there is too short a development time the radiograph will be too light.
- Development *time* (in fresh solutions) depends on the *temperature* of the solution. The usual value recommended is 5 minutes at 20°C.
- If the temperature is too high, development is rapid, the film may be too dark and the emulsion may be damaged. If the temperature is too low, development is slowed and a pale film will result.

Important Points to Note Regarding Fixation

- Fixer solution should be made up to the concentration recommended by the manufacturer. It is an acid solution so contamination with developer should be avoided.
- Ideally films should be fixed for double the *clearing time.* The clearing time is how long it takes to remove the unsensitized silver halide crystals. Total fixing time is usually 8–10 minutes.
- Films may be removed from the fixer after 2–4 minutes for *wet* viewing, but should be returned to the fixer solution to complete fixing.
- Inadequately fixed films may appear greenish yellow or milky owing to residual emulsion. In time these films may discolour further, becoming brown.

Table 5.1

The Typical Constituents of Developer Solution and their Functions

Constituents	Functions
Phenidone	Helps to bring out the image
Hydroquinone	Builds contrast
Sodium sulphite	Preservative – reduces oxidation
Potassium carbonate	Activator – governs the activity of the developing agents
Benzotriazole	Restrainer – prevents fog and controls the activity of the developing agents
Glutaraldehyde	Hardens the emulsion
Fungicide	Prevents fungal growth
Buffer	Maintains pH (7+)
Water	Solvent

Table 5.2

The Typical Constituents of Fixer Solution and their Functions

Constituents	Functions
Ammonium thiosulphate	Removes unsensitized silver halide crystals
Sodium sulphite	Preservative – prevents deterioration of the fixing agent
Aluminium chloride	Hardener
Acetic acid	Acidifier – maintains pH
Water	Solvent

Automatic Processing

This term is used when processing is carried out automatically by a machine. There are several automatic processors available that are designed to carry the film through the complete cycle usually by a system of rollers. Most have a day-light loading facility, eliminating the need for a darkroom (see Fig. 5.13). In the interests of infection control, salivary-contaminated film packets should be wiped with a disinfecting solution such as 1% hypochlorite before being placed into the loading facility.



FIG. 5.13 The IGP Durr XR 24 Pro automatic processor showing **(A)** the daylight loading facility and **(B)** the internal roller system.

Automatic Processing Cycle

The cycle is the same as for manual processing, except that the rollers squeeze off any excess developing solution before passing the film on to the fixer, eliminating the need for the water wash between these two solutions.

Advantages

The main advantages include:

- Time saving – dry films are produced in about 5 minutes
- The need for a darkroom is often eliminated
- Controlled, standardized processing conditions are easy to maintain
- Chemicals can be replenished automatically by some machines.

Disadvantages

The main disadvantages include:

- Strict maintenance and regular cleaning are essential; dirty rollers produce marked films
- Some models need to be plumbed in
- Equipment is relatively expensive
- Smaller machines cannot process large extraoral films.

Self-developing Films

Self-developing films are an alternative to manual processing. An example is the ECO–30 manufactured by Dentalfilm s.l.r (see Fig. 5.14).

The X-ray film is situated at one end of a plastic sachet, and the monobath containing developer and fixer is situated in a pouch at the other end. After exposure, the pouch is squeezed to activate the monobath. The sachet is then repeatedly and continuously massaged from the pouch down to and around the film for 50 seconds. The sachet is then turned upside down and the monobath solution pushed back to the pouch. The film is then removed from the sachet and rinsed thoroughly under running water.

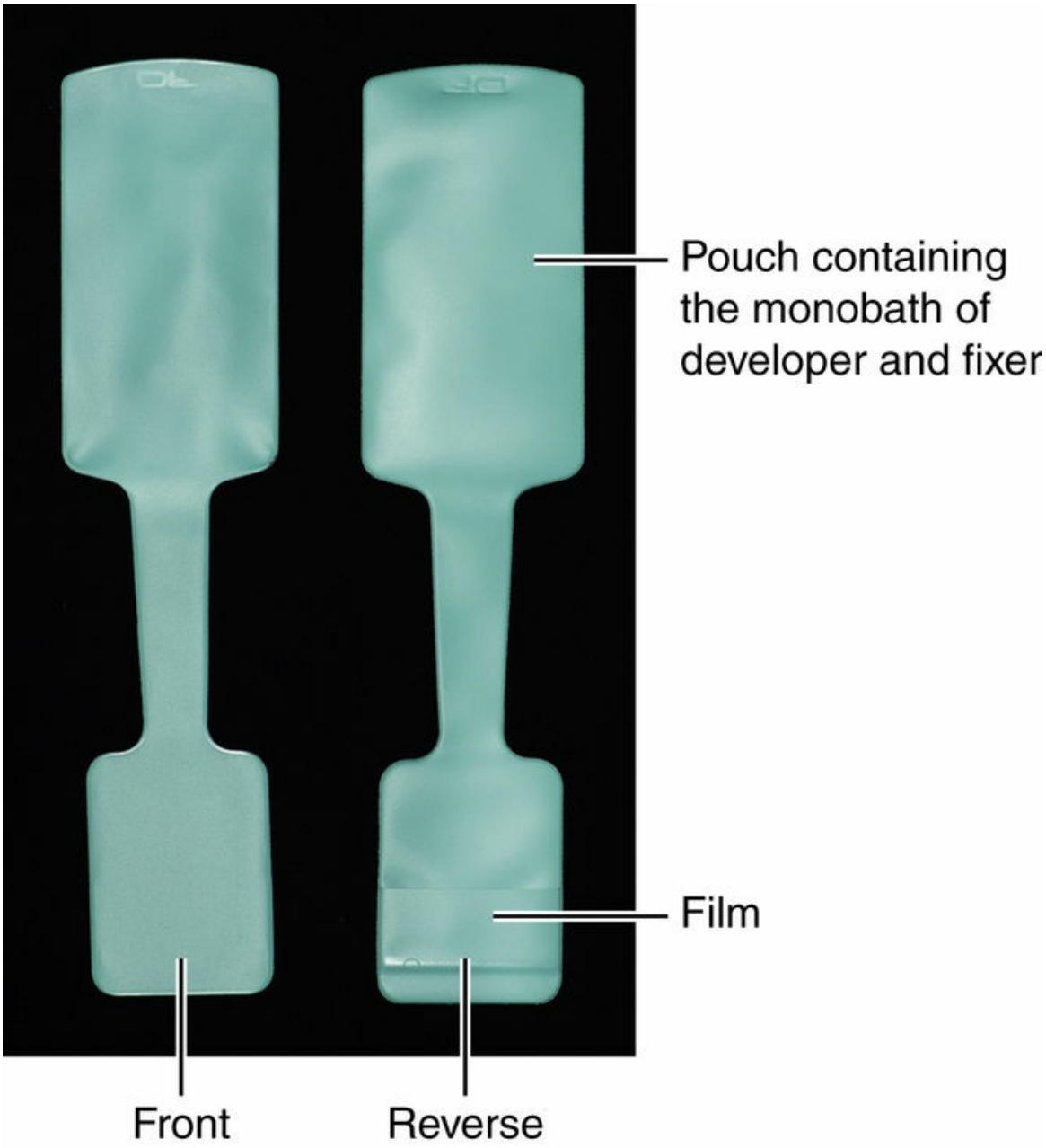


FIG. 5.14 The ECO-30 self-developing film manufactured by Dentalfilm s.l.r.

Advantages

The main advantages include:

- No darkroom or processing facilities are needed

- Time saving – the final radiograph is ready in about 1 minute.

Disadvantages

The main disadvantages include:

- Image quality is usually inferior to conventional film processed manually or automatically
- The image can deteriorate over time, particularly if the film is not washed immediately and thoroughly
- There is no lead foil inside the film packet
- The film packet is very flexible and easily bent
- These films are difficult to use in positioning holders
- Relatively expensive.

A rigid, radiopaque plastic backing support tray for the film is manufactured, which helps to reduce the problems of flexibility and lack of lead foil.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

6

Radiation Dose, Dosimetry and Dose Limitation

Several different terms and units have been used in dosimetry over the years. The use of the word *dose* in multiple different descriptors has made this subject even more confusing. However, it is essential that these terms and units are understood to appreciate what is meant by radiation dose and to allow meaningful comparisons between different investigations to be made. In addition to explaining the various units and how they are measured and calculated, this chapter covers the concept of clinical dose limits and dose limitation, as well as summarizing the estimated doses from various sources of ionizing radiation and the magnitude of radiation doses from common dental and medical clinical investigations.

The more important terms in dosimetry include:

- Radiation-absorbed dose (D)
- Equivalent dose (H_T)
- Effective dose (E)
- Collective effective dose or collective dose
- Dose limits
- Dose rate.

Dose Units

Radiation-absorbed Dose (D)

The radiation-absorbed dose is a measure of the amount of energy absorbed from the radiation beam per unit mass of tissue and can be

measured using a dosimeter.

SI unit:	joules/kg (J/kg)
Special name:	Gray (Gy)
Subunit names:	milligray (mGy) ($\times 10^{-3}$) microgray (μGy) ($\times 10^{-6}$)

Equivalent Dose (H_T)

The equivalent dose is a measure that allows the different radiobiological effectiveness of different types of radiation to be taken into account.

For example, alpha particles (see Chapter 18) penetrate only a few millimetres in tissue, lose all their energy and are totally absorbed, whereas X-rays penetrate much further, lose some of their energy and are only partially absorbed. The biological effect of a particular *radiation-absorbed dose* of alpha particles would be considerably more severe than a similar *radiation-absorbed dose* of X-rays.

By introducing a numerical value known as the *radiation weighting factor* (W_R) , which represents the biological effects of different radiations on different tissues, the unit of *equivalent dose* (H_T) in a particular tissue provides a common unit allowing comparisons to be made between one type of radiation and another. W_R examples include:

X-rays, gamma rays and beta particles	$W_R = 1$
Fast neutrons (10 keV – 100 keV) and protons	$W_R = 10$
Alpha particles	$W_R = 20$

The *equivalent dose* (H_T) in a particular tissue is therefore calculated as follows:

$$\textit{Equivalent dose}\,(H_T) = \text{radiation-absorbed dose (D)} \times \text{radiation weighting factor } (W_R) \text{ in a particular tissue}$$

SI unit:	joules/kg (J/kg)
Special name:	sievert (Sv)
Subunit names:	millisievert (mSv) ($\times 10^{-3}$) microsievert (μSv) ($\times 10^{-6}$)

For X-rays, the *radiation weighting factor* (W_R) is 1; therefore, the *equivalent dose* (H_T) in a particular tissue, measured in *sieverts*, is equal to the *radiation-absorbed dose (D)*, measured in *Grays*.

Effective Dose (E)

This measure allows doses from different investigations of different parts of the body to be compared, by converting all doses to an equivalent whole body dose. This calculation is necessary because some parts of the body are more sensitive to radiation than others. The International Commission on Radiological Protection (ICRP) has allocated each tissue a numerical value, known as the *tissue weighting factor* (W_T), based on its radiosensitivity, i.e. the risk of the tissue being damaged by radiation – the greater the risk, the higher the tissue weighting factor.

The *tissue weighting factors* recommended by the ICRP in 1990 and revised in 2007 are shown in Table 6.1 .

The sum of the individual tissue weighting factors represents the weighting factor for the whole body. The *effective dose (E)* from an individual clinical radiograph, where the X-ray beam is absorbed by different tissues, is calculated as follows:

Table 6.1

Tissue weighting factors (W_T) recommended by the ICRP in 1990 and revised in 2007

Tissue	1990 W_T	2007 W_T
Bone marrow	0.12	0.12
Breast	0.05	0.12

Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Gonads	0.20	0.08
Bladder	0.05	0.04
Oesophagus	0.05	0.05
Liver	0.05	0.04
Thyroid	0.05	0.04
Bone surface	0.01	0.01
Brain	*	0.01
Kidneys	*	0.01
Salivary glands	—	0.01
Skin	0.01	0.01
Remainder tissues	0.05 *	0.12 †

* Adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus.

† Adrenals, extrathoracic airways, gallbladder, heart wall, kidney, lymphatic nodes, muscle, pancreas, oral mucosa, prostate, small intestine wall, spleen, thymus and uterus/cervix.

$$\textit{Effective dose}\ (\mathrm{E}) = \Sigma\ \text{Equivalent dose}\ (\mathrm{H_T}) \text{ in each tissue} \times \text{relevant tissue weighting factor}\ (\mathrm{W_T})$$

Special name:	sievert (Sv)
Subunit names:	millisievert (mSv) (x 10^{-3}) microsievert (μSv) (x 10^{-6})

The 2007 revised tissue weighting factors include the salivary glands as an individual weighted tissue and the oral mucosa in the remainder tissues. Therefore the *effective dose* for dental radiographic examinations may be considerably higher when calculated using these revised tissue weighting factors.

One way of calculating the *effective dose* is by using a tissue-equivalent anthropomorphic phantom with dosimeters placed in the most radiosensitive regions as shown in Fig. 6.1 .

As the individual doses are very small from any one examination, a number of radiographic exposures are repeatedly performed (e.g. 10 times) using typical exposure factors (time, kV and mA), for that particular examination. The dosimeters are then 'read' to give a measurement of the *radiation-absorbed dose (D)* in the individual tissues. Using this data both the *equivalent dose* (H_T) and the *effective dose (E)* may be calculated, as shown in the simplified flow diagram in Fig. 6.2 .



FIG. 6.1 **(A)** An example of an anthropomorphic phantom used in dosimetry. **(B)** One slice of the phantom showing the positions where the individual dosimeters can be placed in specific radiosensitive tissues.

(1) Radiation-absorbed doses (D) in 5 radiosensitive tissues

Tissue	Radiation-absorbed dose (D) (μGy)
Skin	5*
Salivary glands	700
Bone surface	70*
Bone marrow	20*
Thyroid gland	50

*averaged over the total mass of tissue



(2) Equivalent doses (H_T) in 5 radiosensitive tissues

Tissue	Equivalent dose (H_T) = Radiation-absorbed dose x W_R (μSv)
Skin	5 x 1 = 5
Salivary glands	700 x 1 = 700
Bone surface	70 x 1 = 70
Bone marrow	20 x 1 = 20
Thyroid gland	50 x 1 = 50



(3) Effective doses (E) in 5 radiosensitive tissues

Tissue	Tissue weighting factor (W_T)	Equivalent dose (H_T) x Tissue weighting factor (W_T)
Skin	0.01	5 x 0.01 = 0.05
Salivary glands	0.01	700 x 0.01 = 7
Bone surface	0.01	70 x 0.01 = 0.7
Bone marrow	0.12	20 x 0.12 = 2.4
Thyroid gland	0.04	50 x 0.04 = 2



Overall effective dose for the investigation
= 0.05 + 7 + 0.7 + 2.4 + 2 = **12.15 μSv**

FIG. 6.2 Flow diagram illustrating a very simplified example of how the *effective dose* is calculated for a panoramic radiograph using only five tissues of the anthropomorphic phantom. **(1)** The *radiation-absorbed doses* for the five tissues. **(2)** The calculated *equivalent doses* (W_R = 1 for X-rays) for the five tissues. **(3)** The *effective dose* for the investigation, which is the sum of each equivalent dose (H_T) multiplied by the relevant tissue weighting factor (W_T), which in this example is 12.15 μSv. For a real dosimetry study all the radiosensitive tissues irradiated, with specific weighting factors, would be included in the calculations.

When the simple term *dose* is applied loosely, it is the *effective dose (E)* that is usually being described. The *effective dose* can thus be thought of as a broad indication of the risk to health from any exposure to ionizing radiation, irrespective of the type or energy of the radiation or the part of the body being irradiated. A comparison of effective doses from different investigations is shown in Table 6.2 .

Table 6.2

Typical effective doses for a range of dental and routine medical examinations

X-ray examination	Effective dose (E) (mSv)
Bitewing/periapical radiograph	0.0003–0.022
Panoramic radiograph	0.0027–0.075
Upper standard occlusal	0.008
Lateral cephalometric radiograph	0.0022–0.0056
Skull radiograph (PA)	0.02
Skull radiograph (lateral)	0.016
Chest (PA)	0.014
Chest (lateral)	0.038
CT head	1.4
CT chest	6.6
CT abdomen	5.6
CT mandible and maxilla	0.25–1.4
	1.5

Barium swallow	
Barium enema	2.2
Small volume CBCT (height ≤5 cm)	0.0097–0.197
Medium volume CBCT (height 5.1–10.0 cm)	0.0039–0.674
Large volume CBCT (height >10 cm)	0.0088–1.073

Based broadly on the 2011 HPA publication *Frequency and Collective Dose for Medical and Dental X-ray Examinations in the UK,* the 2011 SEDENTEXCT publication *Radiation Protection: Cone Beam CT for Dental and Maxillofacial Radiology,* the 2013 *Selection Criteria for Dental Radiography* and *Effective dose of CBCT of the facial skeleton: a systematic review.* Al-Okshi A; Lindh C; Sale H; Gunnarsson M; Rohlin M. British Journal of Radiology. 88:20140658, 2015.

Collective Effective Dose or Collective Dose

The collective effective dose is used when considering the total effective dose to a population, from a particular investigation or source of radiation, and is measured in man-sieverts (man-Sv).

$$\textit{Collective dose} = \text{effective dose (E)} \times \text{population}$$

For example, in the UK in 2008, the collective dose to the population from all X-ray examinations was calculated by the Health Protection Agency to be 24,700 man-Sv.

Dose Limits

In addition to setting *tissue weighting factors* the ICRP also sets a maximum annual *dose limit* for radiation workers – those people who are exposed to radiation during the course of their work. This

exposure carries no benefit, only risk. The *dose limits* are based on the principle that the risk to any worker who receives the full *dose limit* will be such that the worker will be at no greater risk than a worker in another similar hazardous, but nonradioactive, environment.

The dose limits for workers and the general public in the UK are shown in Table 6.3 . The dose limits are required to protect workers and the general public from the detrimental effects of radiation.

Table 6.3

The current annual dose limits in the UK

	Annual dose limit (mSv)
Workers aged 18 or above	20
Trainees aged under 18 years	6
Any other person (member of the general public)	1

Dose Rate

This is a measure of the dose per unit time, e.g. dose per hour, and is sometimes a more convenient, and measurable, figure than the total annual dose limits shown in Table 6.3 .

SI unit: microsievert/hour ($\mu Sv\ h^{-1}$)

Estimated Annual Doses

Everyone is exposed to some form of ionizing radiation from the environment in which we live. Sources include:

- Natural background radiation
  - Cosmic radiation from the earth's atmosphere
  - Gamma radiation from the rocks and soil in the earth's crust
  - Ingestion of radioisotopes, e.g. ^{40}K, in certain foods
  - Inhalation of radon gas and its decay products; ^{222}Rn

is a gaseous decay product of uranium that is present naturally in granite. As a gas, radon diffuses readily from rocks through soil and can be trapped in poorly ventilated houses and then breathed into the lungs.

  - Inhalation of thoron gas
- Artificial background radiation
  - Fallout from nuclear explosions
  - Radioactive waste discharged from nuclear establishments
- Medical and dental diagnostic radiation
- Radiation from occupational exposure.

The Radiation Protection Division of the Health Protection Agency has estimated the annual doses from these various sources in the UK as illustrated in Table 6.4 **.** As shown, an individual's average dose from *natural background radiation* is estimated at about **2.23 mSv** per year (84%) with an additional **0.423 mSv** (16%) from *artificial sources* (total average dose approximately **2.7 mSv**) including dental radiography. In the United States, *natural background radiation* is estimated at approximately **3.2 mSv** per year with an additional **3.0 mSv** from *artificial sources* (total average dose **6.2 mSv**). These figures are useful to remember when considering the magnitude of the doses associated with various diagnostic procedures (Table 6.2).

Table 6.4

Health Protection Agency estimated average annual doses to the UK population from various sources of ionizing radiation in 2005

Radiation source	Average annual dose (μSv)	Approximate %
Natural sources		
Cosmic radiation	330	—
External exposure from earth's crust	350	—
Internal radiation from certain foodstuffs	250	—
Exposure to radon/ thoron and their decay	1,300	—

products		
Total from natural sources	2,230	84
Artificial sources		
Fallout	6	—
Radioactive waste	1	—
Medical and dental diagnostic radiation	410	—
Occupational exposure	6	—
Total from artificial sources	423	16
Total from all sources	~2.7 mSv	100

Dose Limitation

As mentioned, the ICRP regularly publishes data not only on radiation dose, but also general recommendations on dose limits and dose limitation based on the following general principles:

- No practice shall be adopted unless its introduction produces a positive net benefit *(Justification*)
- All exposures shall be kept **as low as reasonably practicable** (ALARP), taking economic and social factors into account (*Optimization*)
- The dose equivalent to individuals shall not exceed the limits recommended by the ICRP (*limitation*).

For the purposes of dose limitation, the ICRP has divided the population into three groups:

- Patients
- Radiation workers (classified and nonclassified)
- The general public.

Patients

Patients may undergo radiographic examination for either diagnostic

or therapeutic reasons. In dentistry, all radiographic examinations are usually taken for diagnostic purposes. For these examinations:

- There are no set dose limits or dose constraints
- The decision to carry out such an investigation should be based on:
  - A correct assessment of the indications
  - The expected yield
  - The way in which the results are likely to influence the diagnosis and subsequent treatment
  - The clinician having an adequate knowledge of the physical properties and biological effects of ionizing radiation (i.e. the clinician is *adequately trained*)
- All exposures should be kept **as low as diagnostically acceptable** (ALADA)
- The number, type and frequency of the radiographs requested or taken (selection criteria) are the responsibility of the clinician. Evidence-based selection criteria recommendations have been published in different countries in recent years to provide guidance in this clinical area of radiation protection. In the UK, the booklet *Selection Criteria for Dental Radiography* is published and regularly updated by the Faculty of General Dental Practice of the Royal College of Surgeons of England (the third edition was updated in 2018). National selection criteria documentation should be regarded as essential reading for all dentists. An overview of these practical radiation protection recommendations are reproduced in Chapter 7 .

Other groups who may be exposed to ionising radiation include:

- Individuals as part health screening programme
- Asymptomatic individuals
- Individuals involved in medical research
- Individuals undergoing non-medical imaging using X-ray

equipment
- Carers and comforters

Individuals as Part of a Health Screening Programme

- These examinations are carried out on groups, e.g. a breast screening programme.
- There are no set dose limits, but dose constraints should be established.
- These examinations should be evidence based with a high probability of obtaining useful information; hence, the usefulness of selection criteria.
- Advice on their use should be taken from specialist societies.
- The information obtained should be important to the population's health.

Asymptomatic Individuals

- These examinations are generally carried out on individuals at risk of a particular disease. This is often known as individual health assessment.
- Advice should be taken from specialist societies.
- Dose constraints should be set, and attention paid to national dose reference levels for the examination.

Individuals Involved in Medical Research

- There are no set dose limits.
- Dose constraints should be adhered to if there is no direct medical benefit of the investigation.
- All research should be approved by an ethics committee.
- All volunteers should have a full understanding of the risks involved and give their consent.

Individuals Undergoing Non-medical Imaging Using X-ray Equipment

These exposures include 'medicolegal exposures' and examinations taken for occupational and insurance purposes. These examinations should only be performed if it is not possible to obtain the required information without the use of ionising radiation. For these examinations:

- There are no set dose limits
- Dose constraints should be set
- The benefit is primarily to a third party.

Carers and Comforters

- A carer or comforter is an individual who supports or comforts another person who is undergoing the dental exposure, e.g. a mother supporting a young child having an oblique lateral radiograph taken.
- This person must not be a worker and must willingly take part.
- The risks and the benefits to comforter and carer must be considered.
- Dose constraints should be established.
- In the UK a dose constraint of 0.1 mSv per visit is recommended.

Radiation Workers

The dose limits for radiation workers were shown in Table 6.3 . The ICRP divides workers who are exposed to radiation during the course of their work into two subgroups depending on the level of occupational exposure:

- Classified workers

- Non-classified workers

The main features of each group of radiation workers are summarized below.

Classified Workers

- Receive high levels of exposure to radiation at work (if *local rules* are observed this is highly unlikely in dental practice). In the UK, any worker who is likely to receive more than 3/10 of the annual dose limit would be classified, i.e. likely to receive more than 6 mSv per year.
- Require compulsory personal dose monitoring.
- Require compulsory annual health checks.
- Examples of classified workers may include interventional radiologists or radiopharmacists working in nuclear medicine departments.

Non-classified Workers (Most Dental Staff)

- Receive low levels of exposure to radiation at work (as in the dental surgery).
- Provided the *local rules* are observed, all dental staff should receive an annual effective dose of considerably less than 3/10 of the dose limit (6 mSv).
- The regulations in the UK suggest the setting of *dose constraints* . These represent the upper level of individual dose that should not be exceeded in a well-managed practice, and for dental radiography a dose constraint of 0.3 mSv is recommended for all staff working in the dental surgery.

In addition to the above dose limits, the employer must ensure that the dose to the foetus of any pregnant member of staff is unlikely to exceed 1 mSv during the declared term of the pregnancy. This would

be very unlikely in dentistry and no additional radiation protection measures would normally be required.

- Personal monitoring (see Chapter 7) is recommended in the UK for workers who enter the controlled area, to confirm that the arrangements are effective in adequately restricting their exposure. As the doses encountered are likely to be very low, dosimeters may only be required for a short trial period. Continuous monitoring may not be necessary if the trial period demonstrates that doses are being adequately restricted.
- Annual health checks are not required.

The radiation dose to dentists and their staff can come from:

- The primary beam, if they stand in its path
- Scattered radiation from the patient
- Radiation leakage from the tubehead.

The main practical radiation protection measures to limit the dose that workers may receive are described in Chapter 7 .

General Public

This group includes everyone who is not receiving a radiation dose either as a patient or as a radiation worker, but who may be exposed inadvertently, e.g. someone in a dental surgery waiting room, in other rooms in the building or passers-by. The annual dose limits for this group is 1 mSv (see Table 6.3), although the suggested dose constraint is 0.3 mSv. The general public is at risk from the primary beam and the main practical radiation protection measures to limit the dose are described in Chapter 7 . In the UK, the employer must ensure that doses received by the general public are kept **as low as reasonably practicable** (ALARP). With help from their Radiation Protection Adviser (RPA), the employer needs to estimate the dose a

representative member of the general public might receive to ensure the dose limit/dose constraint is not exceeded. The employer must also identify which groups are most likely to receive the highest dose and then measure or estimate their doses.

To access the self-assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/radiography/

7

The Biological Effects Associated with X-rays, Risk and Practical Radiation Protection

Radiation-Induced Tissue Damage

The action of radiation on cells and the resultant damage are classified as:

- *Direct action or damage* as a result of ionization of macromolecules
- *Indirect action or damage* as a result of the free radicals produced by the ionization of water.

Direct Action or Damage

The X-ray photons, or high-energy ejected electrons, interact directly with, and ionize, vital biologic macromolecules such as DNA, RNA, proteins and enzymes, as shown in Fig. 7.1A . This ionization results in the breakage of the macromolecule's chemical bonds, causing them to become abnormal structures, which may in turn lead to inappropriate chemical reactions. Rupture of one of the chemical bonds in a DNA macromolecule may sever one of the side chains of the ladder-like structure. This type of injury to DNA is called a *point mutation.* The subsequent chromosomal effects from direct damage could include:

- Inability to pass on information

- *Abnormal replication*
- *Cell death*
- Only temporary damage – the DNA being repaired successfully before further cell division.

If the radiation directly affects somatic cells, the effects on the DNA (and hence the chromosomes) could result in a radiation-induced malignancy. If the damage is to reproductive stem cells, the result could be a radiation-induced congenital abnormality.

What actually happens in the cell depends on several factors, including:

- The type and number of nucleic acid bonds that are broken
- *The intensity and type of radiation*
- *The time between exposures*
- *The ability of the cell to repair the damage*
- *The stage of the cell's* reproductive cycle when irradiated.

Indirect Action or Damage

This process, which is shown in Fig. 7.1B , involves the ionization of the water molecule producing both ions and *free radicals* which can combine to damage the vital biologic macromolecules such as DNA. The sequence of events involved is summarized in Fig. 7.2 . The free radicals can recombine to form hydrogen peroxide, a cellular poison, and a hydroperoxyl radical, another toxic substance. Both of these substances are highly reactive and produce biological damage. By themselves, free radicals may transfer excess energy to other molecules, thereby breaking their chemical bonds and having an even greater effect. Because about 80% of the body consists of water, the vast majority of the interactions with ionizing radiation are indirect.

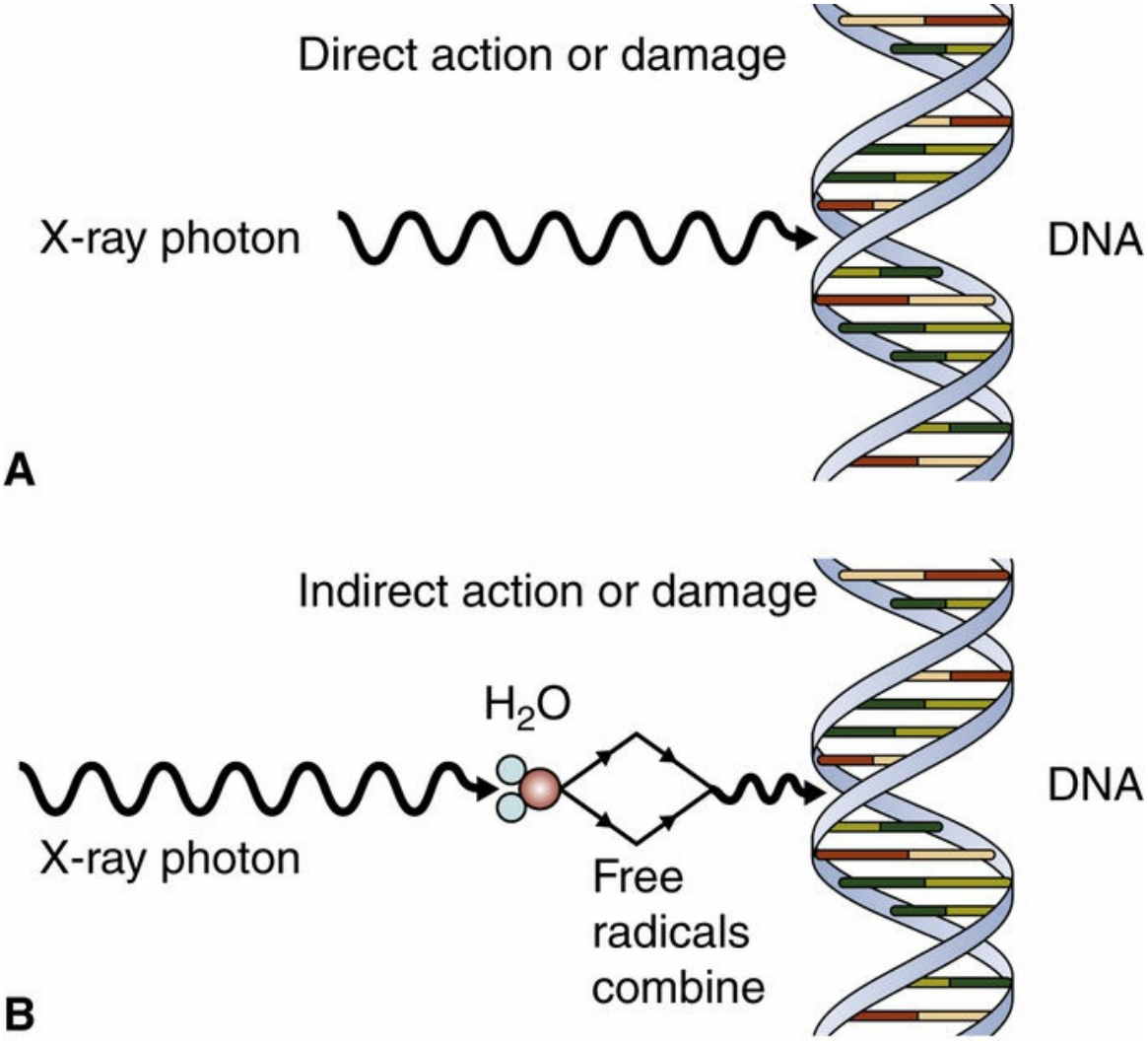


FIG. 7.1 Diagram illustrating the action and damaging effects of radiation on cells. **(A)** *Direct action or damage* – the X-ray photon interacts directly with the DNA. **(B)** *Indirect action or damage* – the X-ray photon ionizes water to produce free radicals which damage the DNA.

Classification of the Biological Effects

Whatever the actual mechanism for the DNA and cellular damage, the biological effects of ionizing radiation are classified into two main categories:

- *Tissue reactions (deterministic effects)*

- *Stochastic effects.*

Tissue Reactions (Deterministic Effects)

These are the noncancer damaging effects, to the body of the person exposed, that will **definitely** result from a specific high dose of radiation. The severity of the effect is proportional to the dose received, and in most cases a *threshold dose* exists below which there will be no effect. They were previously referred to as deterministic effects, but are now referred to as *tissue reactions* by the International Commission on Radiological Protection because it now recognizes that some of these effects are not determined solely at the time of irradiation but can be modified after radiation exposure. They are further subdivided into:

- Early tissue reactions – appearing shortly after exposure, e.g. skin erythema or mucositis

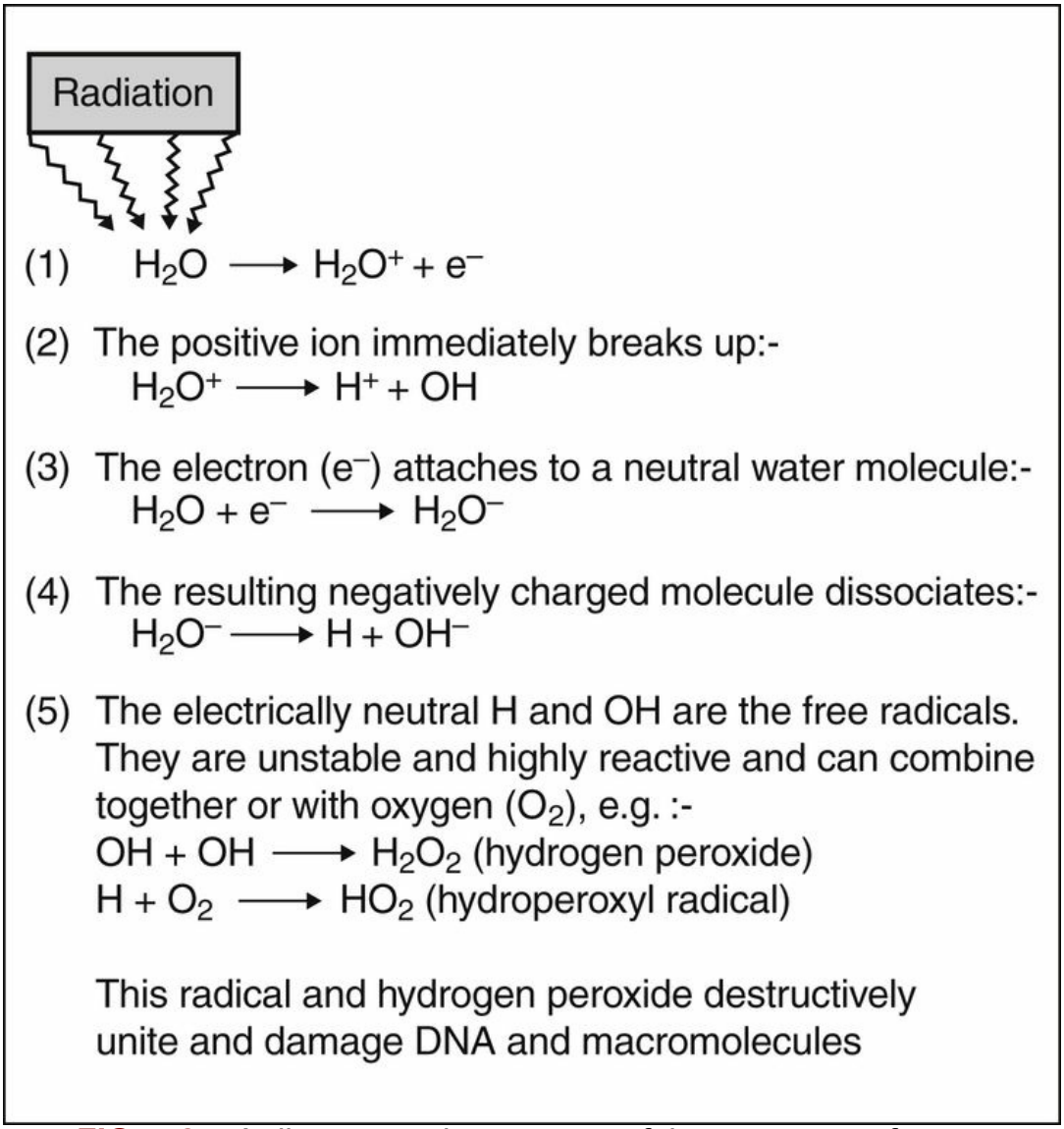


FIG. 7.2 A diagrammatic summary of the sequence of events following ionization of water molecules leading to *indirect damage* to the cell.

- Late tissue reactions – appearing months to years after exposure, e.g. osteoradionecrosis.

Stochastic Effects

Stochastic effects are those that **may** develop. Their development is random and depends on the laws of chance or probability. These damaging effects **may** be induced when the body is exposed to **any**

dose of radiation. Experimentally it has not been possible to establish a *safe dose* – i.e. a dose below which stochastic effects do not develop. It is therefore assumed that there is *no threshold dose,* and that every exposure to ionizing radiation carries with it the **possibility** of inducing a stochastic effect. The lower the radiation dose, the lower the probability of cell damage. However, the severity of the damage is **not related** to the size of the inducing dose. This is the underlying philosophy behind present radiation protection recommendations described later. Stochastic effects are further subdivided into:

- Cancer induction
- Heritable effects (genetic effects).

Cancer Induction

If a somatic (body) cell is irradiated a radiation-induced malignant cancer may develop. Quantifying the risk is complex and controversial. Data from groups exposed to **high** doses of radiation have been analysed and the results used to provide an estimate of the risk from the **low** doses of radiation encountered in diagnostic radiology. The high-dose groups studied include:

- The survivors of the atomic explosions at Hiroshima and Nagasaki
- *Patients receiving radiotherapy*
- *Radiation workers – people exposed to radiation in the course of their work*
- The survivors of the nuclear disaster at Chernobyl.

The problem of quantifying the risk is compounded because cancer is a common disease, so in any group of individuals studied there is likely to be some incidence of cancer. In the groups listed above, that have been exposed to high doses of radiation, the incidence of cancer is likely to be increased and is referred to as the *excess cancer incidence.* From the data collected, it has been possible to construct *dose–response curves* (see Fig. 7.3), showing the relationship between excess cancers

and radiation dose. The graphs can be extrapolated to zero (the controversy on risk assessment revolves around exactly how this extrapolation should be done), and a *risk factor* for induction of cancer by low doses of radiation can be calculated.

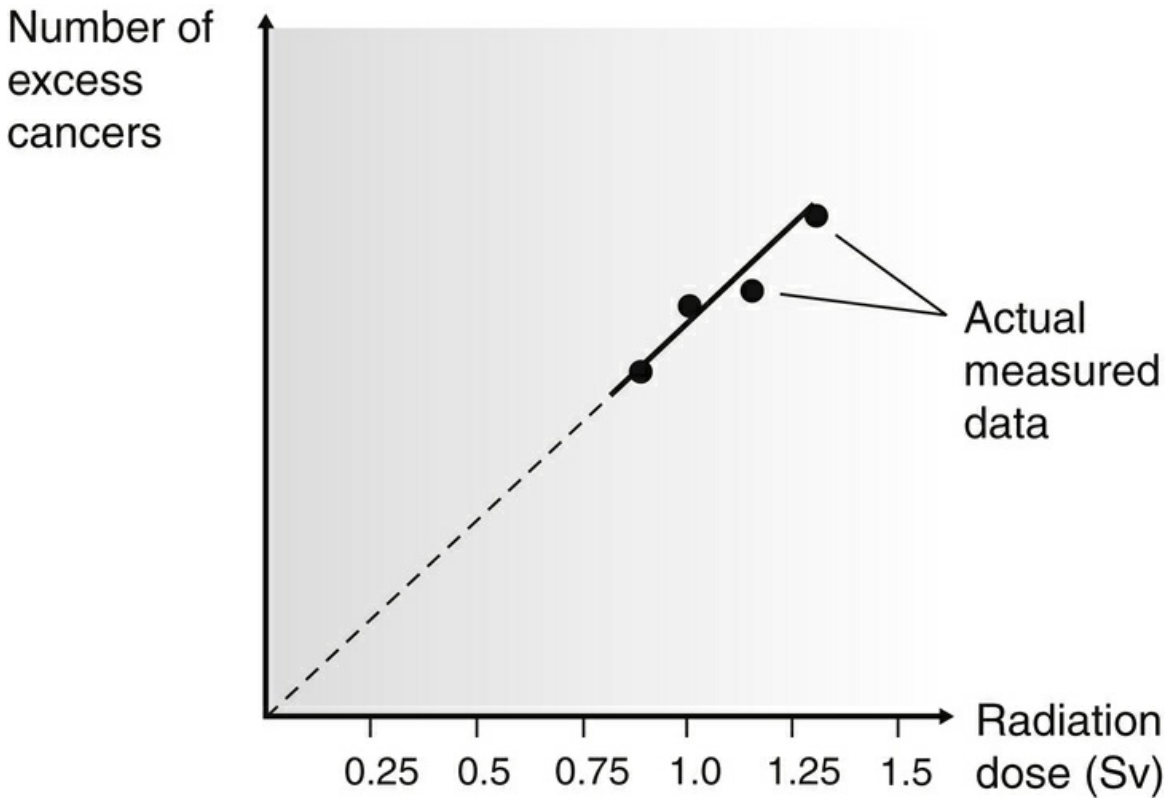


FIG. 7.3 A typical dose–response curve, showing excess cancer incidence plotted against radiation dose and a linear extrapolation of the data to zero.

After reviewing all the available evidence, the International Commission on Radiological Protection suggest there is a 1 in 18,000 chance of developing a fatal cancer for every 1 mSv of effective dose. Using this estimate, a broad estimate of risk from various X-ray examinations may be calculated and these are shown in Table 7.1 .

Risk is age dependent, being greatest for the young and lowest for the elderly. The risks shown in Table 7.1 are for a 30-year-old adult. The 2004 *European Guidelines on Radiation Protection in Dental Radiology* recommend that these should be modified by the multiplication

factors shown in Table 7.2 , which represent averages for the two sexes. In fact, at all ages risks for females are slightly higher and risks for males slightly lower.

Table 7.1

A broad estimate of the risk of a standard 30–year–old adult patient developing a fatal radiation–induced malignancy from a variety of dental and medical X-ray examinations

X-ray examination	Estimated risk of fatal cancer
Bitewing/periapical radiograph (50 kV, round collimation, D-speed film)	1 in 1,000,000
Bitewing/periapical radiograph (70 kV, rectangular collimation, F-speed film/digital sensor)	1 in 10,000,000
Panoramic radiograph (average)	1 in 1,000,000
Upper standard occlusal	1 in 2,250,000
Lateral cephalometric radiograph	1 in 5,000,000
Skull radiograph (PA)	1 in 1,000,000
Skull radiograph (lateral)	1 in 1,250,000
Chest (PA)	1 in 1,300,000
Chest (lateral)	1 in 475,000
CT head	1 in 13,000
CT chest	1 in 2,700
CT abdomen	1 in 3,200
CT mandible and maxilla	1 in 80,000 to 1 in 14,300
Barium swallow	1 in 13,300
Barium enema	1 in 9100
Small volume CBCT (height of ≤5 cm)	1 in 900,000 to 1 in 91,000
Medium volume CBCT (height of 5.1–10.0 cm)	1 in 4,600,000 to 1 in 27,000
Large volume CBCT (height of >10 cm)	1 in 2,000,000 to 1 in 17,000

Table 7.2

The multiplication factor for risk for different age groups based on the 2004 *European Guidelines on Radiation Protection in Dental Radiology*

Age group (yr)	Multiplication factor for risk
<10	×3
10–20	×2
20–30	×1.5
30–50	×0.5
50–80	×0.3
≥80	Negligible risk

This epidemiological information is being updated continually and recent reports suggest that the risk from low-dose radiation may be considerably greater than thought previously. However, the present figures at least provide an idea of the comparative order of magnitude of the risk involved from different investigations. Dental radiology uses low doses of radiation and hence the risk of stochastic cancer induction is very small. However, the total number of intraoral and extraoral dental radiographs taken is very high – estimated at around 20 million per year in the UK alone. It is thought that diagnostic radiology (medical and dental) is responsible for about 700 cases of cancer per year in the UK, of which about 10 cases are attributable to dental radiology – hence the need for the practical radiation measures outlined later.

Heritable Effects (Genetic Effects)

Mutations result from any sudden change to a gene or chromosome. They can be caused by external factors, such as radiation, or may occur spontaneously.

Radiation to the reproductive organs **may** damage the DNA of the sperm or egg cells. This **may** result in a congenital abnormality in the offspring of the person irradiated. However, there is no certainty that these effects will happen, so all genetic effects are described as *stochastic* .

A cause-and-effect relationship is difficult, if not impossible, to

prove. Although ionizing radiation has the potential to cause genetic damage, there are no human data that show convincing evidence of a direct link with radiation. Risk estimates have been based mainly on experiments with mice. It is estimated that a dose to the gonads of 0.5–1.0 Sv would double the spontaneous mutation rate. Once again, it is assumed that there is *no threshold dose.*

Effects on the Unborn Child

The developing foetus is particularly sensitive to the effects of radiation, especially during the period of organogenesis (3–7 weeks after conception). The major problems are:

- *Congenital abnormalities or death associated with large doses of radiation*
- *Mental retardation and decreases in IQ*
- *Cancer induction.*

As a result, there is a maximum permissible dose allowable to the abdomen of a woman who is pregnant. The implications for radiation protection for pregnant women during dental radiography are described later.

Summary of the Harmful Effects Important in Dental Radiology

In dentistry, the size of the doses used routinely are relatively small (see Chapter 6) and well below the threshold doses required to produce *tissue reactions* (deterministic effects). However, the *stochastic effects* can develop with any dose of ionizing radiation. Dental radiology does not usually involve irradiating the reproductive organs, thus in dentistry the heritable effects are of limited importance and the main concern is that of cancer induction.

Practical Radiation Protection

As a result of these damaging effects, ionizing radiation is the subject of considerable safety legislation designed to minimize the risks to radiation workers and to patients. As described in Chapter 6 , the International Commission on Radiological Protection regularly publishes general radiation protection recommendations based on the general principles of justification, optimization and limitation. Their main aims of radiation protection are to:

- Prevent the detrimental tissue reaction (deterministic effects) by having rules and guidelines based on scientific evidence to ensure known threshold doses are not exceeded
- Limit the probability of stochastic effects to acceptable levels by determining the level of risk involved.

Their recommendations to try to achieve these aims are usually incorporated eventually into national legislation and guidelines, although the precise details may vary from one country to another. A link to the current UK legislation and guidelines can be found at www.whaitesessentialsdentalradiography.com . This section summarizes generic practical radiation protection measures and good practice appropriate for patients, the general public and dental staff.

Practical Radiation Protection of Patients

The main radiation dose to patients comes from:

- Being irradiated in the first place, which is totally dependent on the decision and clinical judgement of their dentist
- The main beam of the X-ray equipment.

The main practical radiation protection measures can therefore be considered under three headings:

- Clinical judgement
- Equipment

- Radiographic technique and the technical skill of the staff undertaking the radiography.

Clinical Judgement

- All dentists must have received adequate training in dental radiology and should undertake continuing education and training after qualification to keep their knowledge and skills up to date, particularly in relation to the clinical applications of new technology, e.g. cone beam computed tomography (see Chapter 16). This practice seems to be reasonable; it is the dentist who decides on the acceptability of the risk to which the patient is being subjected.
- Before an exposure can take place, it must be clinically justified by a dentist (i.e. assessed to ensure that it will lead to a change in the patient's management and prognosis). Every exposure should be justified on the grounds of:
    - The availability and/or findings of previous radiographs
    - The specific objectives of the exposure in relation to the history and after a clinical examination of the patient
    - The total potential diagnostic benefit to the patient
    - The radiation risk associated with the radiographic examination
    - The efficacy, benefits and risks of alternative techniques having the same objective, but involving no or less exposure to ionizing radiation.
- To assist with the justification process dentists should make use of published evidence-based selection criteria, e.g. the Faculty of General Dental Practice (UK) of the Royal College of Surgeons of England's *Selection Criteria in Dental Radiography* booklet (the third edition was updated in 2018). Their recommendations are graded on the quality of the evidence available using the following scale:

- **A** = based on evidence from at least one study with *in vitro* validation as part of the body of literature of overall good quality and consistency.
- ***B*** *= based on evidence from well conducted clinical trials but with no specific in vitro validation studies.*
- **C** = based on evidence from expert committee reports or opinions and/or clinical experience of respected authorities and indicates an absence of directly applicable studies of good quality.
- **NSR** = based on evidence from high-quality, non-systematic literature review.

Several of their recommendations are included in Chapters 2 0, 21 and 22. A flow diagram showing how imaging is *justified* on the basis of history, clinical examination, different clinical signs and symptoms of disease and possible treatment plans – based broadly on the recommendations on the *Selection Criteria* (third edition) – is shown in Fig. 7.4 .

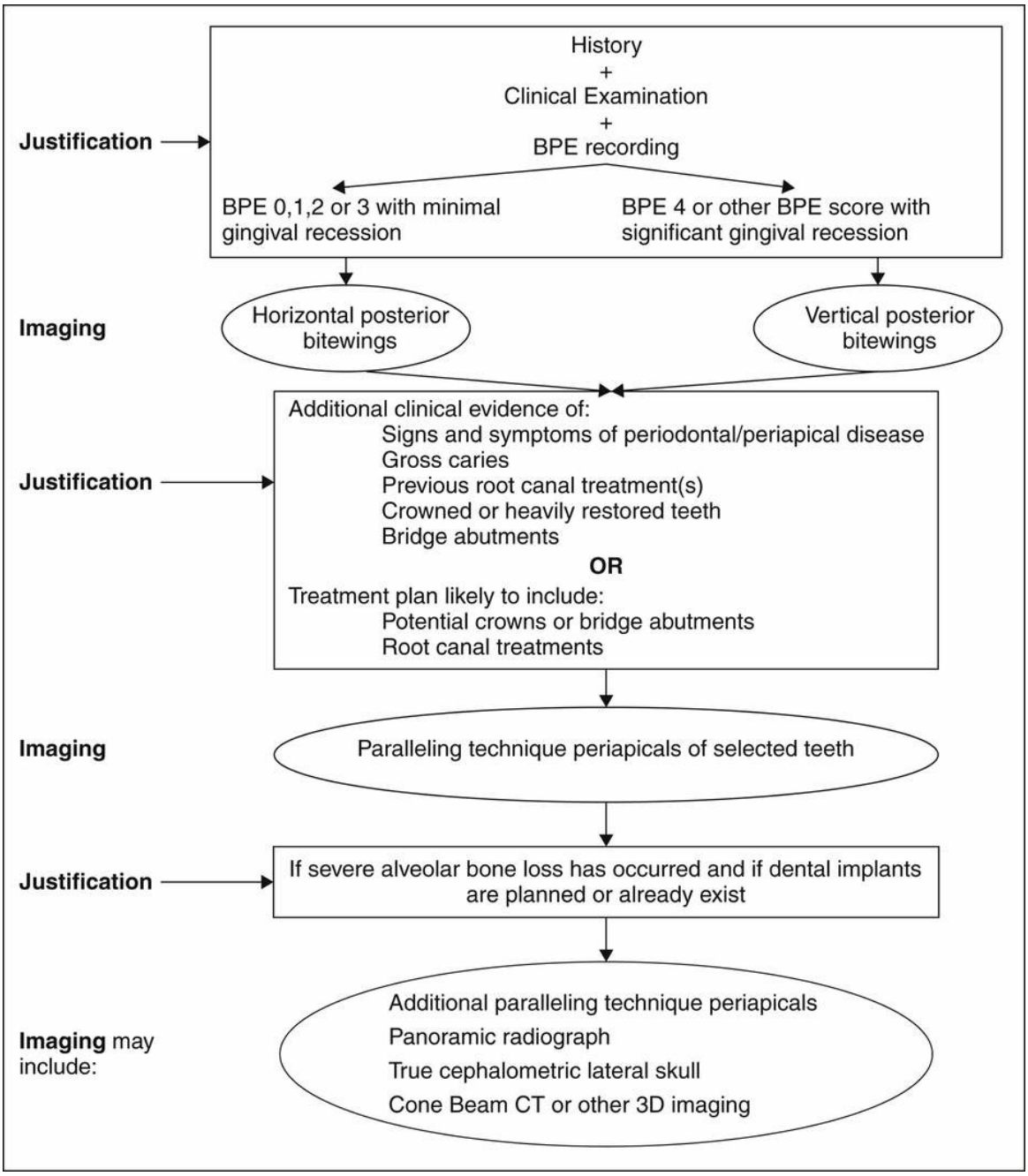


FIG. 7.4 Flow diagram showing how imaging is *justified* on the basic of history, clinical examination, different clinical signs and symptoms of disease and possible treatment plans – based broadly on the imaging strategy for a dentate or partially dentate adult patient from the FGDP (UK)'s 2013 *Selection Criteria for Dental Radiography* (third edition).

Equipment

- All *dental* X-ray generating equipment should:
  - Be installed correctly and tested by a medical physicist for safety and output before being used on a patient
  - Be checked regularly by a medical physicist, e.g. every 1–3 years
  - Function within agreed parameters – typically 60–70 kV and 7–12 mA
  - Contain adequate filtration (inherent and added) – typically 1.5 mm of aluminium for sets operating below 70 kV and 2.5 mm for sets operating above 70 kV (see Chapter 3)
  - Have the main beam collimated to cover the rectangular image receptor (film packet or digital sensor) being used (see Chapter 3) and should not exceed 40 × 50 mm, and preferably less than 35 x 45 mm
  - Have a *focus-to-skin distance* of at least 200 mm
  - Have an exposure switch (timer) that only functions when continuous pressure is maintained and that terminates if pressure is released
  - Be provided with film speed controls and finely adjustable exposure time setting
  - Be assessed as to the actual dose delivered to enable comparison with national diagnostic reference levels (NDRLs) (see Chapter 17).
- All *panoramic* X-ray generating equipment should:
  - Be installed correctly and tested by a medical physicist for safety and output before being used on a patient
  - Be checked regularly by a medical physicist, e.g. every 1–3 years
  - Function within agreed parameters – typically 60–90 kV
  - Contain adequate filtration (inherent and added)

  - Have the beam collimated so that it is no more than required to expose the area of interest
  - Have an exposure switch (timer) that only functions when continuous pressure is maintained and that terminates if pressure is released
  - Be provided with adequate patient-positioning aids incorporating light beam markers (see Chapter 15)
  - Ideally be provided with facilities for field-limitation techniques (see Chapter 15)
  - Be assessed as to the actual dose levels delivered to enable comparison with NDRLs (see Chapter 17).
- All image receptors should:
  - Be the fastest available (digital sensors, F-speed film or rare earth screen-film combination) that will produce satisfactory diagnostic images.

Radiographic Techniques

- All staff involved in X-raying patients should:
  - Have received adequate training and should undertake continuing education and training after qualification to keep their knowledge and skills up to date.
  - Undertake radiography accurately to avoid retakes, e.g. by using image receptor holders and beam-aiming devices for intraoral radiography as described in Chapters 9 and 10 , or by using patient positioning aids during panoramic radiography as described in Chapter 15
  - Use the minimum number of projections
  - Optimize all exposure settings to ensure that all doses are kept as low as reasonably practicable, consistent with the intended purpose
  - Ensure all image processing (computer or chemical) (see Chapter 5) is carried to the highest standards so

that images do not have to be retaken.

Lead Protection

Confusion and controversy still surround the use of lead protection for patients in different countries. In the UK, current guidance suggests that patient protection is best achieved by implementation of the practical dose reduction measures outlined above in relation to clinical judgement, equipment and radiographic technique, and not by lead protection. The latest UK *Guidance Notes* state:

- There is no justification for the routine use of lead aprons for patients undergoing any form of dental radiography or dental CBCT imaging
- Thyroid collars, as shown in Fig. 7.5 , should be used where the thyroid gland in the primary beam. Examples include:
    - Dental cone beam computed tomography, panoramic or cephalometric radiography where the field of view extends well below the mandible
    - Maxillary occlusal radiography and maxillary anterior periapical radiography using the bisected angle technique
    - Radiography of certain patient groups requiring unusual positioning techniques which may place the thyroid in the primary beam
- Lead aprons do not protect against radiation scattered internally within the body
- Protective aprons, having a lead equivalence of not less than 0.25 mm, should be provided for any adult who provides assistance by supporting a patient during radiography
- When a lead apron is provided, it must be correctly stored (e.g. over a suitable hanger) and not folded. Its condition must be routinely checked including a visual inspection at annual intervals.

Specific Radiation Protection Requirements for Female Patients of Childbearing Age

The developing foetus is most susceptible to the dangers of ionizing radiation during the period of organogenesis (3–7 weeks) – often before the woman knows that she is pregnant. Legislation usually prohibits the carrying out of a medical exposure of a female of childbearing age without an enquiry as to whether she is pregnant or likely to be pregnant if the primary beam is likely to irradiate the pelvic area. This situation is highly unlikely in dental radiography. If a patient is known to be pregnant, then the patient should be reassured that the risk to the foetus is negligible during dental radiography and all routine radiation protection measures employed. If the patient is very concerned and cannot be reassured, then the dentist may delay the radiograph if it is in the best interests of the patient.

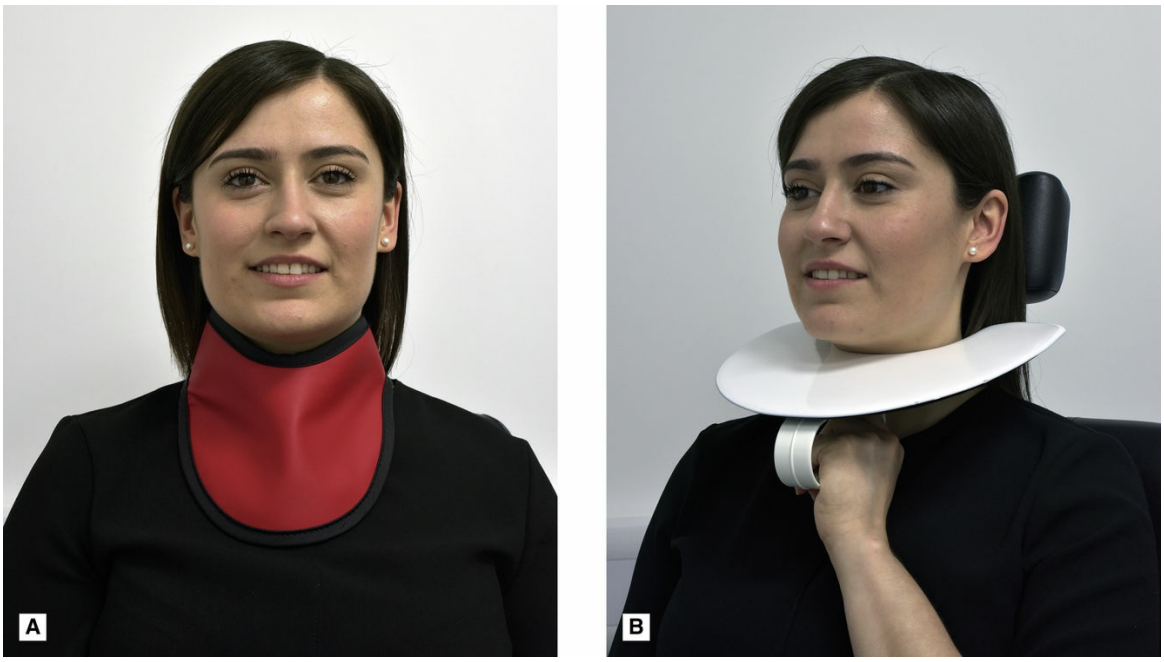


FIG. 7.5 Examples of thyroid lead protection. **(A)** Thyroid collar (0.5 mm Pb equivalent). **(B)** Hand-held thyroid shield (0.5 mm Pb equivalent).

Practical Radiation Protection of the General Public

This group includes everyone who is not receiving a radiation dose either as a patient or as a radiation worker, but who may be exposed inadvertently, e.g. someone in a dental surgery waiting room, in other rooms in the building or passers-by. The general public is at risk from the primary beam, so specific consideration should be given to:

- The siting of X-ray equipment to ensure that the primary beam is not aimed directly into occupied rooms or corridors
- The thickness/material of partitioning walls
- Advice from a medical physicist on the siting of all X-ray equipment, surgery design and the placement of radiation warning signs, as shown in Fig. 7.6
- In the UK there is a legal requirement to estimate effective doses to the general public to ensure the annual dose limits are not exceeded.



FIG. 7.6 An example of a *controlled area* warning sign. The words DO NOT ENTER are illuminated when the exposure button is pressed.

Practical Radiation Protection of Radiation Workers

The radiation dose to dentists and their staff can come from:

- The primary beam, if they stand in its path
- *Scattered radiation from the patient if they stand too close*
- Radiation leakage from the tubehead.

The main protective measures to limit the dose that workers might receive are therefore based mainly on a combination of common sense and the knowledge that ionizing radiation is attenuated by distance and obeys the inverse square law (see Fig. 7.7).

- The main practical radiation protection measures include:
  - – Ensuring all radiation workers (dental staff) know the risks to their own health created by exposure to X-rays and the safety precautions they need to take, including:
  - – Always standing outside the so-called *controlled area* **.** In the UK, it is considered preferable to make the whole room/surgery the controlled area. Where it is not practicable to designate the whole room as the controlled area, the operator should stand at least 1.5 m from the X-ray machine and the patient (or behind appropriate lead screens/barriers) and **never** in the path of the main beam until it has been sufficiently attenuated by distance or shielding as shown in Fig. 7.8 .

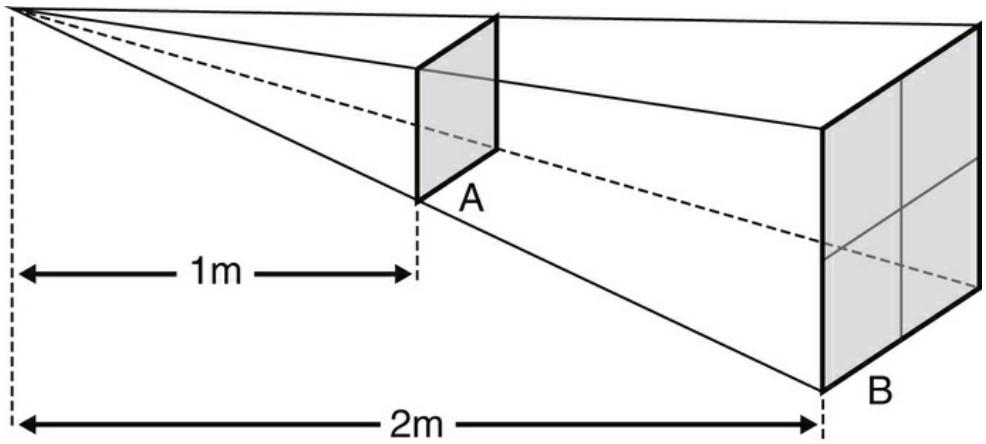


FIG. 7.7 Diagrammatic representation of the inverse square law. Doubling the distance from the source means that the area of **(B)** is four times the area of (A), thus the radiation per unit area at **(B)** is one-quarter that at **(A)** .

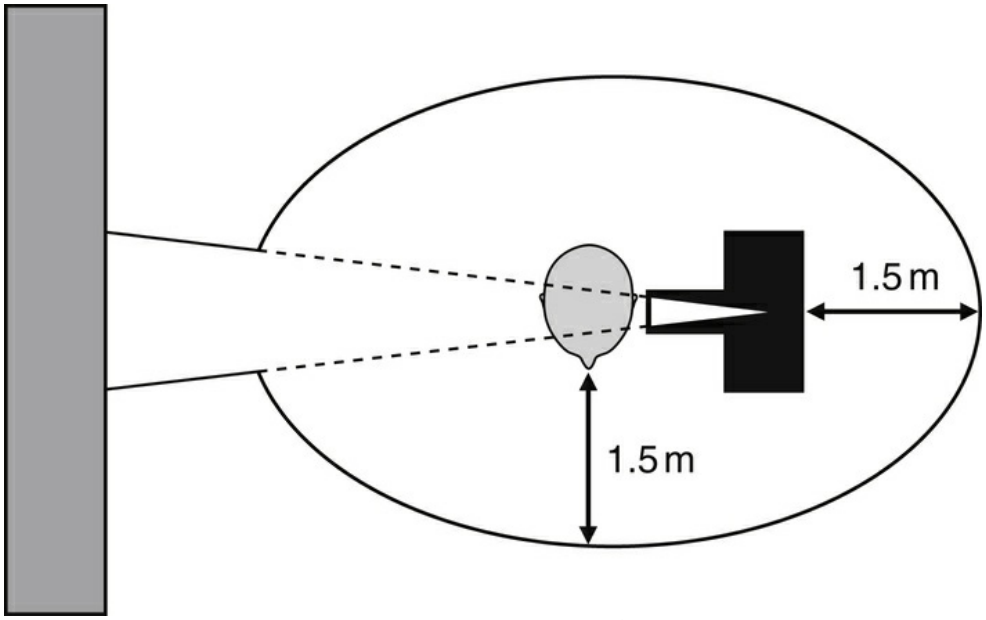


FIG. 7.8 Diagram showing the size of the *controlled area,* 1.5 m in any direction from the patient and tubehead and anywhere in the line of the main beam until it is attenuated in this case by a solid wall. Note this approach is to be used only when it is impracticable to designate the whole room as the *controlled area* .

– Never holding an image receptor in a patient's mouth

  - Never holding the X-ray tubehead during an exposure
  - Always using the X-ray equipment safely and in accordance with current guidance and good practice.

Monitoring

Dental staff are almost always designated as nonclassified workers by the International Commission on Radiological Protection. As such, as explained in Chapter 6 , they should not receive an effective dose exceeding 6mSv per year. In the UK, Public Health England regards a dose constraint of 0.3 mSv as more appropriate for dental staff working in general practice. The amount of radiation received by individuals can be monitored and measured using a variety of different monitoring devices that can include:

- Film badges
- Thermoluminescent dosimeters (TLD)
  - Badge
  - Extremity monitor
- *Optically stimulated luminescence dosimeters*
- Personal electronic dosimeters.

These devices do not protect against radiation. They merely provide data as to the amount of radiation that has been received over a period of time. More immediate information that the wearer is being irradiated can be provided by personal electronic dosimeters, including sophisticated systems such as the Unfors Alert dosimeter. A selection of various dosimeters is shown in Fig. 7.9 .



FIG. 7.9 A selection of monitoring devices. **(A)** **(i)** Personal monitoring plastic film badge; **(ii)** badge opened showing the different metal filters built into the badge and the film. **(B)** Personal body thermoluminescent dosimeter monitor. **(C)** Polimaster personal electronic dosimeter. **(D)** Personal OSLD badge.

Film badges

The main features of film badges are:

- They consist of a coloured plastic frame containing a variety of different metal filters and a small radiographic film which reacts to radiation.
- They are worn on the outside of the clothes, usually at the level of the reproductive organs, for 1–3 months before being processed.
- They are the most common form of personal monitoring device currently in use.

Advantages

- Provide a permanent record of dose received
- May be checked and reassessed at a later date
- Can measure the type and energy of radiation encountered
- Simple, robust and relatively inexpensive.

Disadvantages

- No immediate indication of exposure – all information is retrospective
- *Processing is required which may lead to errors*
- The badges are prone to filter loss.

Thermoluminescent dosimeters (TLDs)

The main features of TLDs are:

- They are used for personal monitoring of the whole body and/or the extremities, as well as measuring the skin dose from particular investigations
- They contain materials such as lithium fluoride (LiF) which absorb radiation and then release the energy in the form of light when heated
- The intensity of the emitted light is proportional to the radiation energy absorbed originally
- Personal monitors consist of a coloured plastic holder, worn like the film badge for 1–3 months.

Advantages

- The lithium fluoride is reusable
- *Read-out measurements are easily automated and rapidly produced*
- Suitable for a wide variety of dose measurements.

Disadvantages

- Read-out is destructive, giving no permanent record, and the

results cannot be checked or reassessed
- *Only limited information is provided on the type and energy of the radiation*
- Dose gradients are not detectable
- Relatively expensive.

Optically stimulated luminescence dosimeters (OSLDs)

The main features of OSLDs are:

- *They are used for personal monitoring of the whole body*
- *They consist of a badge containing an aluminium oxide detector and metal and plastic filters*
- The detector is read by exposing it to a light source, which releases the stored radiation energy in the aluminium oxide as blue light (luminescence)
- The radiation exposure can be calculated from the amount and intensity of blue light released.

Advantages

- Quick, nondestructive readout
- *Multiple readouts possible so radiation doses can be verified if required*
- Good sensitivity and respond to a wide range of energies
- Relatively robust.

Disadvantages

- No immediate indication of exposure – all information is retrospective.

Personal electronic dosimeters

The main features of personal electronic dosimeters are:

- They are battery operated devices normally worn in the operator's pocket for personal monitoring of the whole body
- They are usually based on an energy-activated silicon diode (a solid-state detector) to measure radiation dose
- Some also measure the dose rate and have an audible alarm to indicate radiation as it is received.

Advantages

- Direct digital read-out gives immediate information
- *Once purchased, no ongoing running costs*
- Relatively robust.

Disadvantages

- Initial cost can be expensive
- *Only sophisticated devices give a permanent record of exposure*
- *No indication given of the type or energy of the radiation*
- Not very sensitive to low-energy radiation, and so may not be reliable in the energy range encountered in dental radiography.

Footnote

All dental staff should be fully aware of the biological effects associated with X-rays, the risks involved for both patients and themselves and hence the practical radiation protection measures that are required. In the UK, the latest dental guidance notes state that personal monitoring for staff working in the controlled area may only be required for a short time period to confirm that the written arrangements are effective at restricting their exposure. However, any significant changes to the radiographic workload, X-ray equipment, technique or surgery layout may require a further period of monitoring.

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PART III
Radiography

OUTLINE

8. Dental Radiography – General Patient Considerations including Control of Infection

9. Periapical Radiography

10. Bitewing Radiography

11. Occlusal Radiography

12. Oblique Lateral Radiography

13. Skull and Maxillofacial Radiography

14. Cephalometric Radiography

15. Tomography and Panoramic Radiography

16. Cone Beam Computed Tomography

17. The Quality of Radiographic Images and Quality Assurance

18. Alternative and Specialized Imaging Modalities

8

Dental Radiography – General Patient Considerations including Control of Infection

This short chapter is designed as a preface to the radiography section. It summarizes the general guidelines relating to patient care, pertinent to all aspects of dental radiography, thus avoiding unnecessary repetition in subsequent chapters. Measures aimed at the control of infection during radiography are also discussed.

General Guidelines on Patient Care

- For intraoral radiography the patient should be positioned comfortably in the dental chair, ideally with the occlusal plane horizontal and parallel to the floor. For most projections the head should be supported against the chair to minimize unwanted movement. This upright positioning is assumed in subsequent chapters when describing radiographic techniques. However, some clinicians elect to X-ray their patients in the supine position along with most other dental surgery procedures. All techniques need to be modified accordingly, but it can sometimes be more difficult to assess angulations and achieve accurate alignment of image receptor and tubehead with the patient lying down.
- For extraoral views the patient should be reassured about the large, possibly frightening or unfriendly-looking equipment, before being positioned within the machine. This point is of particular importance with children.

- The procedure should be explained to the patients in terms they can understand, including warning them not to move during the investigation.
- Spectacles, dentures or orthodontic appliances should be removed. Jewellery including earrings may also need to be removed for certain projections.
- A protective lead thyroid collar, if deemed appropriate for the investigation being carried out, should be placed on the patient (see Chapter 7).
- The exposure factors on the control panel should be selected before positioning the intraoral image receptor and X-ray tubehead, to decrease the time of any discomfort associated with the investigation.
- The intraoral image receptor should be positioned carefully to avoid trauma to the soft tissues taking particular care where tissues curve, e.g. the anterior hard palate, lingual to the mandibular incisor teeth and distolingual to the mandibular molars.
- The radiographic investigation should be carried out as accurately and as quickly as possible, to avoid having to retake the radiograph and to decrease patient discomfort.
- The patient should always be watched throughout the exposure to check that he or she has obeyed instructions and has not moved.

Specific Requirements When X-Raying Children and Patients with Disabilities

These two groups of patients can present particular problems during radiography, including:

- Difficulty in obtaining cooperation
- Anatomical difficulties, such as:
    - Large tongue (macroglossia)

  - Small mouth (microstomia)
  - Tight oral musculature
  - Limited neck movement
  - Narrow dental arches
  - Shallow palate
  - Obesity
- Neurological disabilities, such as:
  - Communication and learning difficulties
  - Tremor
  - Palsy.

As a result of these difficulties, the following additional guidelines should be considered:

- Only radiographic investigations appropriate to the limitations imposed by the patient's age, cooperation or disability should be attempted.
- Select an intraoral image receptor of appropriate size, modifying standard techniques as necessary.
- Use assistant(s) to help hold the image receptor and/or steady and reassure the patient. This step can normally be accomplished by using an accompanying friend or relative.

NOTE: Radiation protection regulations usually require that during an exposure a designated *controlled area* or exclusion zone must exist around the X-ray set and theoretically only the patient is allowed in this area (see Chapter 7). Therefore, if assistance is needed and this requirement cannot be fulfilled, a *Radiation Protection Adviser* (RPA) or a *Medical Physics Expert* (MPE) must advise on the appropriate protective measures for the assistant.

- Perform any necessary radiography under general anaesthesia if an uncooperative patient is having their dental treatment in this manner. Radiographs taken are usually restricted to oblique laterals and periapicals, although bitewings can be

taken.

- Avoid panoramic radiography because of the need for the patient to remain still for approximately 18 seconds (see Chapter 15). Oblique lateral radiographs should be regarded as the extraoral views of choice.
- Use the paralleling technique, if possible, for periapical radiography because with this technique the relative positions of the image receptor, teeth and X-ray beam are maintained, irrespective of the position of the patient's head (see Chapter 9).

Control of Infection

In the UK, the Health and Safety at Work etc. Act of 1974 states that every person working in hospitals or general practice (referred to as *health care workers*) has a legal duty to ensure that all necessary steps are taken to prevent cross-infection to protect themselves, their colleagues and the patients. In addition, the Management of Health and Safety Regulations 1992 requires that a risk assessment is carried out for all procedures to decrease the possibility of harm to staff and patients. Effective infection control measures are therefore required in dental radiography – even though most investigations are regarded as *non-invasive* or *non–exposure prone procedures,* because they do not involve breaches of the mucosa or skin. The main risk of cross-infection is from one patient to another from salivary contamination of work areas and equipment.

Routes of Disease Transmission

All dental staff are potentially at risk from infectious disease by a number of routes, namely:

- *Direct contact* – including skin-to-skin and blood-to-mucous membrane contact. Pathogens such as herpes simplex virus and hepatitis B may be transmitted in this way.

- *Indirect contact* – requires an intermediate object such as personal protective equipment (PPE) or the surgery/hospital environment for transfer. Bacteria such as methicillin-resistant *Staphylococcus aureus* and *Clostridium difficile* may be transmitted by this route.
- *Droplet and airborne routes* – examples of pathogens transmitted by these routes include the influenza viruses and *Mycobacterium tuberculosis,* respectively. Transmission may occur during a range of activities including talking, sneezing and interventions such as aerosol generation and cardiopulmonary resuscitation.

Micro-Organisms That May Be Encountered

The transmission of blood borne viruses such as HIV and hepatitis B and C during radiography is rare. However, these viruses may be transmitted as a result of inoculation injuries such as percutaneous sharps injuries and splashes to mucous membranes. Each of the three bloodborne viruses may be detected in saliva, although for HIV and hepatitis C, saliva is not regarded as a likely source of transmission of infection. Hepatitis B is highly infectious and can be transmitted by a small amount of blood present in saliva.

Whilst heath care workers are usually protected via vaccination, a small percentage of health care workers do not respond adequately to the vaccine. In addition, patient to patient transmission of this virus has been documented in the dental setting.

Because patients in the UK are not yet routinely vaccinated against hepatitis B, particular care must be taken in decontamination of work areas and equipment likely to be contaminated with saliva (which may be blood stained) either from direct glove contact or splatter and aerosol generation.

Tuberculosis continues to increase in some parts of the UK, and in other parts of the world, and multidrug resistance is an increasing

problem. The skin of patients may be colonised by multidrug resistant bacteria such as *C difficile*.

Herpes simplex virus is extremely infectious and may be present at high levels within herpetic lesions, and importantly is often shed in the saliva of patients in the absence of obvious lesions. Herpetic whitlow (infection of the nail bed) has decreased with glove wearing, but infection of the eyes may result from exposure. There are many other examples of micro-organisms that may be transmitted in the dental setting, but these are beyond the scope of this book.

Standard and Transmission-Based Precautions

Standard precautions are a combination of universal precautions and body substance isolation practices, which should be followed for every patient. The underlying premise is that all body fluid and all patients are potentially infectious. Standard precautions include:

- Respiratory hygiene
- Cough etiquette
- Hand hygiene
- Use of PPE when contact with blood or body fluids is anticipated.

Standard precautions are supplemented by additional transmission-based precautions (contact, droplet and airborne) to prevent the transmission of particular micro-organisms associated with significant morbidity and mortality, e.g. multidrug resistant bacteria, measles, influenza and transmissible spongiform encephalopathies (TSEs). Once again such transmission-based precautions are beyond the scope of this book and local infection control guidelines and specialists should be consulted.

Important Point to Note

If dental clinicians are requesting other health care workers to take their radiographs, either in hospitals or general dental practice, it is their responsibility to ensure that these workers are made aware of any known medical problems or risks, e.g. epilepsy or current infections.

Infection Control Measures

Education and Training

All dentists and dental care professionals should receive comprehensive induction and refresher training on the nature of potential infectious risks and the protocols and procedures they should adopt to reduce risks in all clinical areas including radiography.

Personal Protection

All *health care workers* should liaise with occupational health units to ensure that they have received routine childhood and pre-employment vaccinations relevant to their role. This would normally include demonstration of successful vaccination against hepatitis B.

Personal Protective Equipment (PPE) appropriate to the procedures should be used. This would routinely include the use of gloves and eye and face protection for intraoral radiography. Aprons may be considered for more invasive procedures such as sialography (see Chapter 32).

Optimal hand hygiene and aseptic techniques protect the patient, the operator, and other staff and should be undertaken before donning and after removing gloves and after any unplanned contact with body fluids or a contaminated environment. Suitable additional precautions may be considered under pre- and post-radiological examination.

Pre-Examination

- Open wounds on the hands and forearms should be covered with waterproof dressings.
- Hand hygiene should be undertaken before glove donning and gloves worn for all radiographic procedures and changed for each new patient, or when torn. Gloves should be worn by all radiology staff including assistants.
- Eye and face protection such as glasses or visors should be worn (see Fig. 8.1). Note that standard surgical masks provide protection mainly from splatter and do not provide respiratory protection so are not usually required in conjunction with a visor.
- It is good practice to place all of the required image receptors and holders on a holding tray (disposable or reusable following appropriate decontamination) (see Fig. 8.2).



FIG. 8.1 A Henry Schein® visor suitable for eye protection during dental radiography.

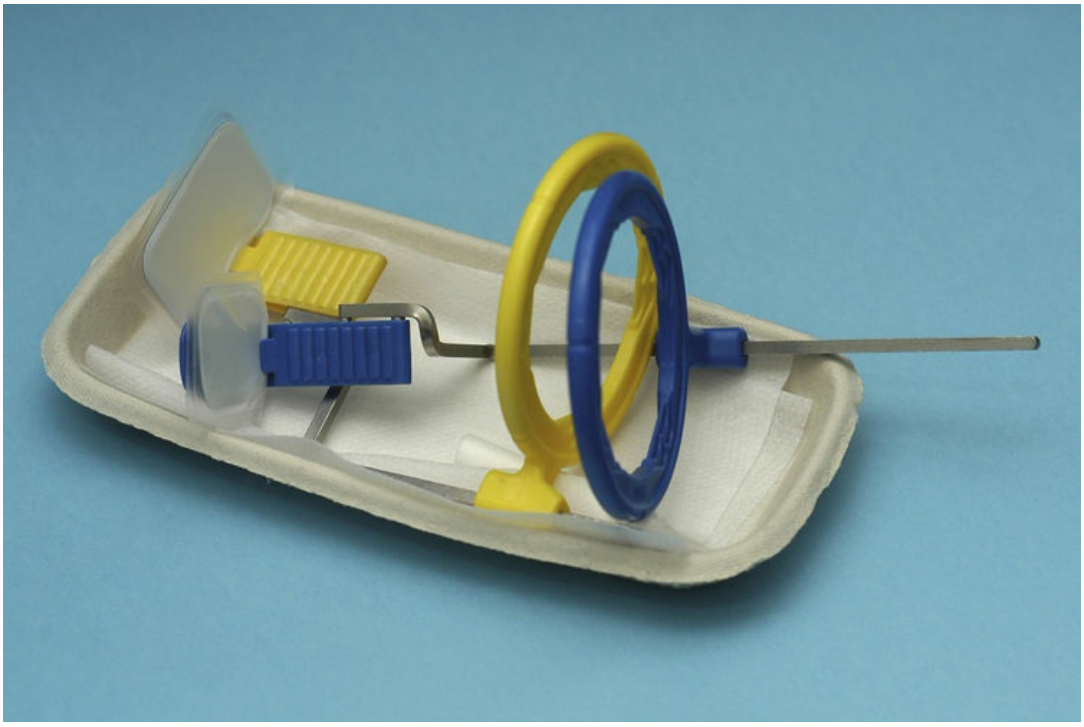


FIG. 8.2 Image receptor holders ready for clinical use on a disposable tray.

- Film packets should be placed in barrier envelopes or prepurchased in such barriers (see Fig. 8.3).
- Digital radiography sensors must also be placed inside appropriate barrier envelopes (see Fig. 8.4).
- Ensure that all paperwork (e.g. clinical notes) is placed away from the work area to prevent contamination.

Post-Examination

- Sensors and films should be removed from holders using an appropriate absorbent material, e.g. tissue paper.
- After intraoral use, sensors and films should be emptied out of the barrier envelope onto a clean surface after which they can be handled safely for processing. The wrappings are discarded as clinical waste.
- Note that powdered gloves should not be used for processing because the powder may produce artefacts.

- Gloves and other items of PPE should be discarded as clinical waste or decontaminated according to manufacturer's guidelines, e.g. glasses and visors.
- Image receptor holders should be disposed of into clinical waste (single use) or, if reusable, decontaminated according to the manufacturer's instructions.
- X-ray equipment, including the tubehead, control panel, timer switch and cassettes, that has been touched during the radiographic procedure should be thoroughly cleaned and disinfected with a suitable surface combination detergent/disinfectant, e.g. Mikrozid®. The head rest, chin rest and earposts should be decontaminated by similar methods.
- Alternatively, equipment can be covered, for example with cling film or dedicated barrier sleeves that can be replaced after every patient (see Fig. 8.5).

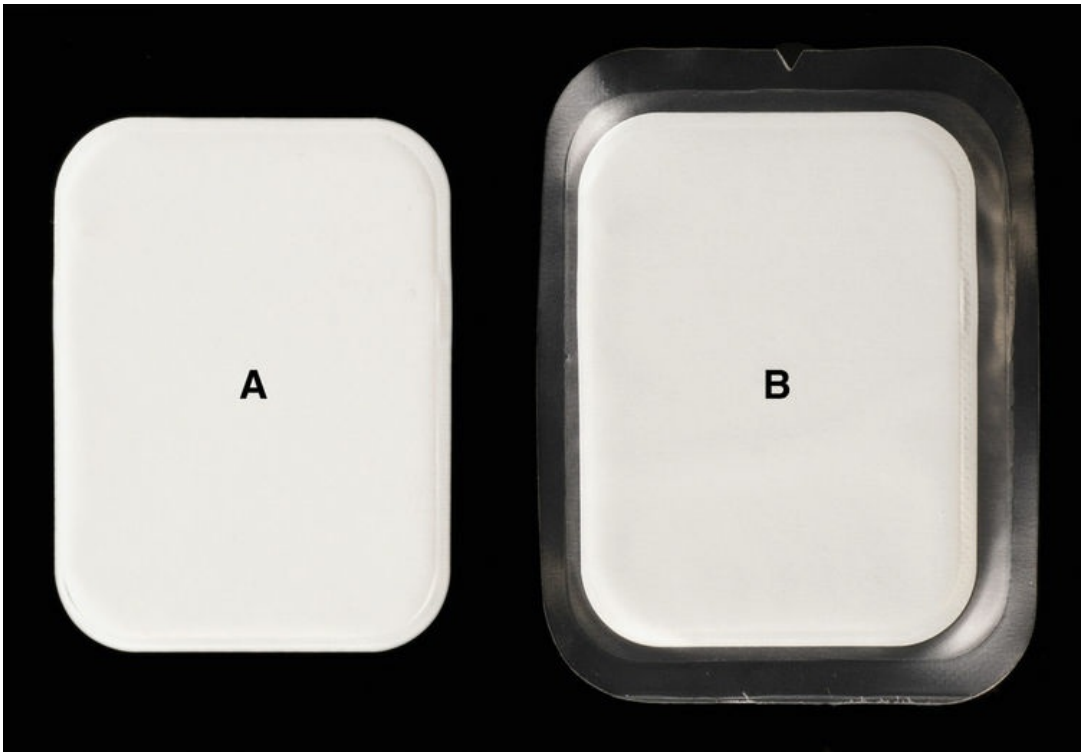


FIG. 8.3 **(A)** Conventional unprotected 31 x 41 mm periapical film packet and **(B)** Pre-packed periapical film packet inside its barrier envelope.


schick 33
sirona
A


B

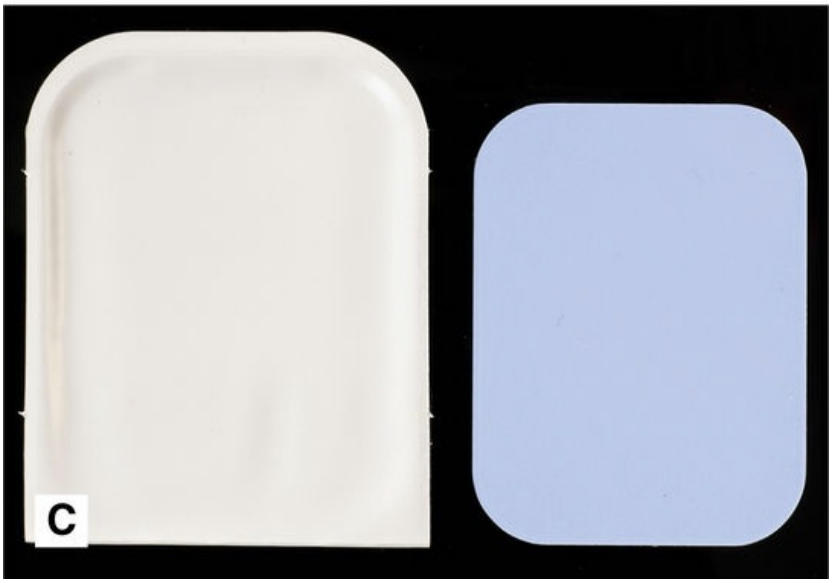

C

FIG. 8.4 **(A)** Solid-state digital sensor inside a barrier envelope. **(B)** Barrier-wrapped solid-state sensor inserted into a sensor holder. **(C)** Barrier envelope for the 31 × 41 mm digital phosphor plate shown.



FIG. 8.5 Examples of different pieces of equipment barrier-wrapped in cling film barrier sleeves and ready for clinical use. **(A)** A panoramic control panel. **(B)** A dental X-ray tubehead. **(C)** A cassette for extraoral use.

- All additional surfaces where contact with oral secretions is suspected should be wiped thoroughly with a combined detergent/disinfectant wipe.

Important Point to Note

- When X-raying patients with known, or suspected, transmissible spongiform encephalopathy, extraoral radiographic techniques, which avoid salivary contamination, should be chosen whenever possible (preferably using a technique that does not involve any form of intraoral positioning device) and films/phosphor plates should be processed immediately and not left on work surfaces.

Footnote

The importance of effective control of infection measures during dental radiography cannot be overemphasized. All health care workers should remember that they have a duty of care to do no harm to their patients. Inadequate infection control measures may put other/subsequent patients at risk from infection whether transmitted directly or indirectly.

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9

Periapical Radiography

Periapical radiography describes intraoral techniques designed to show individual teeth and the tissues *around the apices.* Each image usually shows two to four teeth and provides detailed information about the teeth and the surrounding alveolar bone.

Main Indications

The main clinical indications for periapical radiography include:

- Detection of apical infection/inflammation
- Assessment of caries and the periodontal status
- After trauma to the teeth and associated alveolar bone
- Assessment of the presence and position of unerupted teeth
- Assessment of root morphology before extractions
- During endodontics
- Preoperative assessment and postoperative appraisal of apical surgery
- Detailed evaluation of apical cysts and other lesions within the alveolar bone
- Evaluation of implants postoperatively.

Ideal Positioning Requirements

The ideal requirements for the position of the image receptor (digital sensor or film packet) and the X-ray beam, relative to a tooth, are shown in Fig. 9.1 . They include:

- The tooth under investigation and the image receptor should be in contact or, if not feasible, as close together as possible.

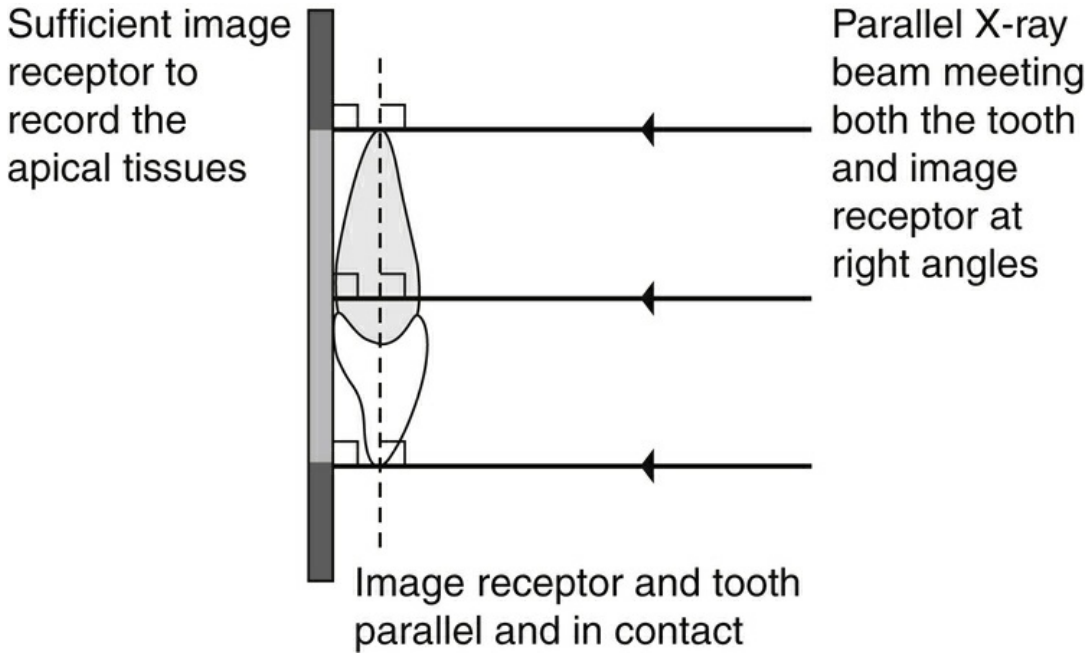


FIG. 9.1 Diagram illustrating the ideal geometrical relationship between image receptor, tooth and X-ray beam.

- The tooth and the image receptor should be parallel to one another.
- The image receptor should be positioned with its long axis vertically for incisors and canines, and horizontally for premolars and molars with sufficient receptor beyond the apices to record the apical tissues.
- The X-ray tubehead should be positioned so that the beam meets the tooth and the image receptor at right angles in both the vertical and the horizontal planes.
- The positioning should be reproducible.

Radiographic Techniques

The anatomy of the oral cavity does not always allow all these ideal

positioning requirements to be satisfied. In an attempt to overcome the problems, two techniques for periapical radiography have been developed:

- The paralleling technique
- The bisected angle technique.

Paralleling Technique

Theory

1. The image receptor is placed in a holder and positioned in the mouth **parallel** to the long axis of the tooth under investigation.
2. The X-ray tubehead is then aimed at right angles (vertically and horizontally) to both the tooth and the image receptor.
3. By using a sensor/film holder with fixed image receptor and X-ray tubehead positions, the technique is reproducible.

This positioning has the potential to satisfy four of the five ideal requirements mentioned. However, the anatomy of the palate and the shape of the arches mean that the tooth and the image receptor cannot be both parallel and in contact. As shown in Fig. 9.2 , the image receptor has to be positioned some distance from the tooth.

To prevent the magnification of the image that this separation would cause, an X-ray beam as non-divergent as possible is required (see Fig. 9.3). As explained in Chapter 3 , this is achieved by having a **long** *focus-to-skin distance (fsd),* ideally of at least 200 mm.

Digital Sensor/Film Packet Holders

A variety of holders has been developed for this technique. The different holders vary in cost and design, but essentially consist of three basic components (see Fig. 9.4):

- A mechanism for holding the image receptor parallel to the

teeth that also prevents bending of the receptor
- A bite block or platform
- An X-ray beam-aiming device. This component may or may not provide additional collimation of the beam.

The different components of the various holders usually need to be assembled together before the holder can be used clinically. The holder design used depends on whether the tooth under investigation is:

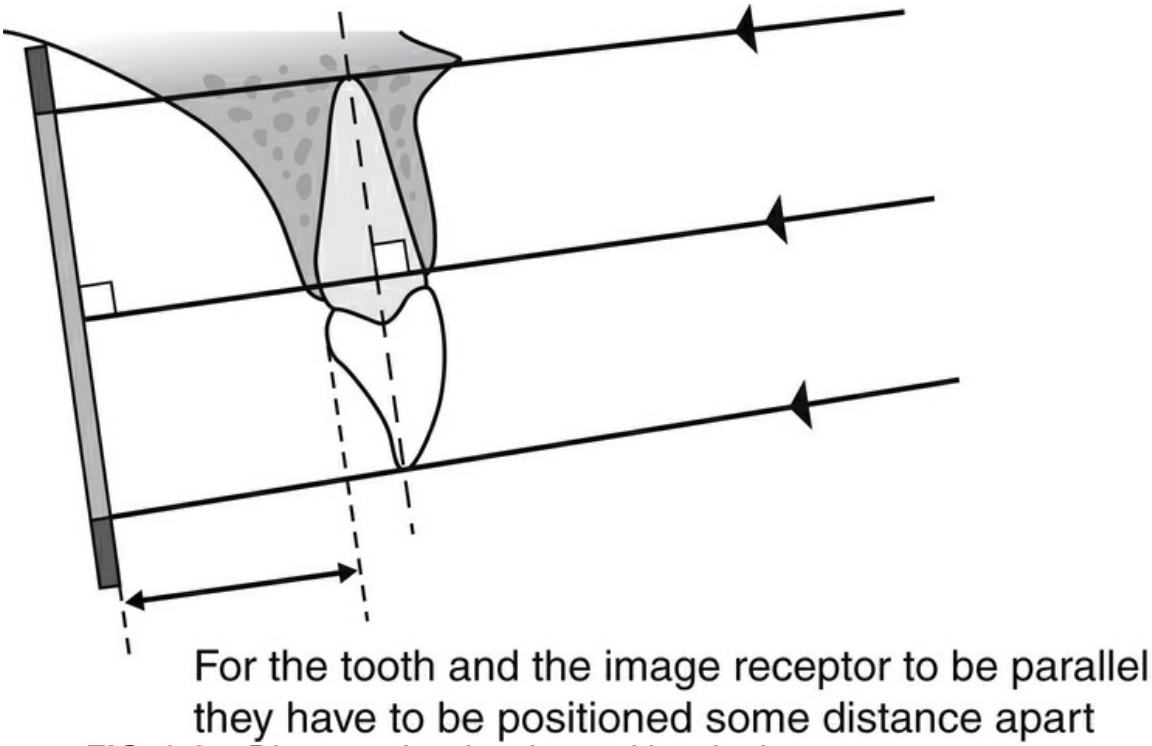


FIG. 9.2 Diagram showing the position the image receptor has to occupy in the mouth to be parallel to the long axis of the tooth, because of the slope of the palate.

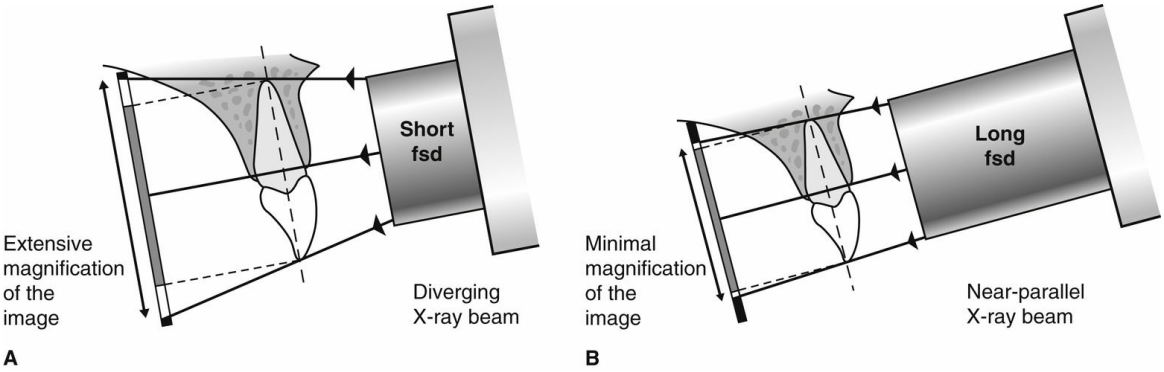


FIG. 9.3 Diagrams showing the magnification of the image that results from using **(A)** a short *focus-to-skin distance* and a diverging X-ray beam and **(B)** a long *focus-to-skin distance* and a near-parallel X-ray beam.

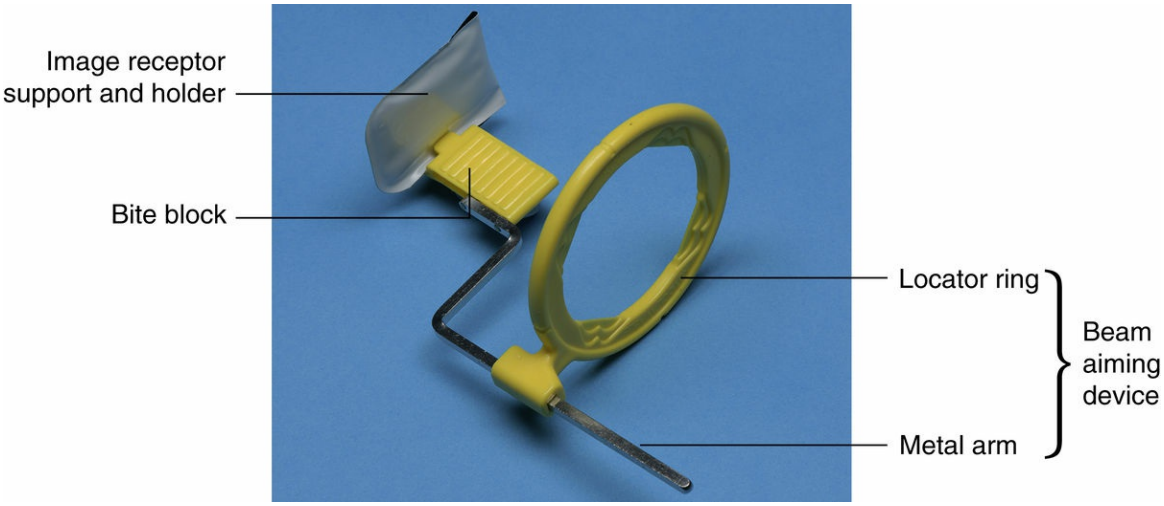


FIG. 9.4 Posterior Rinn® XCP image receptor holder showing the three basic components common to most holders.

- Anterior or posterior
- In the mandible or maxilla
- On the right or the left hand side of the jaw.

These variables mean that assembling the holder can be confusing, but it must be done correctly. To facilitate this assembly some

manufacturers now colour code the various components. Once assembled correctly the entire image receptor should be visible when viewed through the beam-aiming device as shown in Fig. 9.5 .

The choice of holder is a matter of personal preference and depends on the type of image receptor – film packet or digital sensor (solid-state or phosphor plate) – being used. A selection of different holders is shown in Fig. 9.6 .

Typically, the same anterior holder can be used for right and left maxillary and mandibular *incisors* and *canines* using a small image receptor (22 × 35 mm) with its long axis vertical. Four images in the maxilla and three images in the mandible are usually required to cover the right and left incisors and canines (see Fig. 9.7).

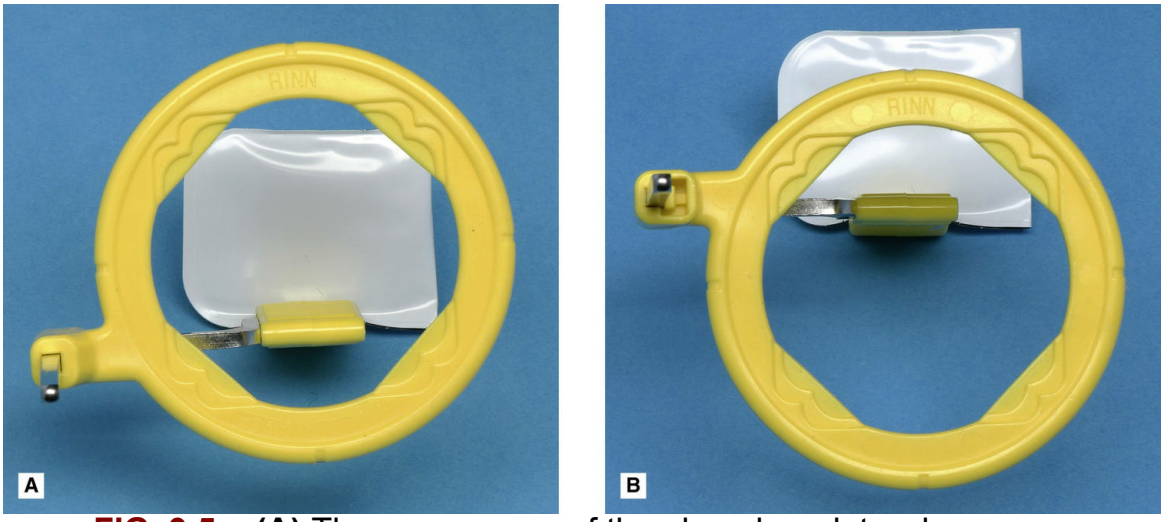


FIG. 9.5 **(A)** The appearance of the phosphor plate when viewed through the locator ring of a *correctly* assembled Rinn® XCP holder. **(B)** The appearance when the image receptor holder has been assembled *incorrectly* .

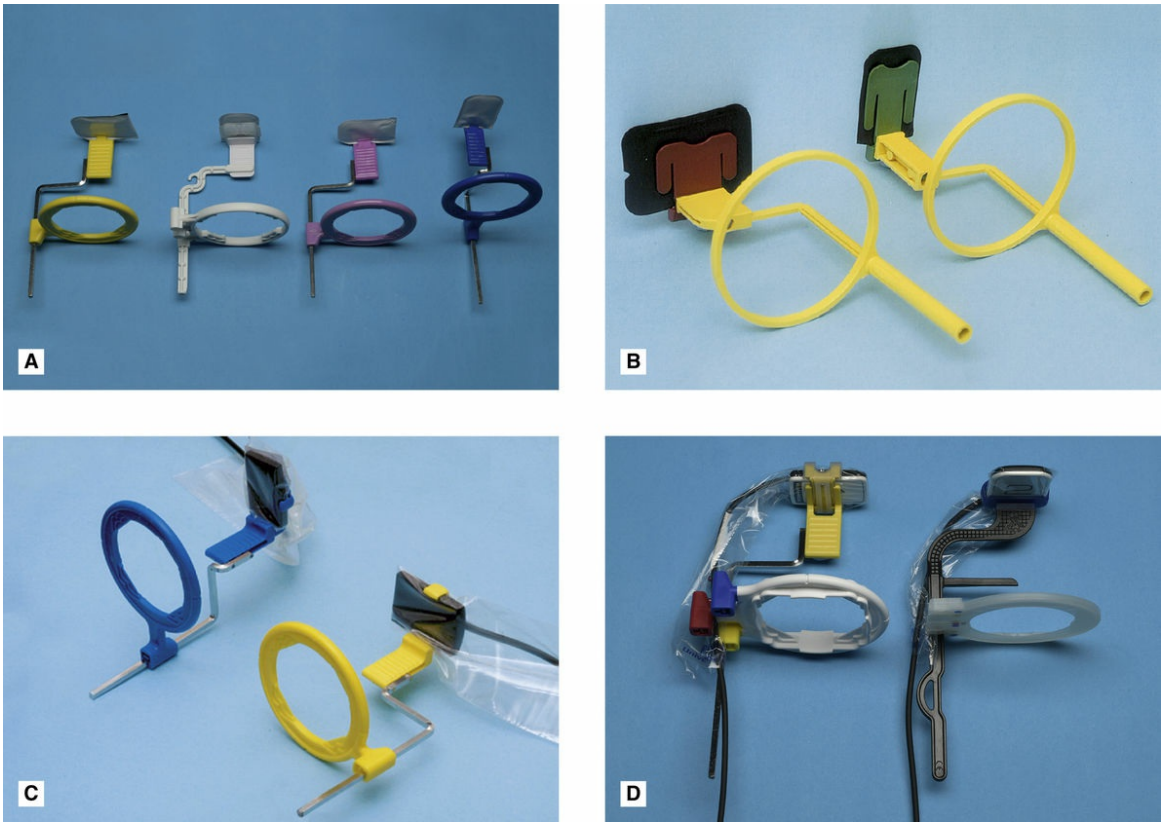


FIG. 9.6 Paralleling technique image receptor holders with beam aiming devices. **(A)** Various Rinn® XCP-DS phosphor plate and film packet holders. **(B)** Green/yellow anterior and red/yellow posterior Hawe-Neos phosphor plate/film packet holders. **(C)** Rinn® XCP blue anterior and yellow posterior solid-state sensor holders. **(D)** Rinn® XCP Universal multi-coloured solid-state sensor holder and the black Kimera Trollbyte solid-state sensor holder.

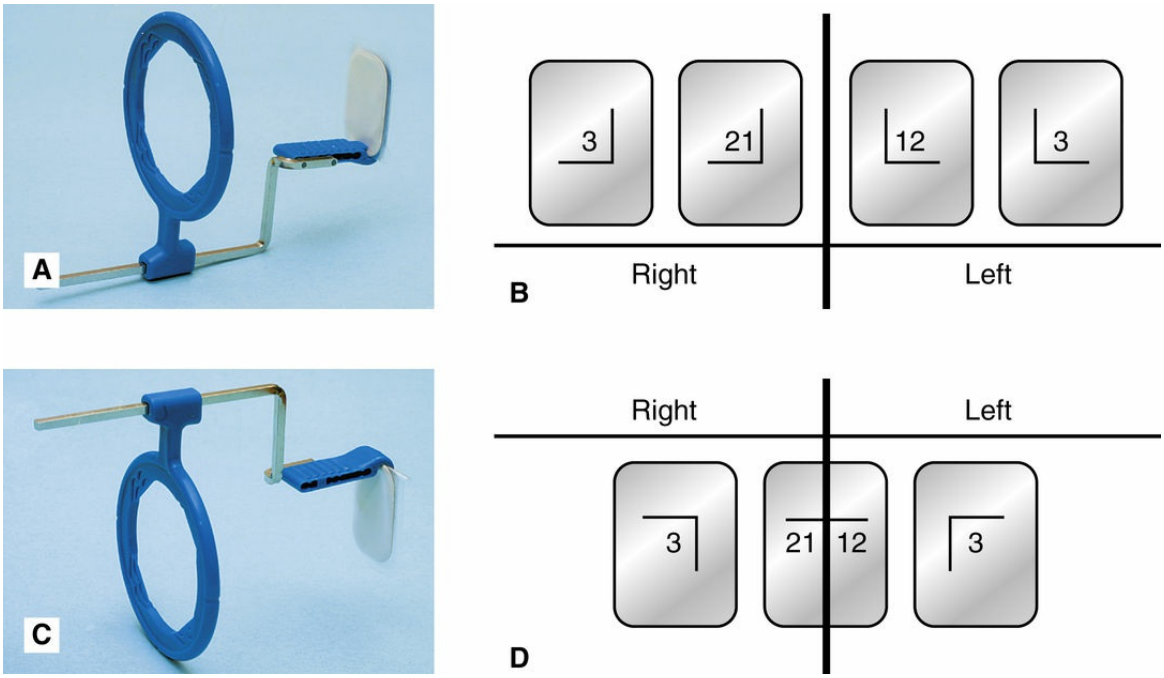


FIG. 9.7 **(A)** The blue anterior Rinn® XCP holder suitable for imaging the maxillary incisors and canines. **(B)** Diagram showing the *four* small image receptors required to image the right and left maxillary incisors and canines. **(C)** The blue anterior Rinn® XCP holder suitable for imaging the mandibular incisors and canines. **(D)** Diagram showing the three small image receptors required to image the right and left mandibular incisors and canines.

Typically, **different** holders are required for the **right** and **left** *premolar* and *molar* maxillary and mandibular posterior teeth. The different designs allow the holders to hook around the cheek and corner of the mouth. A large image receptor (31 × 41 mm) is ideally used with its long axis horizontal. Two images are usually required to cover the premolar and molar teeth in each quadrant (see Fig. 9.8).

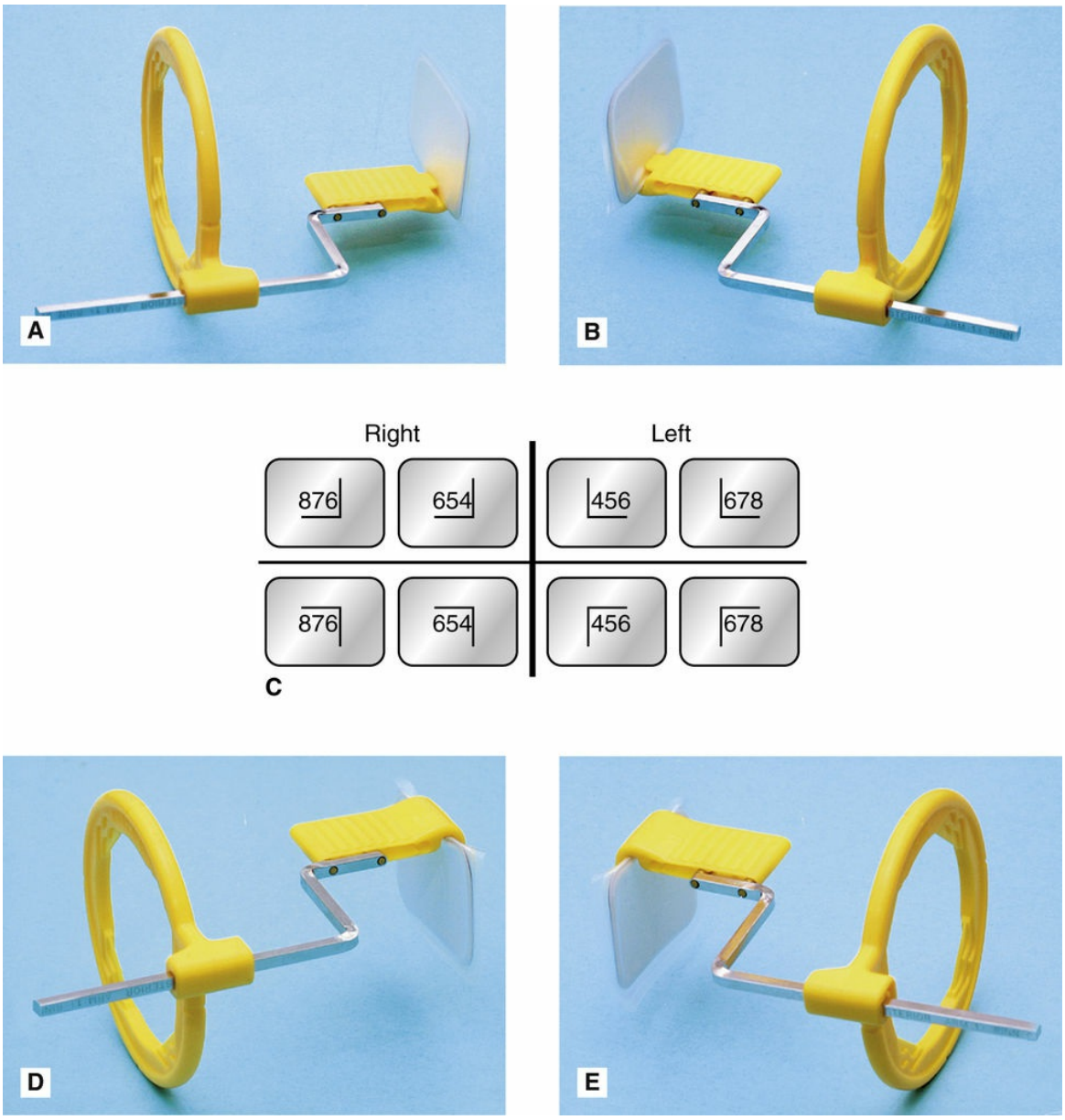


FIG. 9.8 **(A)** The yellow posterior Rinn® XCP holder assembled for imaging the RIGHT maxillary premolars and molars. **(B)** The yellow posterior Rinn® XCP holder assembled for imaging the LEFT maxillary premolars and molars. **(C)** Diagram showing the *two* large image receptors required to image the right and left premolars and molars in each quadrant. **(D)** The yellow posterior Rinn® XCP holder assembled for imaging the RIGHT mandibular premolars and molars. **(E)** The yellow posterior Rinn® XCP holder assembled for imaging the LEFT mandibular premolars and molars.

Positioning Techniques

The radiographic techniques for the permanent dentition can be summarized as follows:

1. The patient is positioned with the head supported and with the occlusal plane horizontal.
2. The holder and image receptor are placed in the mouth as follows:
    a. *Maxillary incisors and canines* – the image receptor is positioned sufficiently posteriorly to enable its height to be accommodated in the vault of the palate
    b. *Mandibular incisors and canines* – the image receptor is positioned in the floor of the mouth, approximately in line with the lower canines or first premolars
    c. *Maxillary premolars and molars* – the image receptor is placed in the midline of the palate, again to accommodate its height in the vault of the palate
    d. *Mandibular premolars and molars* – the image receptor is placed in the lingual sulcus next to the appropriate teeth.
3. The holder is rotated so that the teeth under investigation are touching the bite block.
4. A cottonwool roll is placed on the reverse side of the bite block. This step often helps to keep the tooth and image receptor parallel and may make the holder less uncomfortable.
5. The patient is requested to bite **gently** together, to stabilize the holder in position.
6. The locator ring is moved down the indicator rod until it is just in contact with the patient's face. This ensures the correct *focus-to-skin distance* .
7. The spacer cone is aligned with the locator ring. This automatically sets the vertical and horizontal angles and centres the X-ray beam on the image receptor.

8. The exposure is made.

Positioning clinically using film packets and digital phosphor plates is shown in Figs 9.9 –9.16 for the following different areas of the mouth:

Maxillary central incisor (see Fig. 9.9)
Maxillary canine (see Fig. 9.10)
Maxillary premolars (see Fig. 9.11)
Maxillary molars (see Fig. 9.12)
Mandibular incisors (see Fig. 9.13)
Mandibular canine (see Fig. 9.14)
Mandibular premolars (see Fig. 9.15)
Mandibular molars (see Fig. 9.16)

Note

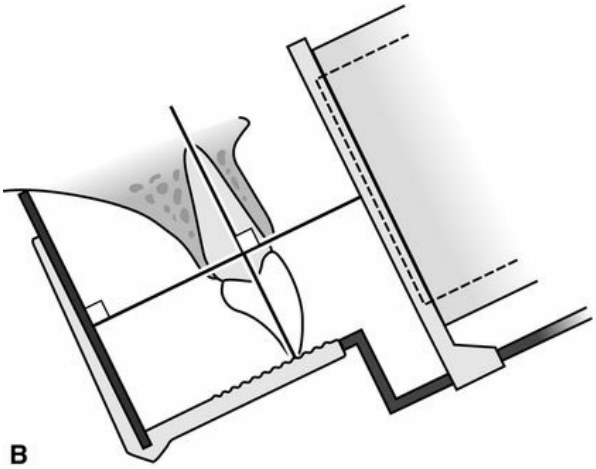
1. *Full mouth survey* is the terminology used to describe the full collection of 15 periapical radiographs (seven anterior and eight posterior) showing the full dentition.
2. When using film packets and some digital phosphor plates the end of the receptor with the orientation dot should be placed opposite the crowns of the teeth to avoid subsequent superimposition of the dot over an apex.

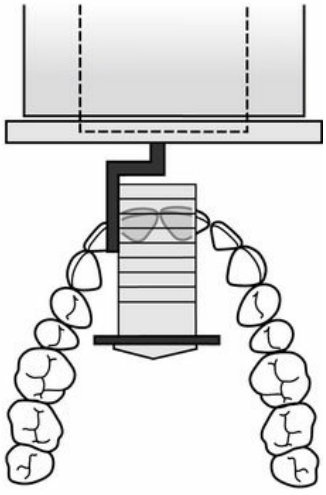
Positioning Using Solid-state Digital Sensors

Clinical positioning of holders for the paralleling technique when using solid-state digital sensors can be more difficult because of the bulk and absolute rigidity of the sensor. Those systems using cables also require extra care with regard to the position of the cable to avoid damaging it. Once the holder is inserted into the mouth, the positioning of the tubehead is the same as described previously when using phosphor plates or film packets and is shown in Fig. 9.17 for different parts of the mouth.

Maxillary incisors


HELIODENT PLUS
A


B


C


D

FIG. 9.9 Maxillary incisors. **(A)** Patient positioning (maxillary central incisor). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Maxillary canine

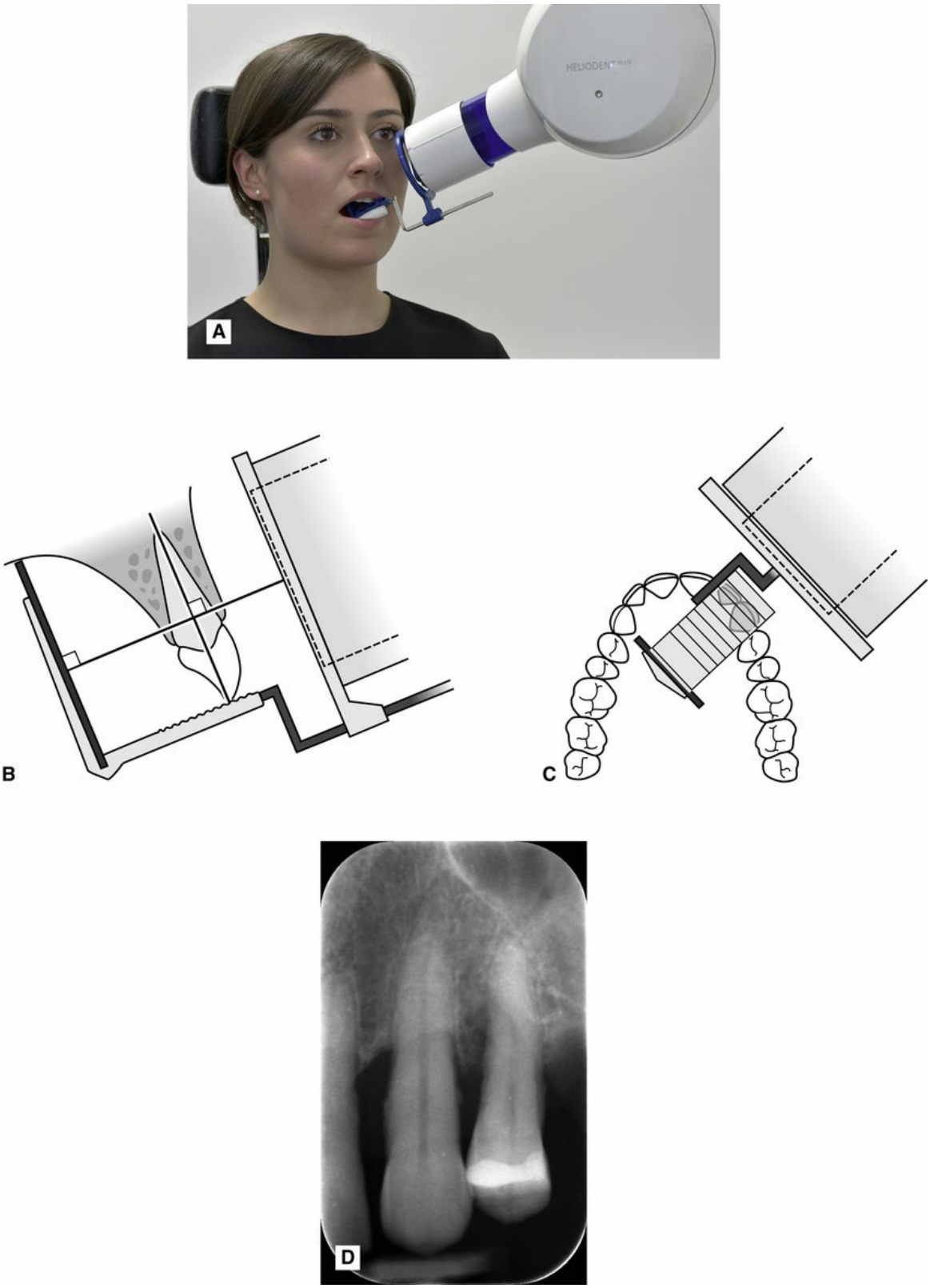


FIG. 9.10 Maxillary canine. **(A)** Patient positioning (maxillary canine). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Maxillary premolars

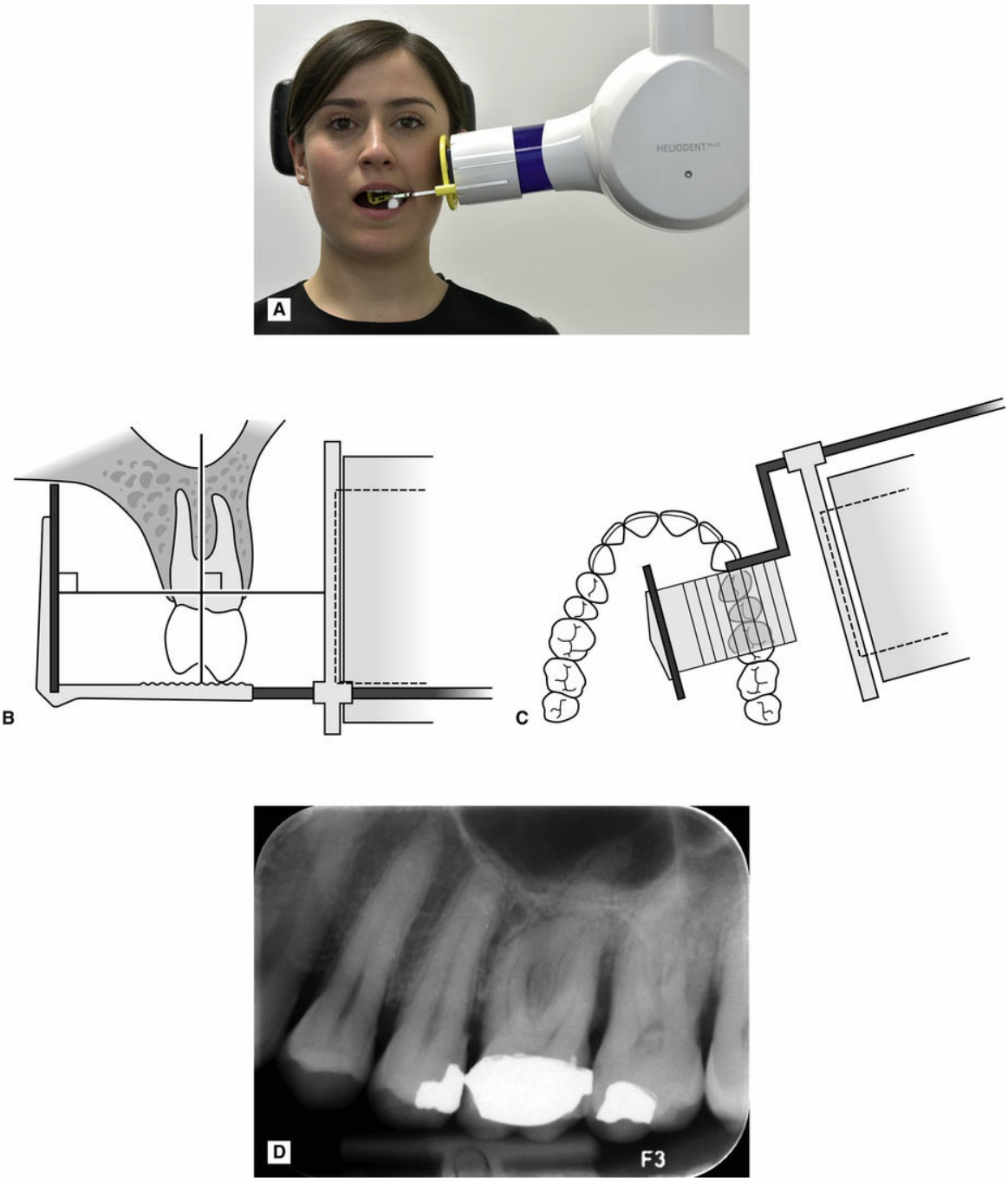


FIG. 9.11 Maxillary premolars. **(A)** Patient positioning (maxillary premolars). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Maxillary molars

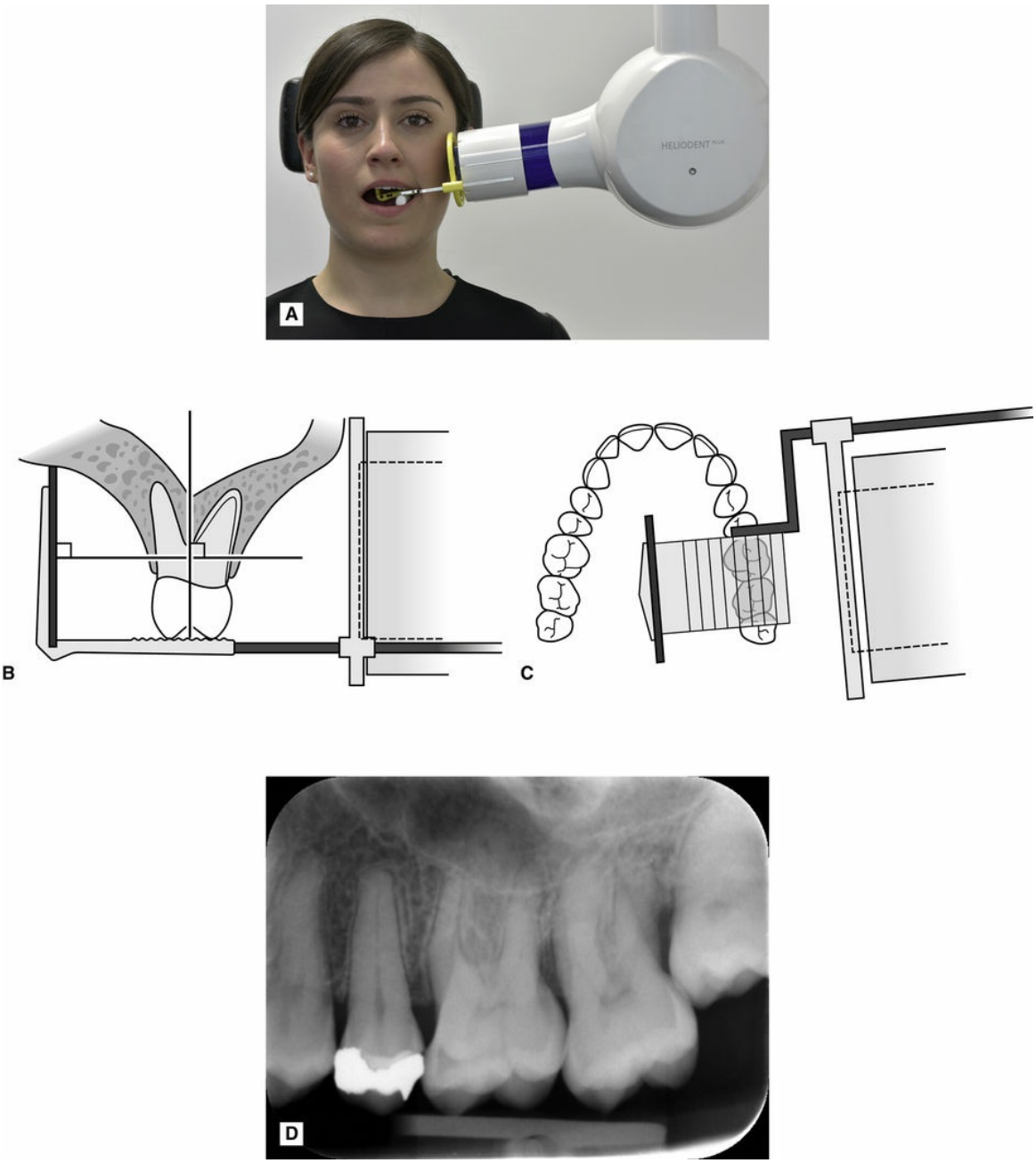


FIG. 9.12 Maxillary molars. **(A)** Patient positioning (maxillary molars). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Mandibular incisors

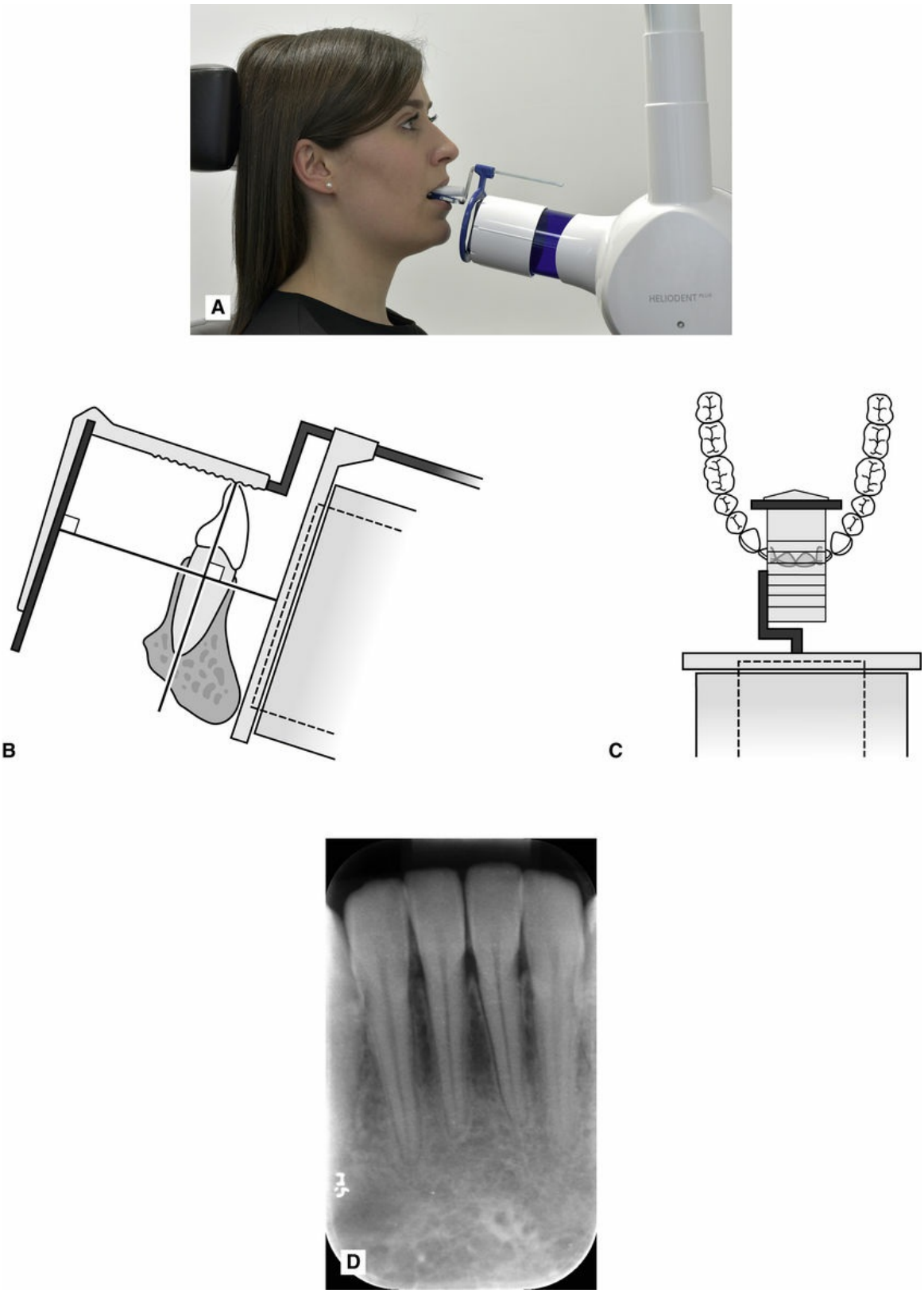


FIG. 9.13 Mandibular incisors. **(A)** Patient positioning (mandibular incisors). **(B)** Diagram of the positioning. **(C)** Plan

view of the positioning. **(D)** Resultant radiograph.

Mandibular canine

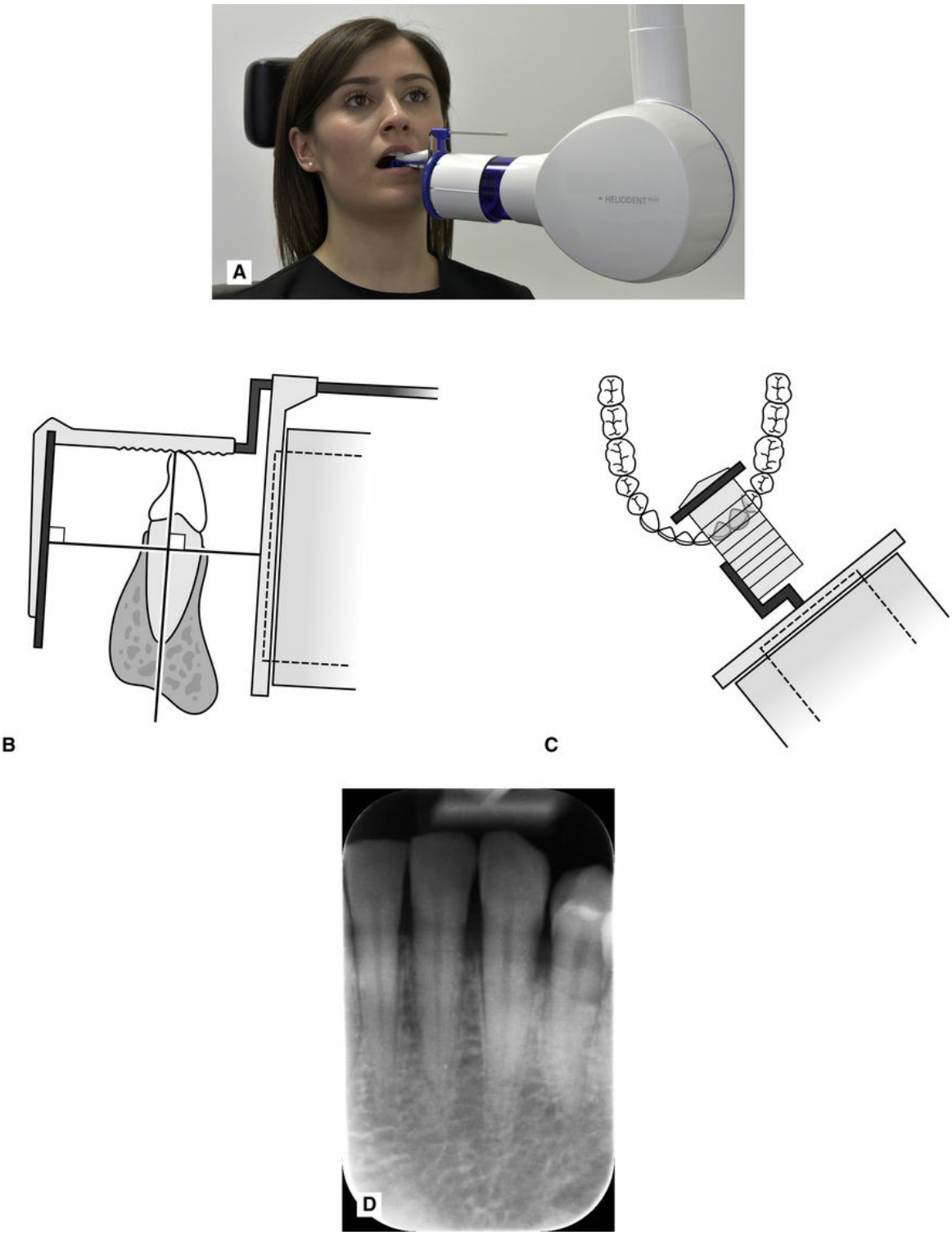


FIG. 9.14 Mandibular canine. **(A)** Patient positioning (mandibular canine). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Mandibular premolars

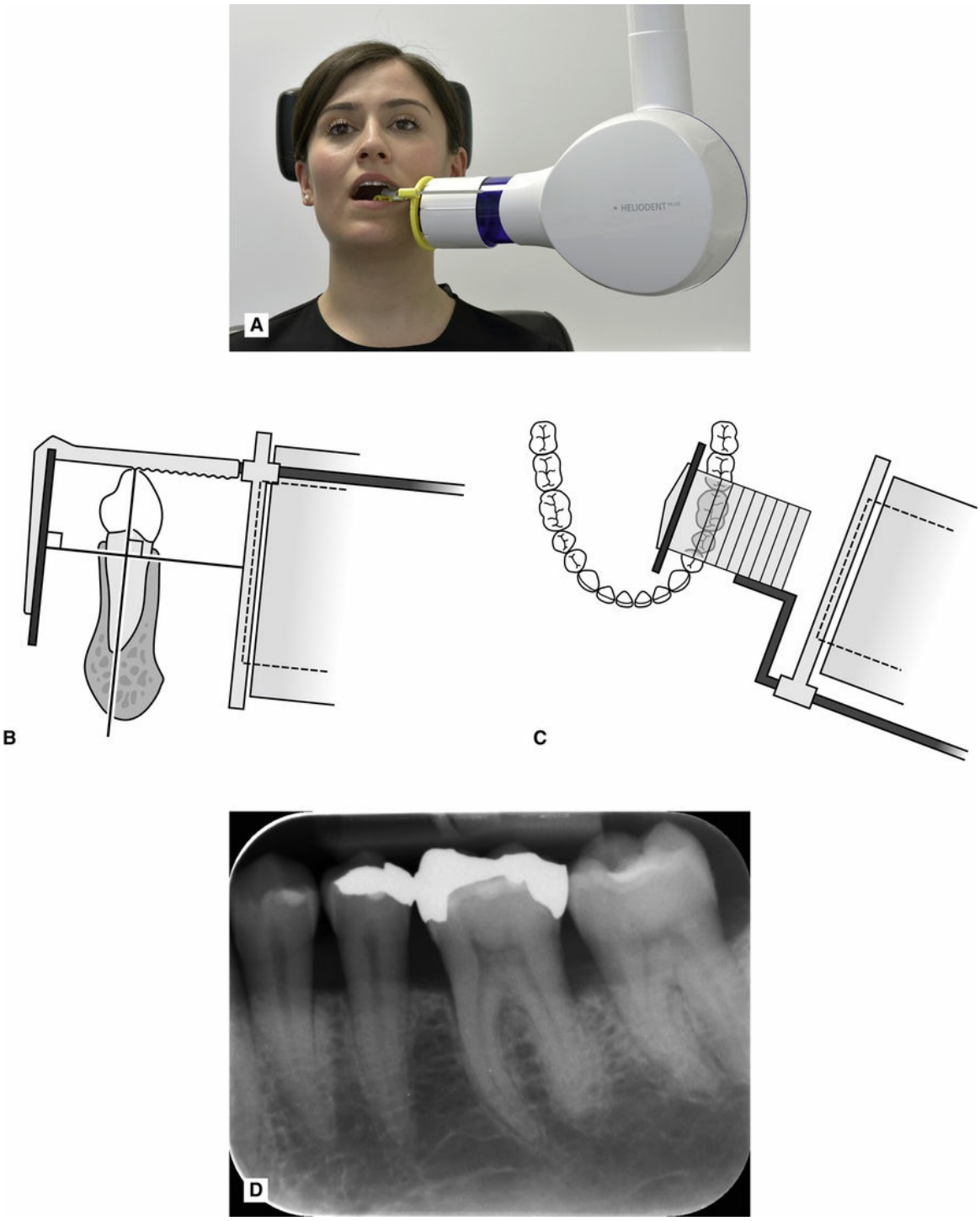


FIG. 9.15 Mandibular premolars. **(A)** Patient positioning (mandibular premolars). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Mandibular molars

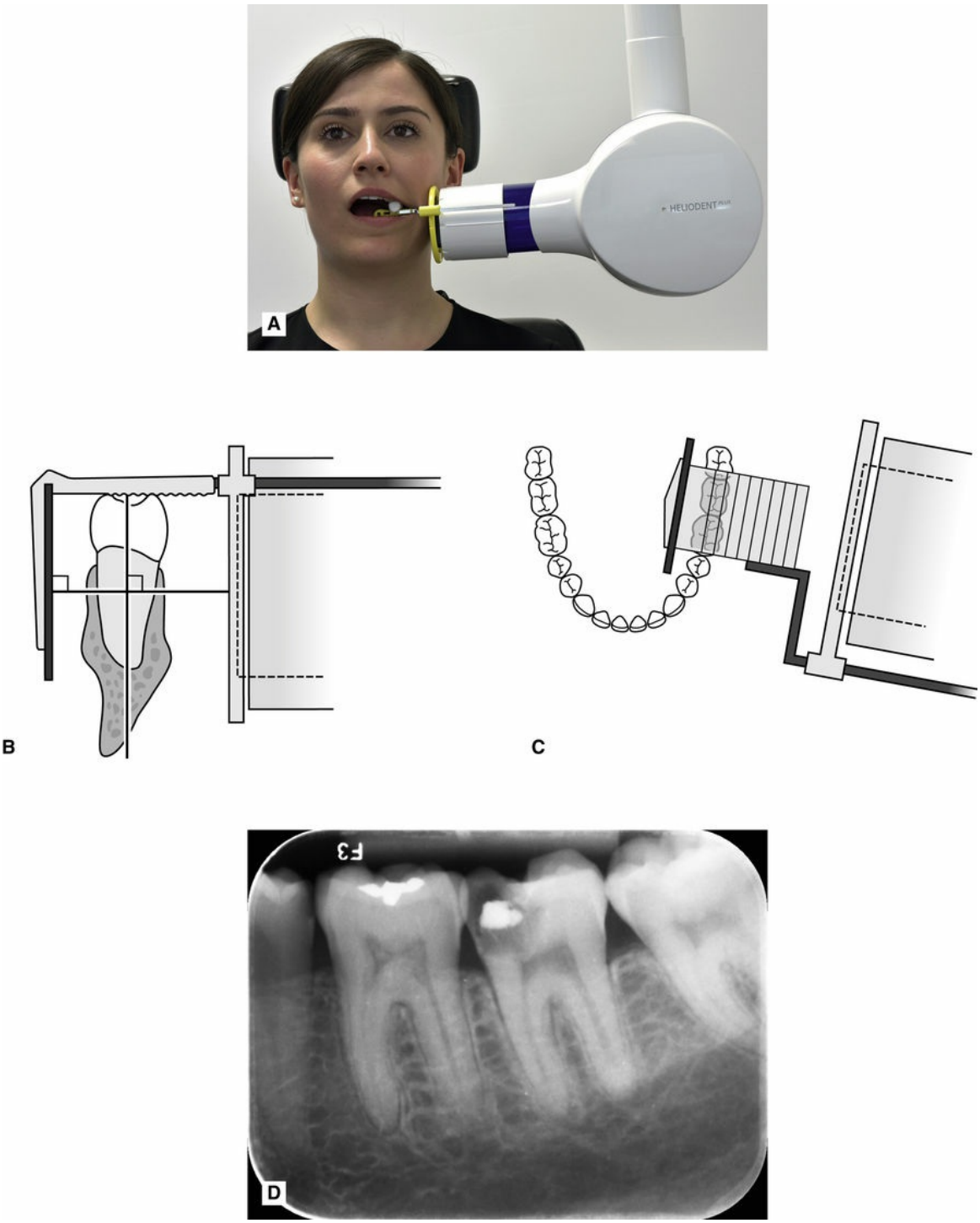


FIG. 9.16 Mandibular molars. **(A)** Patient positioning (mandibular molars). **(B)** Diagram of the positioning. **(C)** Plan view of the positioning. **(D)** Resultant radiograph.

Solid-state digital sensor positioning

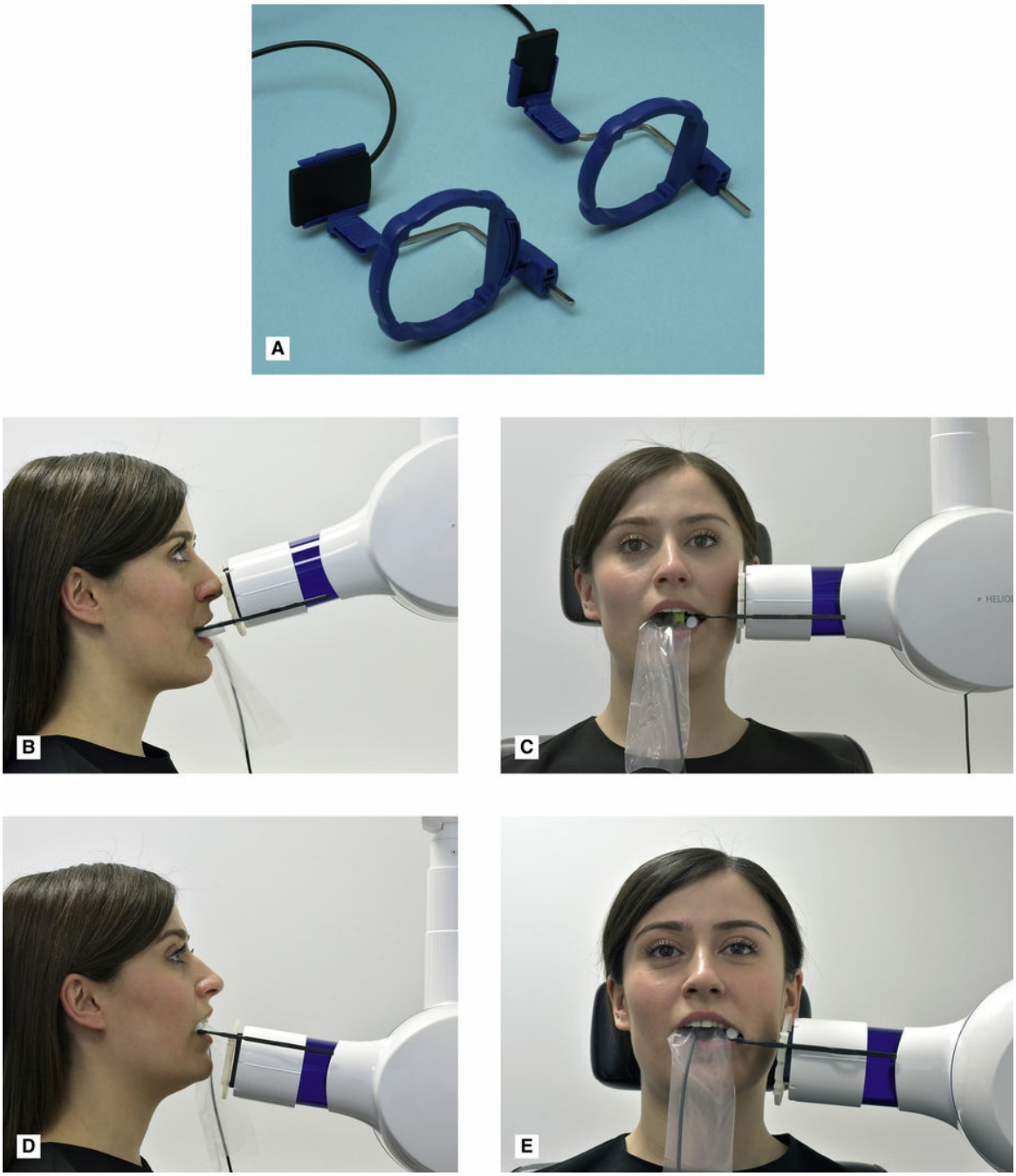


FIG. 9.17 Solid-state digital sensor positioning. **(A)** Anterior and posterior Planmeca solid-state sensor holders and their clinical positioning for **(B)** Maxillary incisors. **(C)** Maxillary molars. **(D)** Mandibular incisors and **(E)** Mandibular molars.

Anatomy

Normal maxillary and mandibular anatomical features often evident on anterior and posterior periapical radiographs are shown in Figs. 9.18 –9.21 .

Normal Maxillary Anatomy

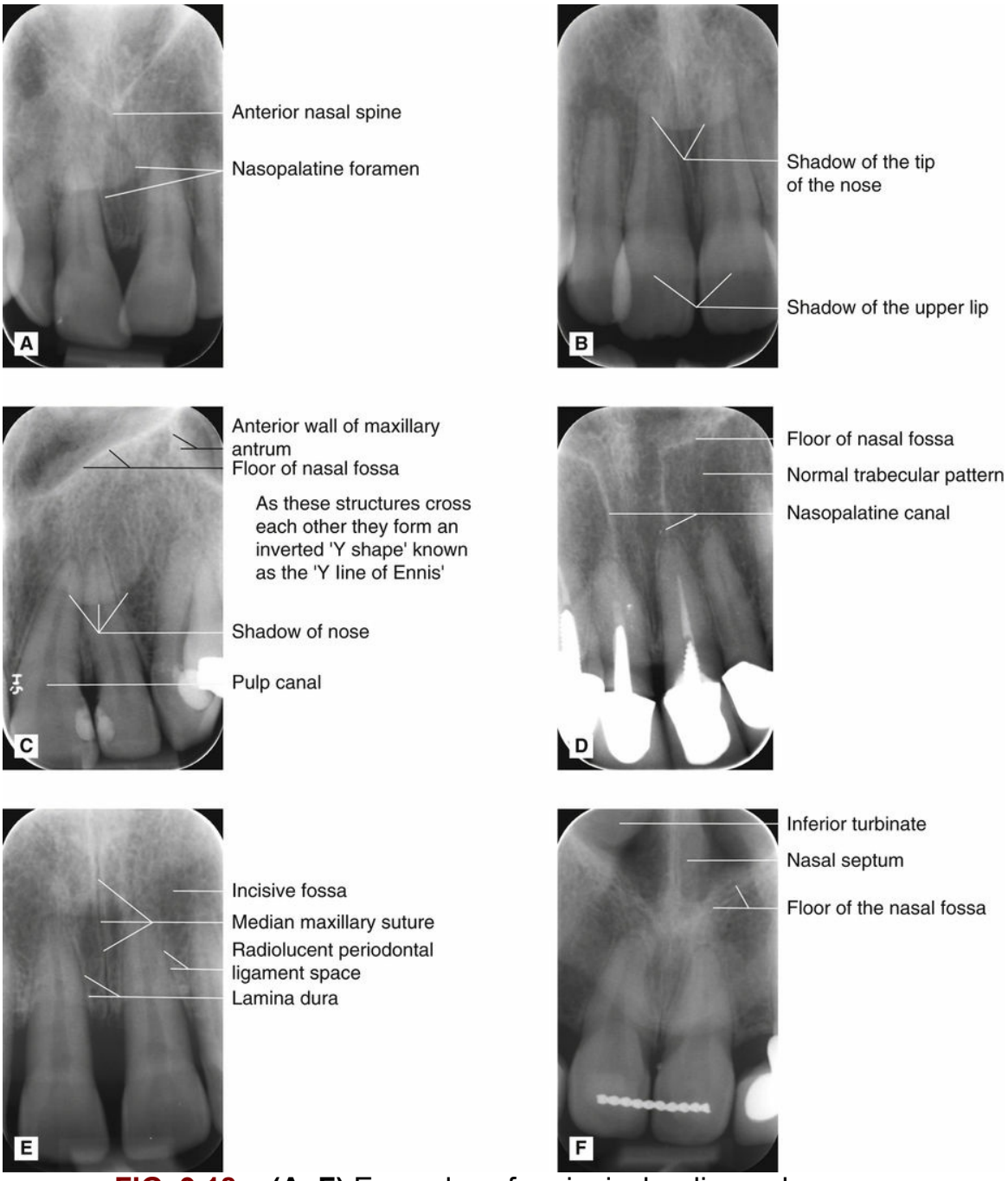


FIG. 9.18 **(A–F)** Examples of periapical radiographs showing various normal anatomical structures in the anterior maxilla.

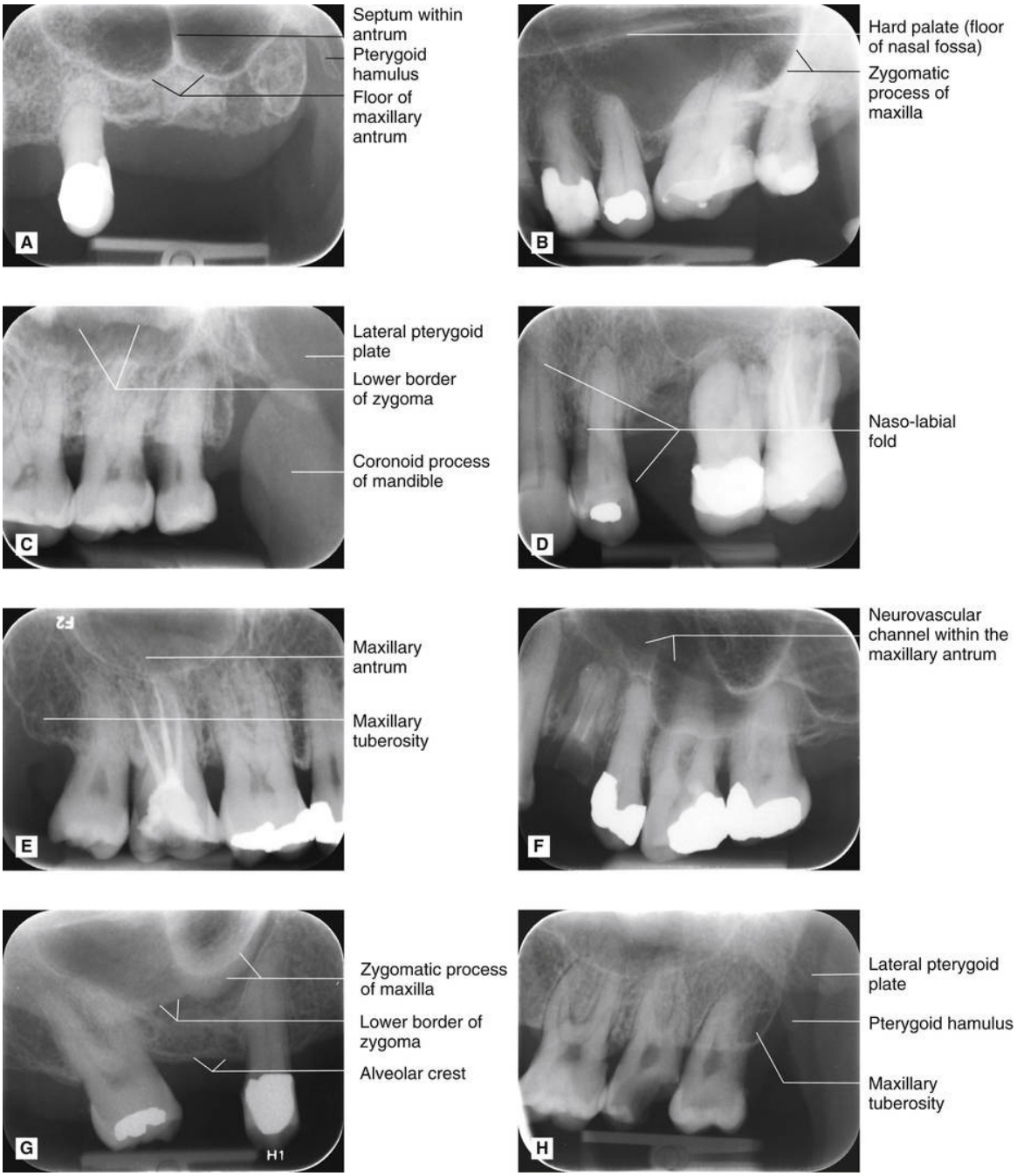


FIG. 9.19 **(A–H)** Examples of periapicals showing various normal anatomical structures in the posterior maxilla.

Normal Mandibular Anatomy

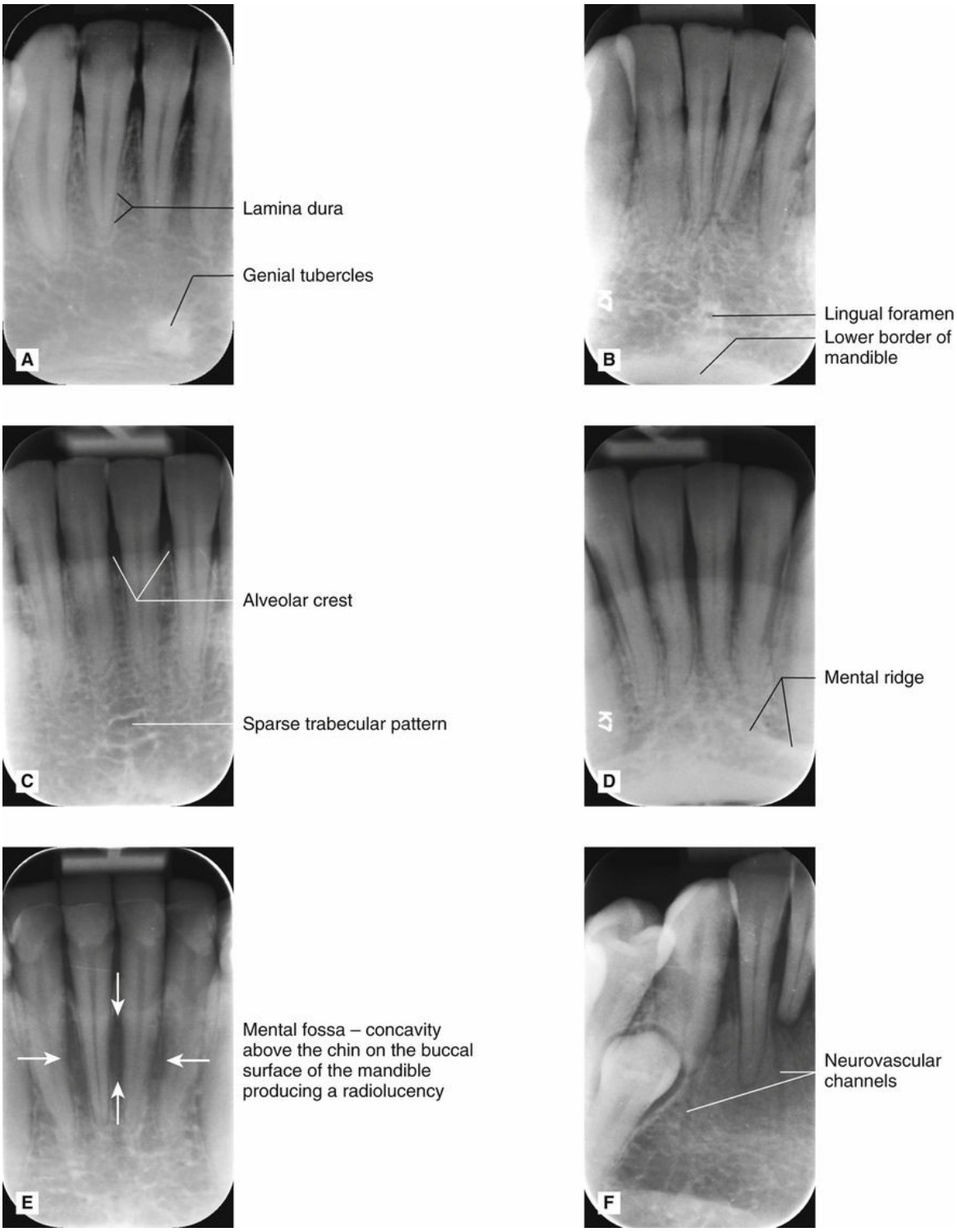


FIG. 9.20 **(A–F)** Examples of periapicals showing various normal anatomical structures in the anterior mandible.

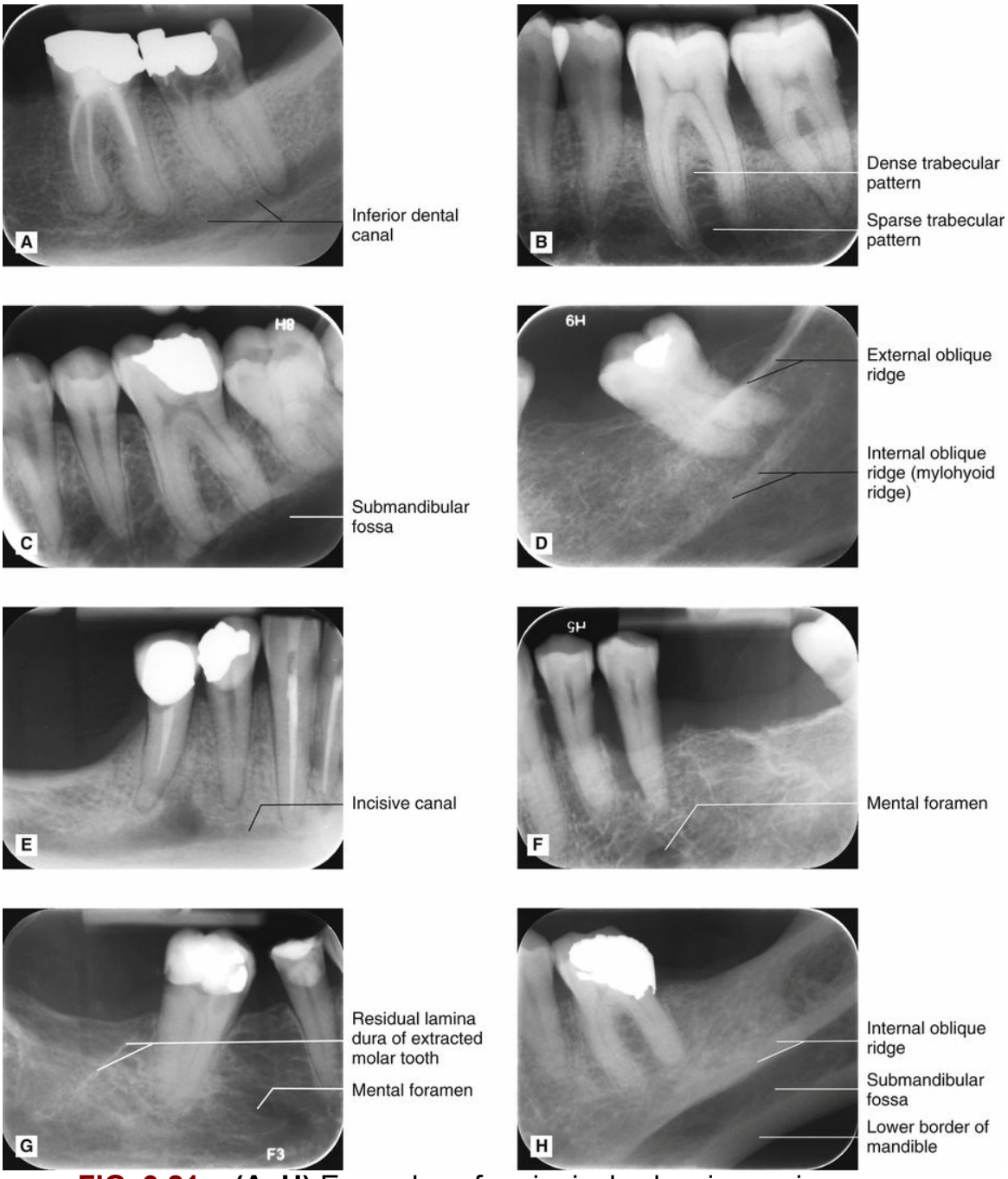


FIG. 9.21 **(A–H)** Examples of periapicals showing various normal anatomical structures in the posterior mandible.

Bisected Angle Technique

Theory

The theoretical basis of the bisected angle technique is shown in Fig. 9.22 and can be summarized as follows:

1. The image receptor is placed as close to the tooth under investigation as possible without bending the receptor.
2. The angle formed between the long axis of the tooth and the long axis of the image receptor is assessed and mentally bisected.
3. The X-ray tubehead is positioned at right angles to this bisecting line with the central ray of the X-ray beam aimed through the tooth apex.
4. Using the geometrical principle of similar triangles, the actual length of the tooth in the mouth will be equal to the length of the tooth on the image.

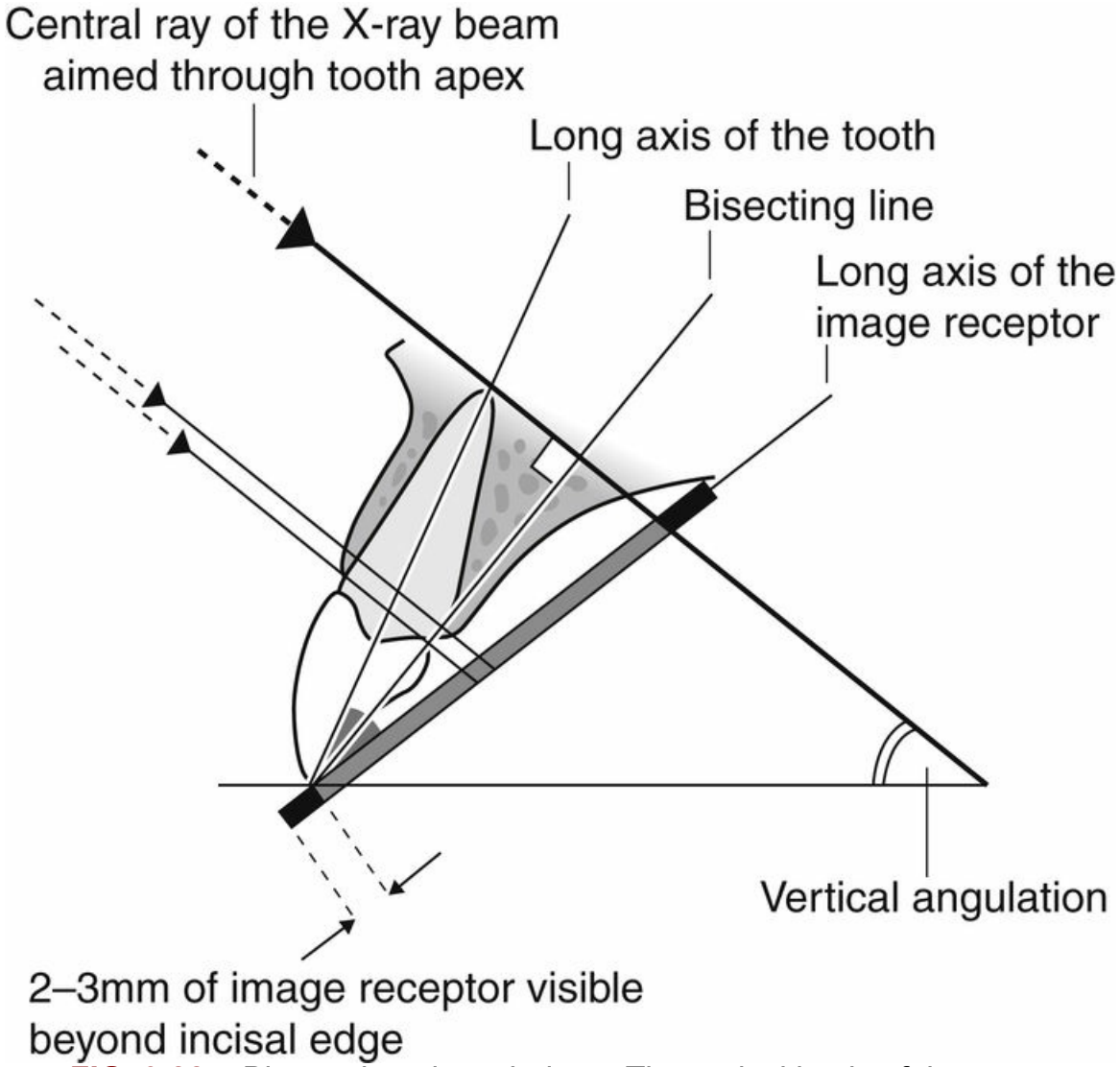


FIG. 9.22 Bisected angle technique. Theoretical basis of the bisected angle technique. The angle between the long axis of the tooth and image receptor is bisected and X-ray beam aimed at right angles to this line, through the apex of the tooth. With this geometrical arrangement, the length of the tooth in the mouth is equal to the length of the image of the tooth on the image receptor, but, as shown, the periodontal bone levels will not be represented accurately.

Vertical Angulation of the X-ray Tubehead

The angle formed by continuing the line of the central ray until it meets the occlusal plane determines the *vertical angulation* of the X-ray

beam to the occlusal plane (see Fig. 9.22).

NOTE: Vertical angles are often quoted but inevitably they are only approximate. Patient differences including head position and individual tooth position and inclination mean that each positioning should be assessed independently. The vertical angulations suggested later should be taken only as a general guide.

Horizontal Angulation of the X-ray Tubehead

In the horizontal plane, the central ray should be aimed through the interproximal contact areas, to avoid overlapping the teeth. The *horizontal angulation* is therefore determined by the shape of the arch and the position of the teeth (see Fig. 9.23).

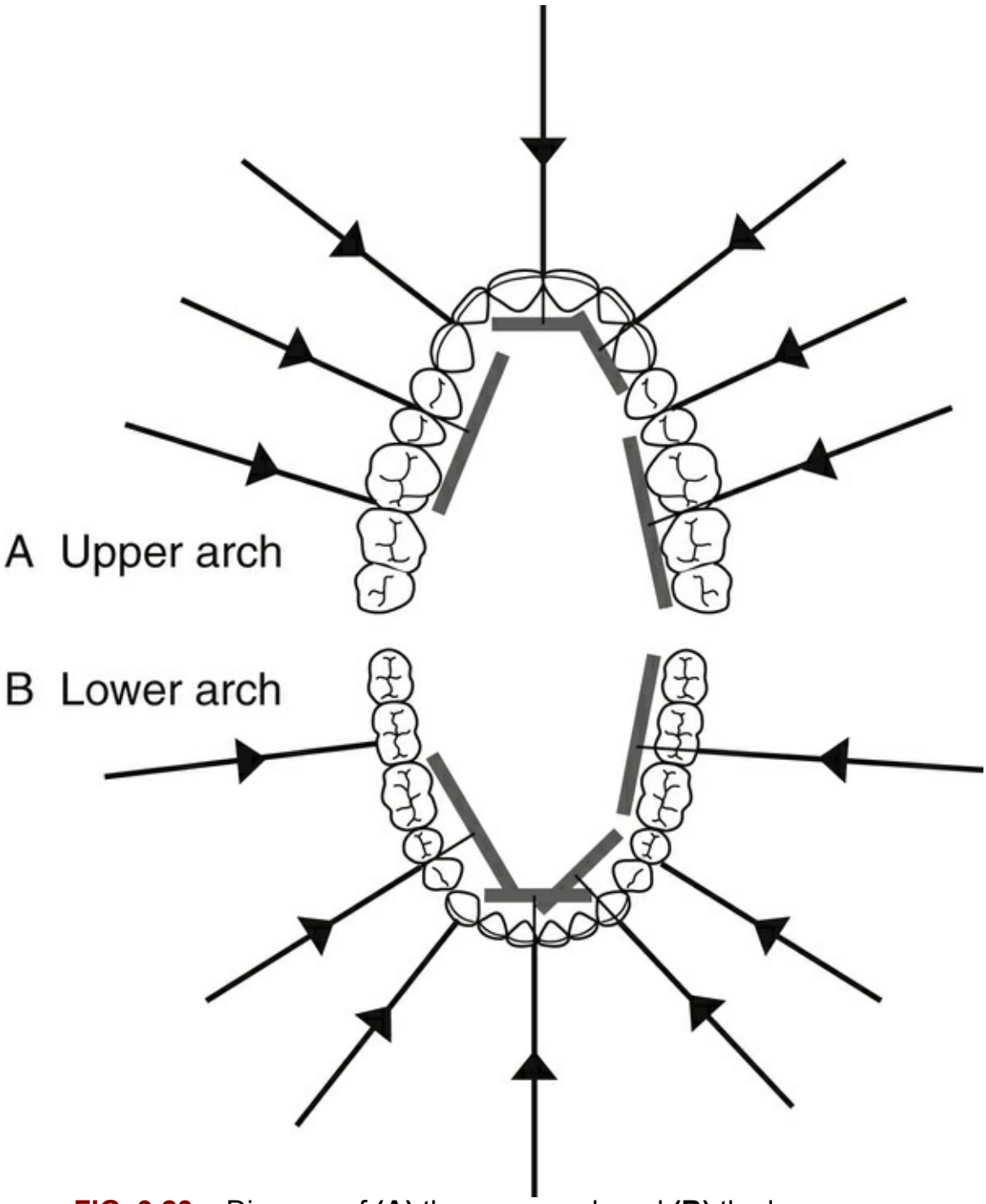


FIG. 9.23 Diagram of **(A)** the upper arch and **(B)** the lower arch. The various horizontal angulations of the X-ray beam are shown.

Positioning Techniques

The bisected angle technique can be performed either by using an image receptor holder to support the image receptor in the patient's mouth or by asking the patient to support the image receptor **gently** using either an index finger or thumb. Both techniques are described.

It is, however, good practice that the image receptor should be held by the patient only when it cannot otherwise be kept in position.

Using Digital Sensor/Film Packet Holders

Various holders are available, a selection of which are shown in Fig. 9.24 . The Rinn Bisected Angle Instruments closely resemble the paralleling technique holders and consist of the same three basic components – image receptor holding mechanism, bite block and an X-ray beam-aiming device – but the image receptor is not held parallel to the teeth. The more simple holders and the disposable bite blocks hold the image receptor in the desired position but the X-ray tubehead then has to be aligned independently. In summary:

1. The image receptor is pushed securely into the chosen holder. Either a large or small size of image receptor is used so that the particular tooth being examined is in the middle of the receptor (see Fig. 9.25). When using a film packet the white surface faces the X-ray tubehead and the film orientation dot is opposite the crown.
2. The X-ray tubehead is positioned using the beam-aiming device if available OR the operator has to assess the *vertical* and *horizontal angulations* by observation and then position the tubehead without a guide.
3. The exposure is made.

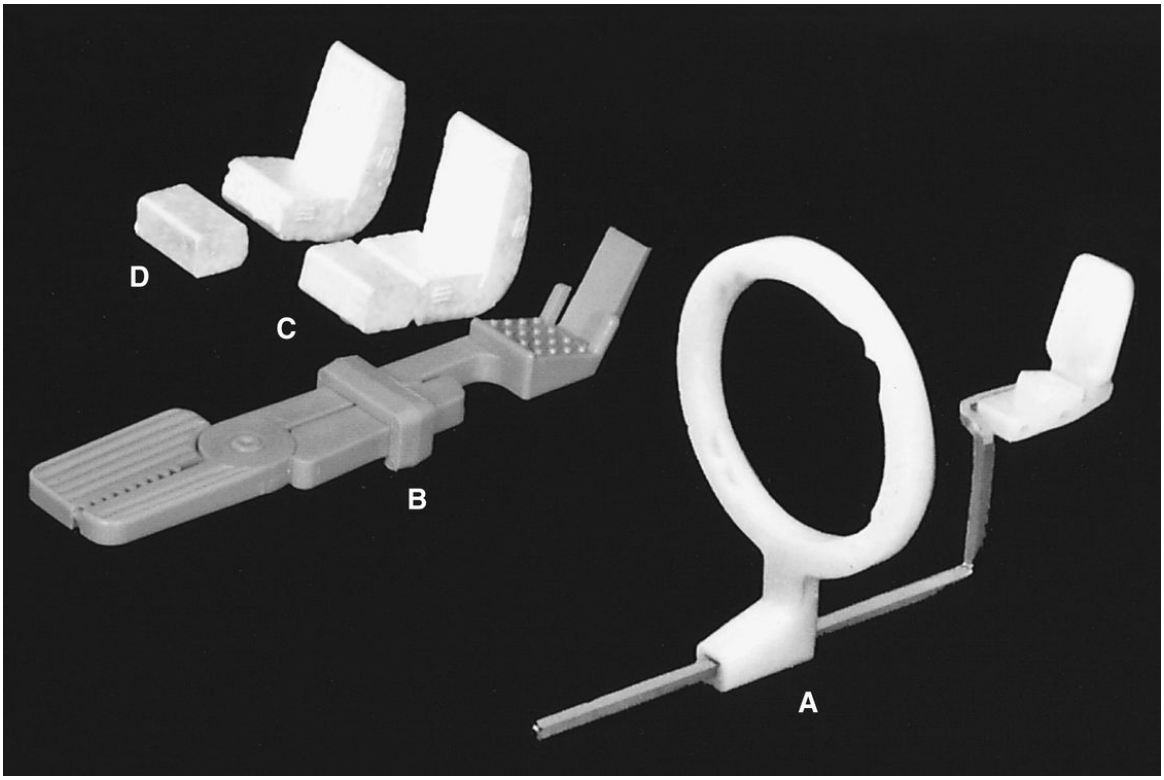


FIG. 9.24 A selection of phosphor plate/film packet holders for the bisected angle technique. **(A)** The Rinn® bisected angle instrument. **(B)** The Emmenix® film holder. **(C)** The Rinn Stabe® bite block. **(D)** The Rinn Stabe® bite block reduced in size for easier positioning and for use in children.

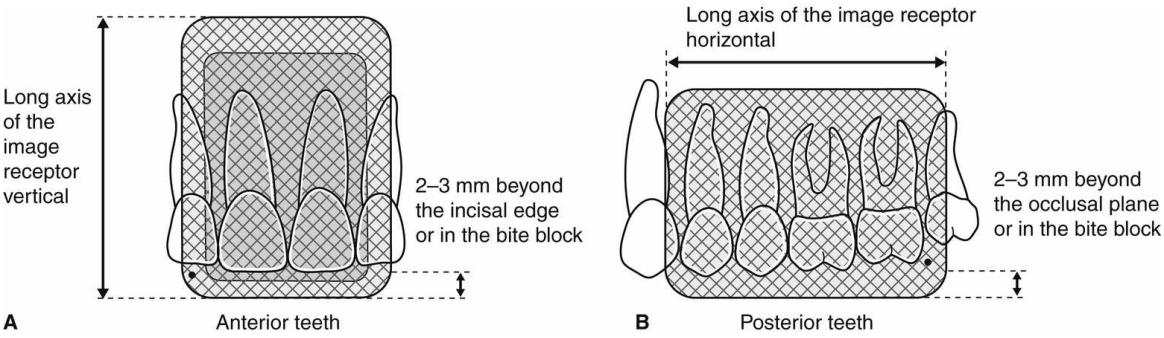


FIG. 9.25 Diagrams showing the general requirements of the image receptor position. **(A)** Anterior teeth using a large or small image receptor with its long axis vertically. **(B)** Posterior teeth with the large image receptor with its long axis horizontally.

Using the Patient's Finger

1. The appropriate sized image receptor is positioned and orientated in the mouth as was shown in Fig. 9.22 with about 2 mm extending beyond the incisal or occlusal edges, to ensure that all of the tooth will appear on the image. The patient is then asked to gently support the image receptor using either an index finger or thumb.
2. The operator then assesses the *vertical* and *horizontal angulations* by observation and positions the tubehead without a guide. The effects of incorrect tubehead position are shown in Fig. 9.26 .
3. The exposure is made.

The specific positioning for different areas of the mouth, using both simple holders and the patient's finger to support the image receptor, is shown in Figs. 9.27 –9.34 .

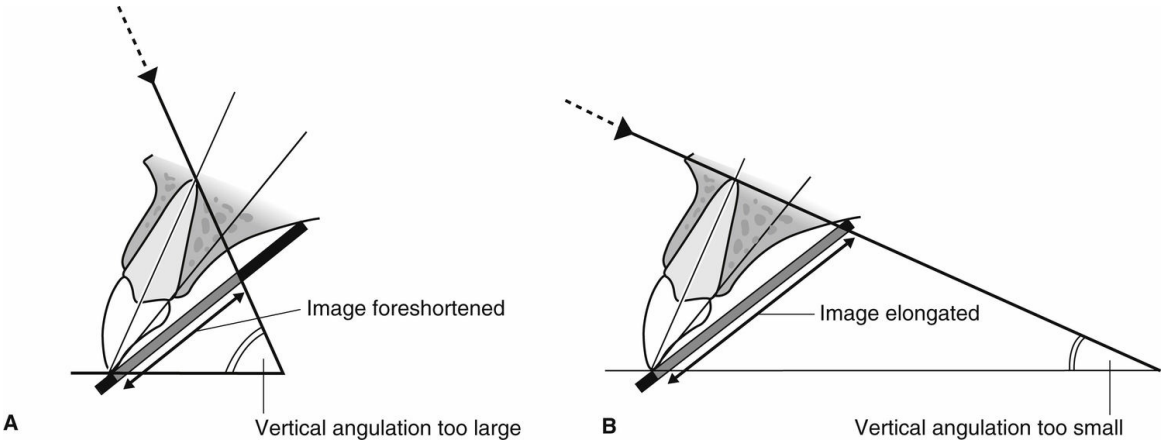


FIG. 9.26 Diagrams showing the effects of incorrect vertical tubehead positioning. **(A)** Foreshortening of the image. **(B)** Elongation of the image.

Positioning Using Digital Phosphor Plates and Film Packets

Maxillary central incisors


A


B

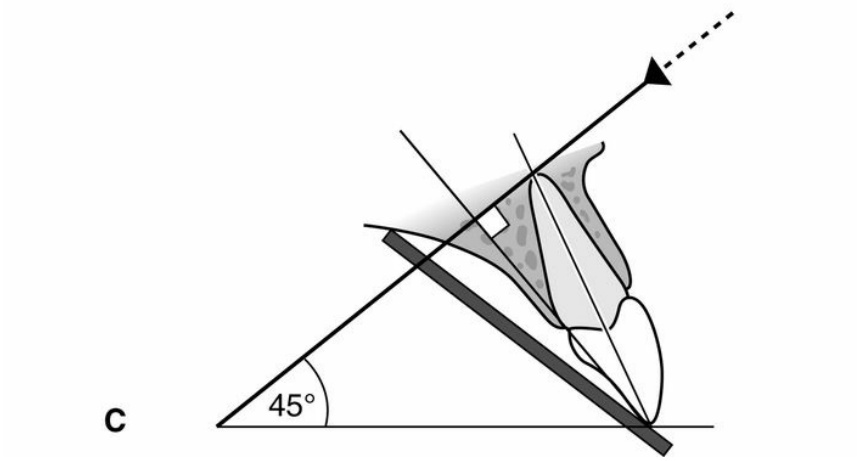

45°
C

FIG. 9.27 Maxillary central incisors. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient supporting the image receptor with the ball of the left thumb. **(C)** Diagram of the relative positions of the image receptor, maxillary incisor and X-ray beam.

Maxillary canine


A


B

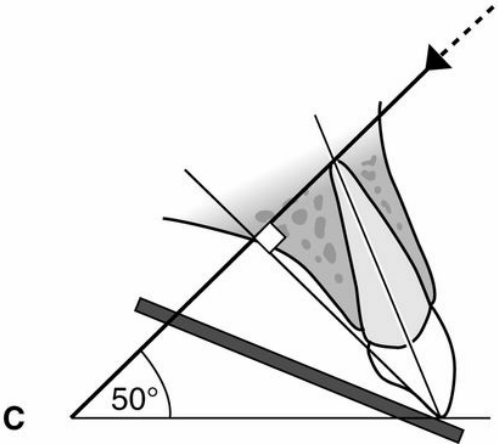

50°
C

FIG. 9.28 Maxillary canine. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient supporting the image receptor with the ball of the right index finger. **(C)** Diagram of the relative positions of the image receptor, maxillary canine and X-ray beam.

Maxillary premolars


A


B

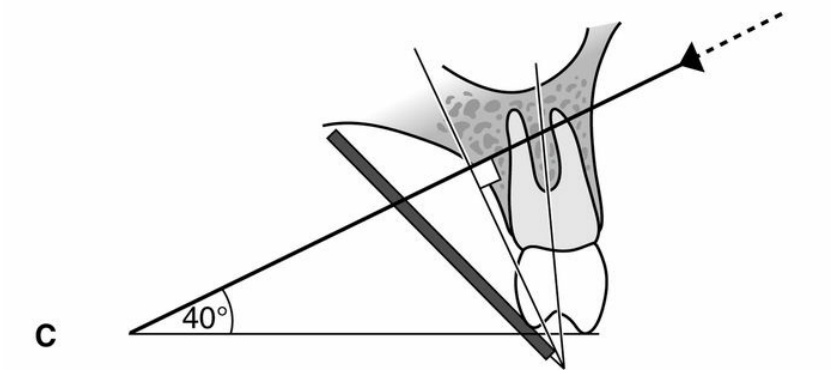

40°
C

FIG. 9.29 Maxillary premolars. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient supporting the image receptor. **(C)** Diagram of the relative positions of the image receptor, maxillary premolar and X-ray beam.

Maxillary molars


A


B

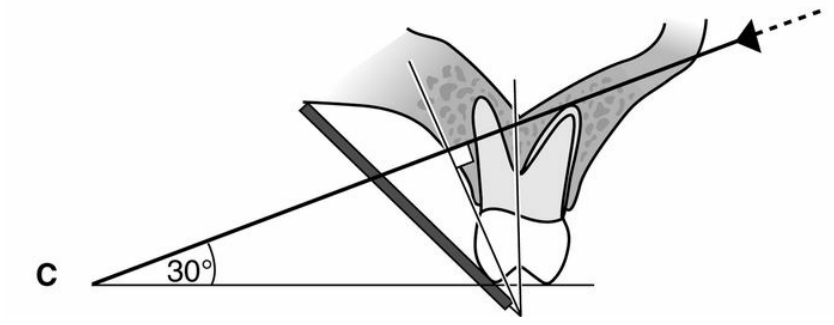
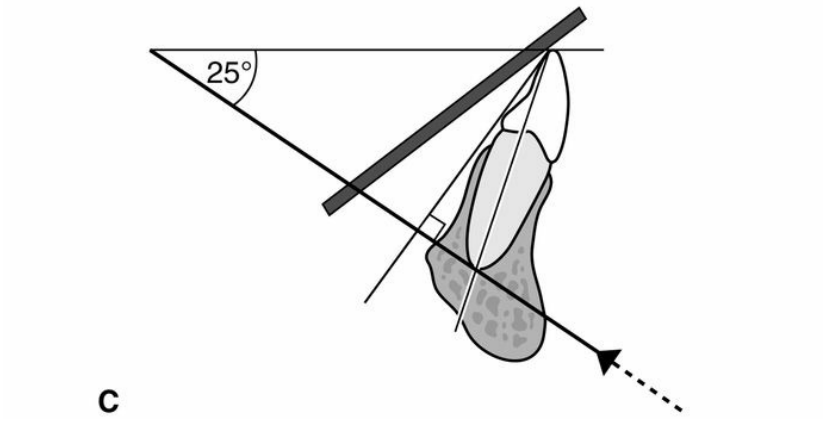

C
30°

FIG. 9.30 Maxillary molars. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient supporting the image receptor. **(C)** Diagram of the relative positions of the image receptor, maxillary molar and X-ray beam.

Mandibular incisors







C

FIG. 9.31 Mandibular incisors. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient's index finger on the upper edge of the image receptor, supporting and depressing it into the floor of the mouth. **(C)** Diagram of the relative positions of the image receptor, mandibular incisor and X-ray beam.

Mandibular canine


A


B

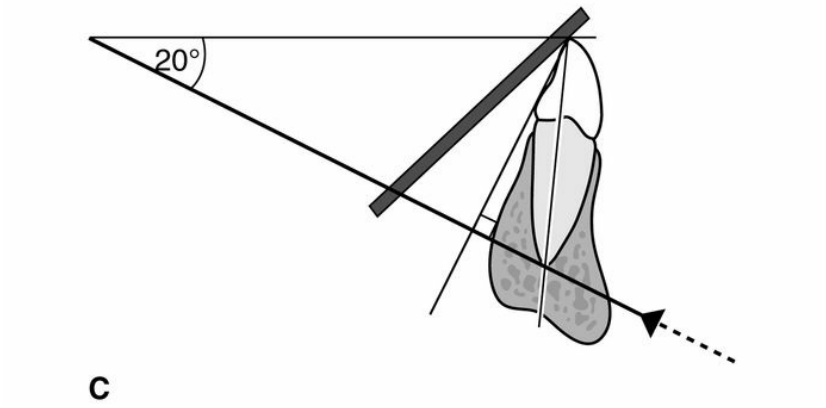

20°
C

FIG. 9.32 Mandibular canine. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient's index finger supporting and depressing the image receptor. **(C)** Diagram of the relative positions of the image receptor, mandibular canine and X-ray beam.

Mandibular premolars


A


B

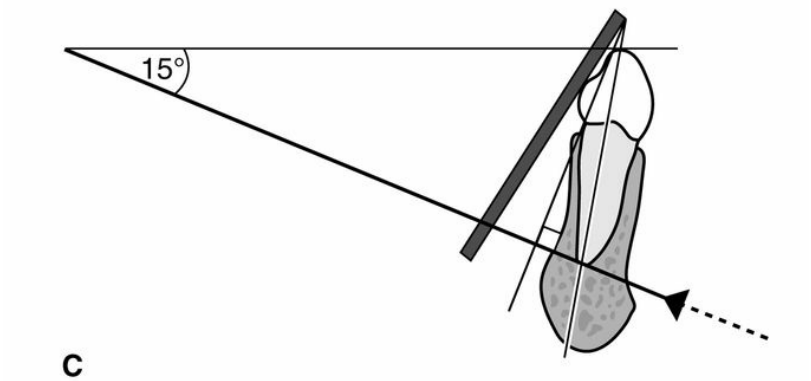
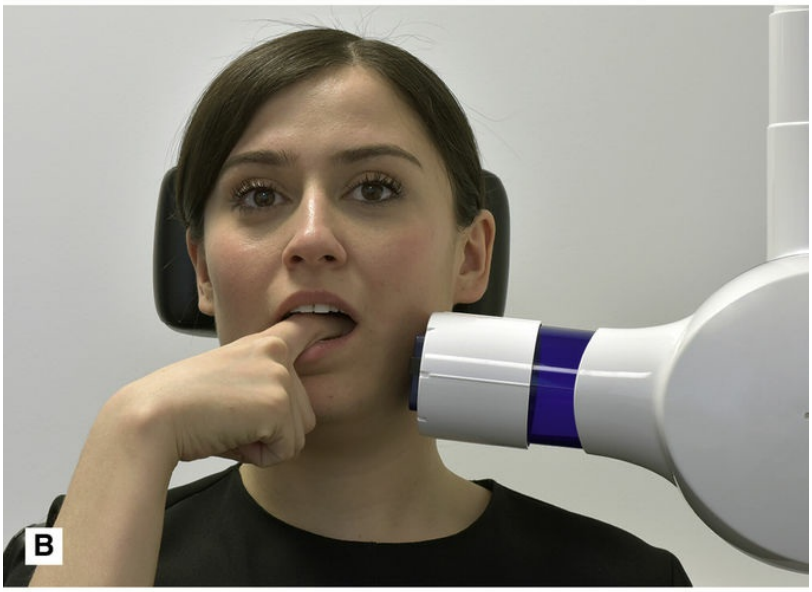

15°
C

FIG. 9.33 Mandibular premolars. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient's index finger supporting and depressing the image receptor. **(C)** Diagram of the relative positions of the image receptor, mandibular premolar and X-ray beam.

Mandibular molars


A


B

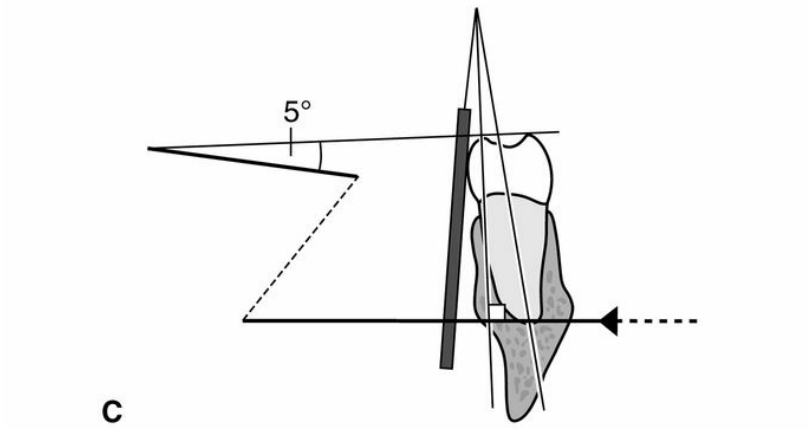

5°
C

FIG. 9.34 Mandibular molars. Patient positioning **(A)** using a Rinn Stabe® bite block to hold the image receptor and **(B)** with the patient's index finger supporting and depressing the image receptor. **(C)** Diagram of the relative positions of the image receptor, mandibular molar and X-ray beam.

Comparison of The Paralleling and Bisected Angle Techniques

The advantages and disadvantages of the two techniques can be summarized as follows.

Advantages of the Paralleling Technique

- Geometrically accurate images are produced with little magnification.
- The shadow of the zygomatic buttress appears above the apices of the molar teeth.
- The periodontal bone levels are well represented.
- The periapical tissues are accurately shown with minimal foreshortening or elongation.
- The crowns of the teeth are well shown enabling the detection of proximal caries.
- The horizontal and vertical angulations of the X-ray tubehead are automatically determined by the positioning devices if placed correctly.
- The X-ray beam is aimed accurately at the centre of the image receptor – all areas of the image receptor are irradiated and there is no *coning off* or *cone cutting.*
- Reproducible radiographs are possible at different visits and with different operators.
- The relative positions of the image receptor, teeth and X-ray beam are always maintained, irrespective of the position of the patient's head. This is useful for some patients with

disabilities.

Disadvantages of the Paralleling Technique

- Positioning of the image receptor can be very uncomfortable for the patient, particularly for posterior teeth, often causing gagging.
- Positioning the holders within the mouth can be difficult for inexperienced operators, particularly when using solid-state digital sensors.
- The anatomy of the mouth sometimes makes the technique impossible, e.g. a shallow, flat palate.
- The apices of the teeth can sometimes appear very near the edge of the image.
- Positioning the holders in the lower third molar regions can be very difficult.
- The technique cannot be performed satisfactorily using a short *focus-to-skin distance* (i.e. a short spacer cone) because of the resultant magnification.
- The holders need to be sterilizable or disposable.

Advantages of the Bisected Angle Technique

- Positioning of the image receptor is reasonably comfortable for the patient in all areas of the mouth.
- Positioning is relatively simple and quick.
- If all angulations are assessed correctly, the image of the tooth will be the same length as the tooth itself and should be *adequate* (but not ideal) for most diagnostic purposes.

Disadvantages of the Bisected Angle Technique

- The many variables involved in the technique often result in the image being badly distorted.

- Incorrect vertical tubehead angulation will result in foreshortening or elongation of the image.
- The periodontal bone levels are poorly shown.
- The shadow of the zygomatic buttress frequently overlies the roots of the upper molars.
- The horizontal and vertical angles have to be assessed by observation for every patient and considerable skill is required.
- It is not possible to obtain reproducible views.
- *Coning off* or *cone cutting* may result if the central ray is not aimed at the centre of the image receptor, particularly if using rectangular collimation.
- Incorrect horizontal tubehead angulation will result in overlapping of the crowns and roots.
- The crowns of the teeth are often distorted, thus preventing the detection of proximal caries.
- The buccal roots of the maxillary premolars and molars are foreshortened.

A visual comparison between the two techniques, showing how dramatic the variation in image quality and reproducibility can be, is shown in Figs. 9.35 and 9.36 .

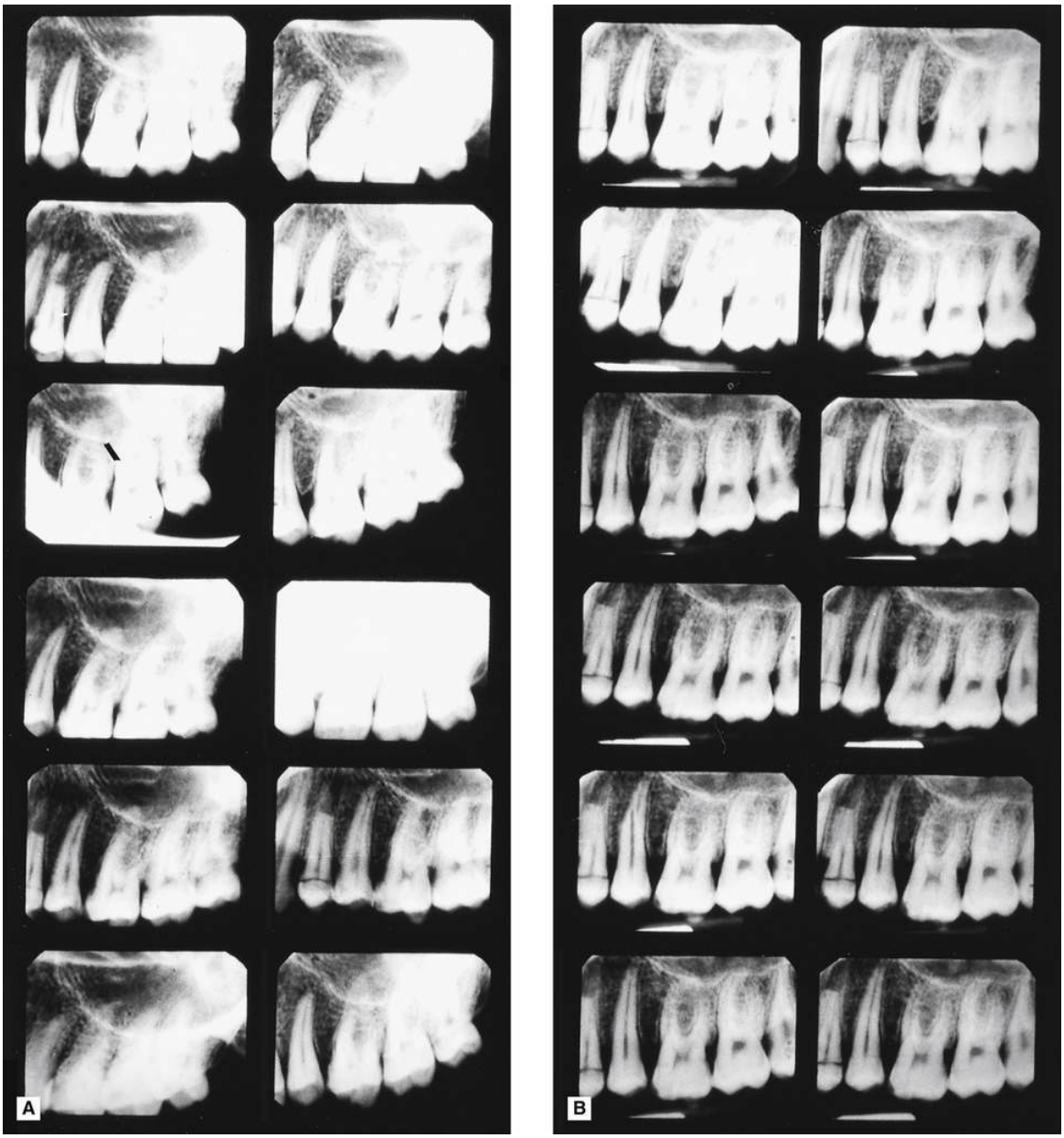
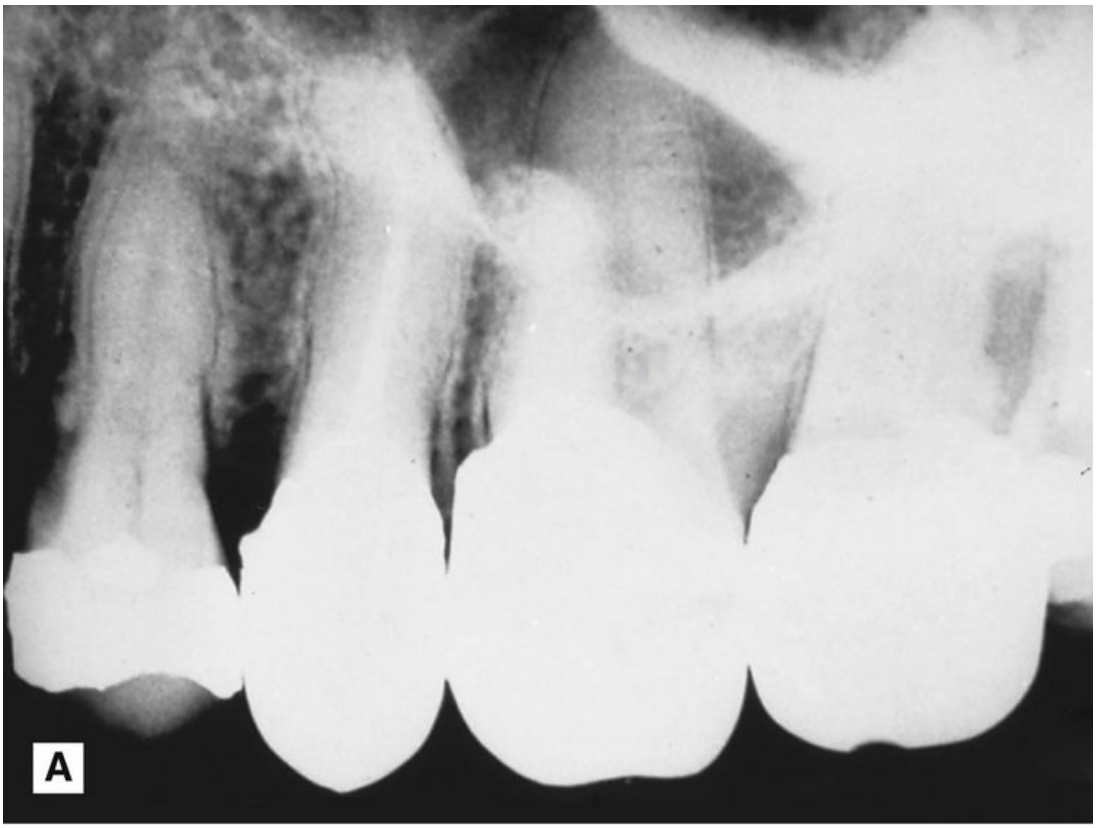


FIG. 9.35 **(A)** Bisected angle and **(B)** paralleling technique periapical radiographs of ⌊6, on a phantom head, taken by 12 *different* experienced operators. The obvious reproducibility and accurate imaging show why the paralleling technique should be regarded as the technique of choice.


A

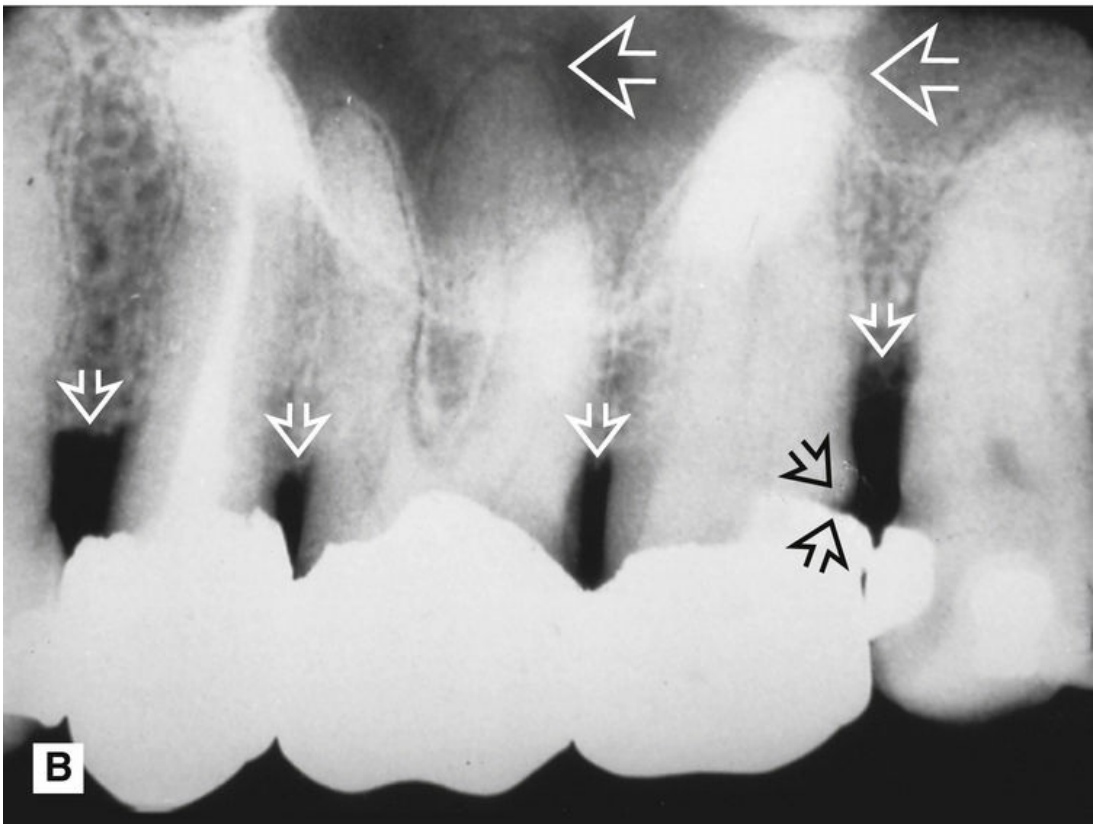

B

FIG. 9.36 **(A)** Bisected angle and **(B)** paralleling technique periapicals of the ⌊45678 taken on the *same* patient, by the *same* operator, on the *same* day. Note the difference in the periodontal bone levels (small white open arrows), the restoration in ⌊7 (black open arrows) and the apical tissues ⌊67 (large white open arrows).

Conclusion

The diagnostic advantages of the accurate, reproducible images produced by the paralleling technique using image receptor holders and beam-aiming devices ensure that this technique should be regarded as the technique of choice for periapical radiography. It is good practice that whenever practicable, techniques using image receptor holders with beam-aiming devices should be adopted.

Positioning Difficulties Often Encountered in Periapical Radiography

Placing the image receptor intraorally in the *textbook-described* positions is not always possible. The radiographic techniques described earlier often need to be modified. The main difficulties encountered involve:

- Mandibular third molars
- Gagging
- Endodontics
- Edentulous alveolar ridges
- Children
- Patients with disabilities (see Chapter 8).

Problems Posed by Mandibular Third Molars

The main difficulty is placement of the image receptor sufficiently posteriorly to record the entire third mandibular molar (particularly when it is horizontally impacted) **and** the surrounding tissues, including the inferior dental canal (see Fig. 9.37).

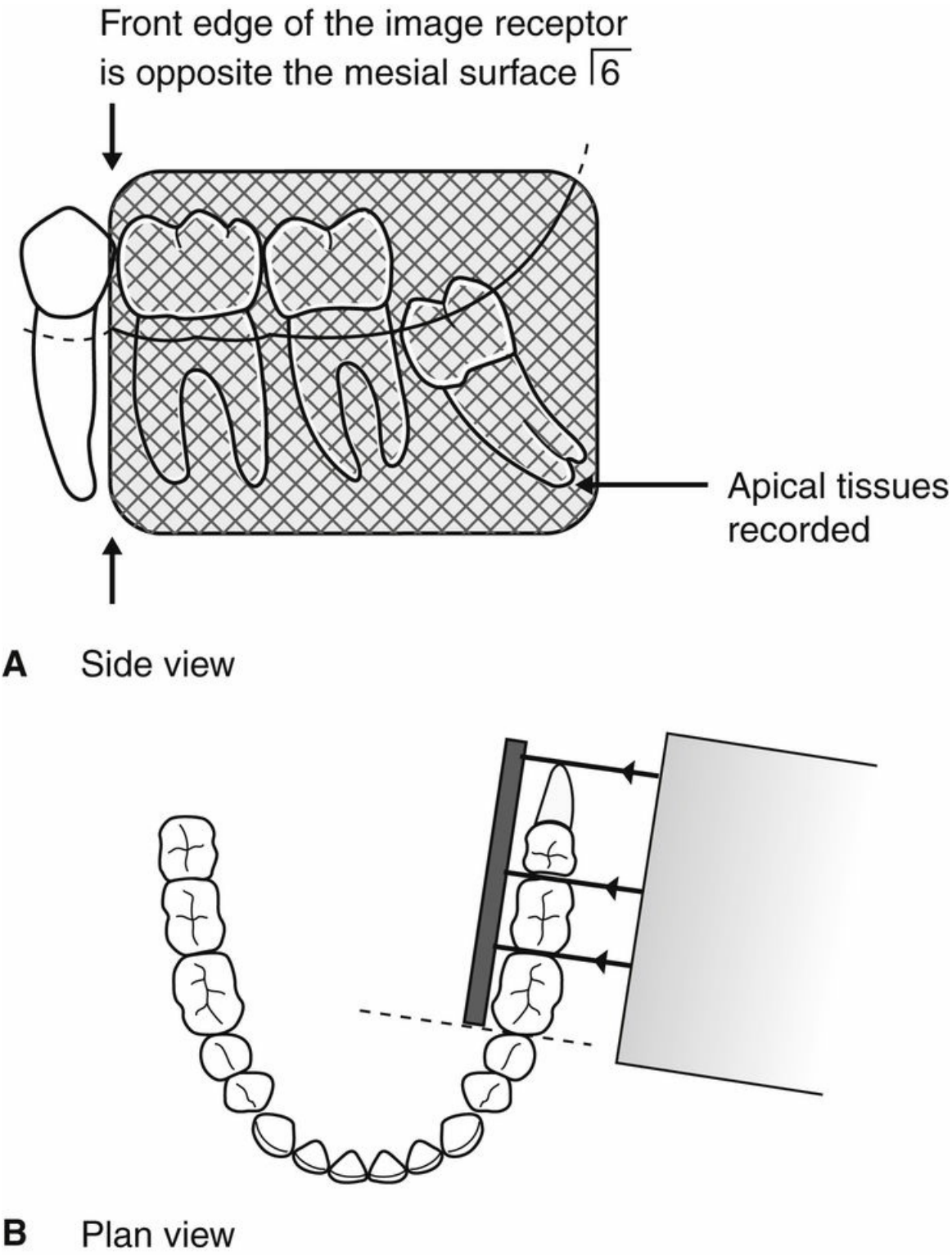


FIG. 9.37 **(A)** Side view and **(B)** plan view diagrams showing the ideal image receptor position for mandibular third molars to ensure the tooth and apical tissues are recorded.

Possible Solutions

These include:

- Using specially designed or adapted holders as shown in Fig. 9.38 to hold and position the image receptor in the mouth, as follows:
    1. The holder is clipped securely onto the top edge of the image receptor.
    2. With the patient's mouth open, the image receptor is positioned gently in the lingual sulcus as far posteriorly as possible.
    3. The patient is asked to close the mouth (so relaxing the tissues of the floor of the mouth) and at the same time the image receptor is eased further back into the mouth, if required, until its front edge is opposite the mesial surface of the mandibular first molar.
    4. The patient is asked to bite on the holder and to support it in position.
    5. The X-ray tubehead is positioned at right angles to the third molar and the image receptor and centred 1 cm up from the lower border of the mandible, on a vertical line dropped from the outer corner of the eye (see Fig. 9.38).
- Taking two radiographs of the third molar using two different horizontal tubehead angulations, as follows:
    1. The image receptor is positioned as posteriorly as possible (using the technique described with the holders).
    2. The X-ray tubehead is aimed with the *ideal* horizontal angulation so the X-ray beam passes between the second and third molars. (With horizontally impacted third molars, the apex may not be recorded using this positioning, as shown in Fig. 9.39 .)

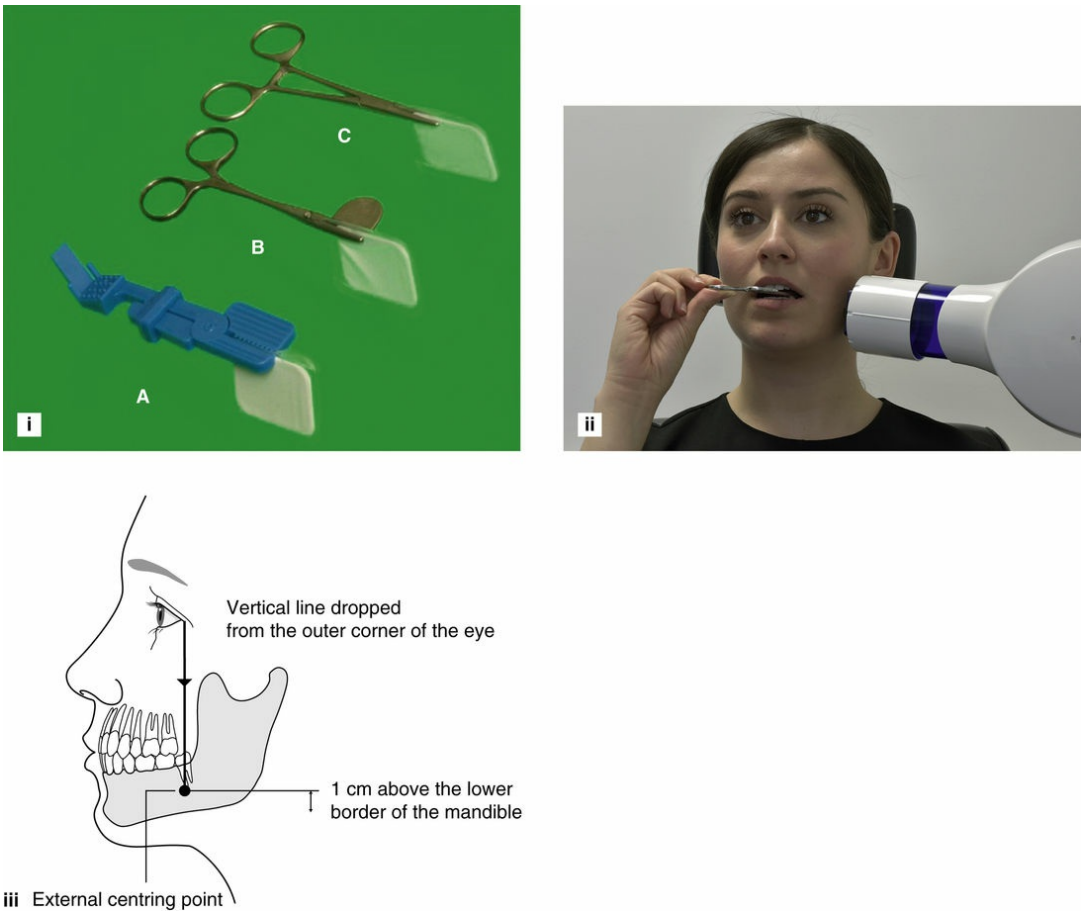


FIG. 9.38 (i) A selection of film packet/phosphor plate holders for mandibular third molars: **(A)** Emmenix® film holder, **(B)** Worth film holder and **(C)** a conventional pair of artery forceps. (ii) Patient positioning – having closed the mouth, the patient is stabilizing the image receptor holder with a hand. **(iii)** Diagram indicating the external centring point for the X-ray beam.

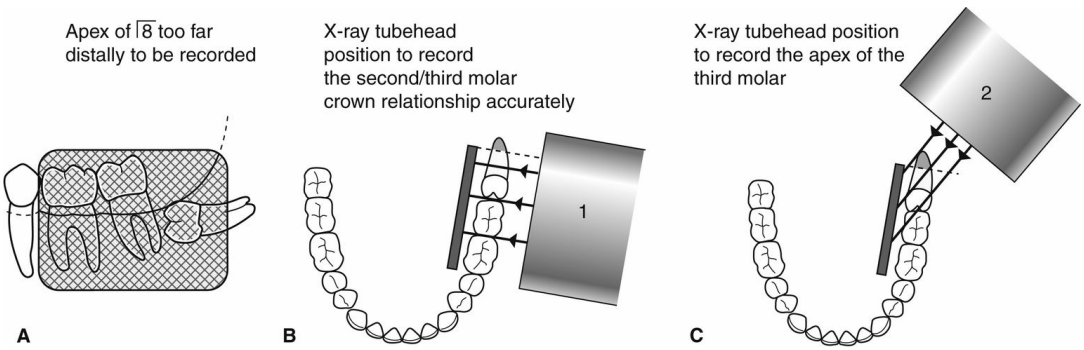


FIG. 9.39 The problem of the horizontal third molar.

(A) Side view showing the often achievable image receptor position. **(B)** Plan view showing X-ray tubehead position 1. **(C)** Plan view showing X-ray tubehead position 2.

3. A *second* image receptor is placed in the same position as before, but the X-ray tubehead is positioned further posteriorly aiming forwards to project the apex of the third molar on to the receptor. (With this positioning, the crowns of the second and third molars will be overlapped, as shown in Fig. 9.39 .)

NOTE: The vertical angulation of the X-ray tubehead is the same for both projections.

Problems of Gagging

The gag reflex is particularly strong in some patients. This makes the placement of the image receptor in the desired position particularly difficult, especially in the upper and lower molar regions.

Possible Solutions

These include:

- Patient sucking a local anaesthetic lozenge before attempting to position the image receptor
- Asking the patient to concentrate on breathing deeply while the image receptor is in the mouth
- Placing the image receptor flat in the mouth (in the occlusal plane) so it does not touch the palate, and applying the principles of the bisected angle technique – the long axes of the tooth and image receptor are assessed by observation and the X-ray tubehead's position modified accordingly, as shown in Fig. 9.40 .

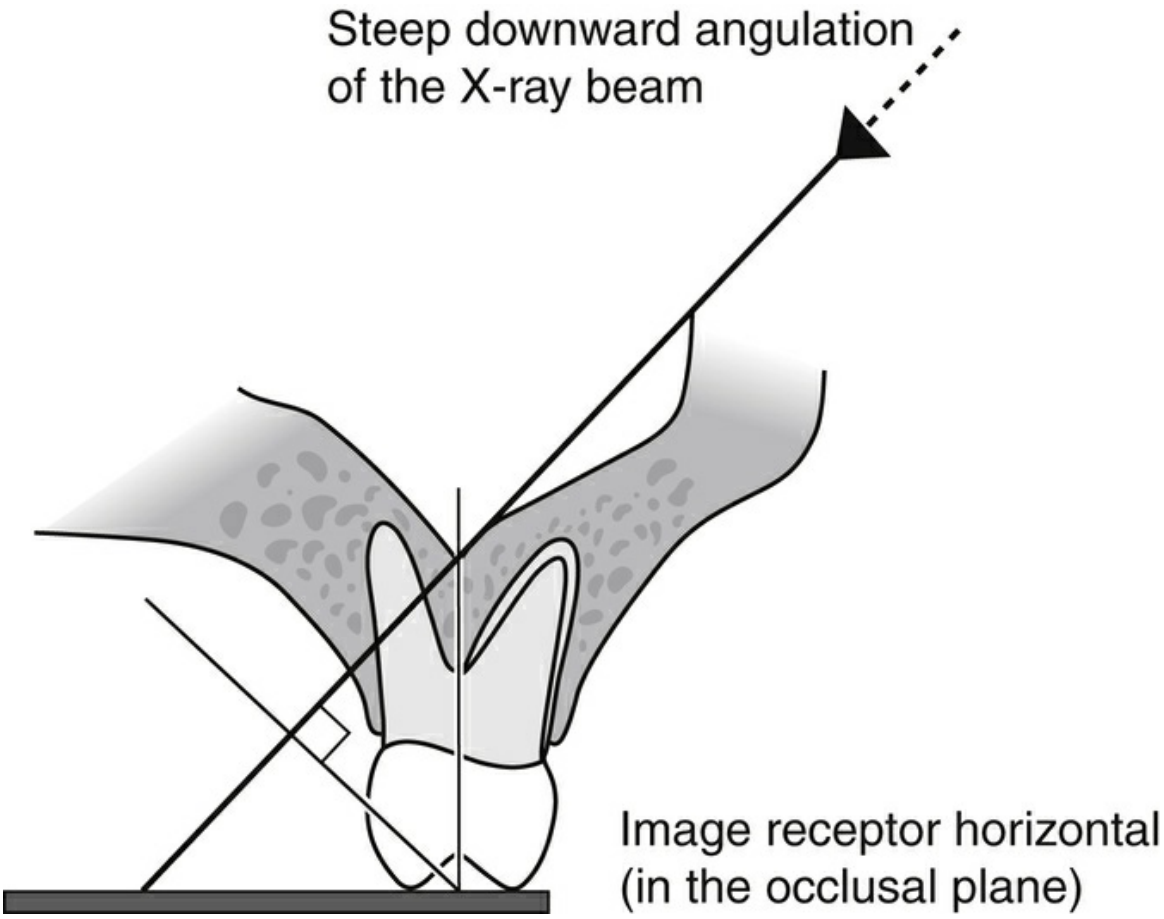


FIG. 9.40 Diagram showing the relative position of the X-ray beam to the maxillary molar and receptor, when the image receptor is placed in the occlusal plane. Note: The length of the image of the tooth on the radiograph should again equal the length of the tooth in the mouth. However, there will be considerable distortion of the surrounding tissues.

Problems Encountered During Endodontics

The main difficulties involve:

- Image receptor placement and stabilization when endodontic instruments, rubber dam and rubber dam clamps are in position
- Identification and separation of root canals
- Assessing root canal lengths from foreshortened or elongated radiographs.

Possible Solutions

These include:

- The problem of image receptor placement and stabilization can be solved by:
  - – Using a simple image receptor holder such as the Rinn Eezee-Grip®, as shown in Fig. 9.41 . This is positioned in the mouth and then held in place by the patient.
  - – Using one of the special endodontic image receptor holders that have been developed. These incorporate a modified bite platform area, to accommodate the handles of the endodontic instruments, while still allowing the image receptor and the tooth to be parallel (see Fig. 9.42).
- The problem of identifying and separating the root canals can be solved by taking at least two radiographs, using different horizontal X-ray tubehead positions (see Fig. 9.43).

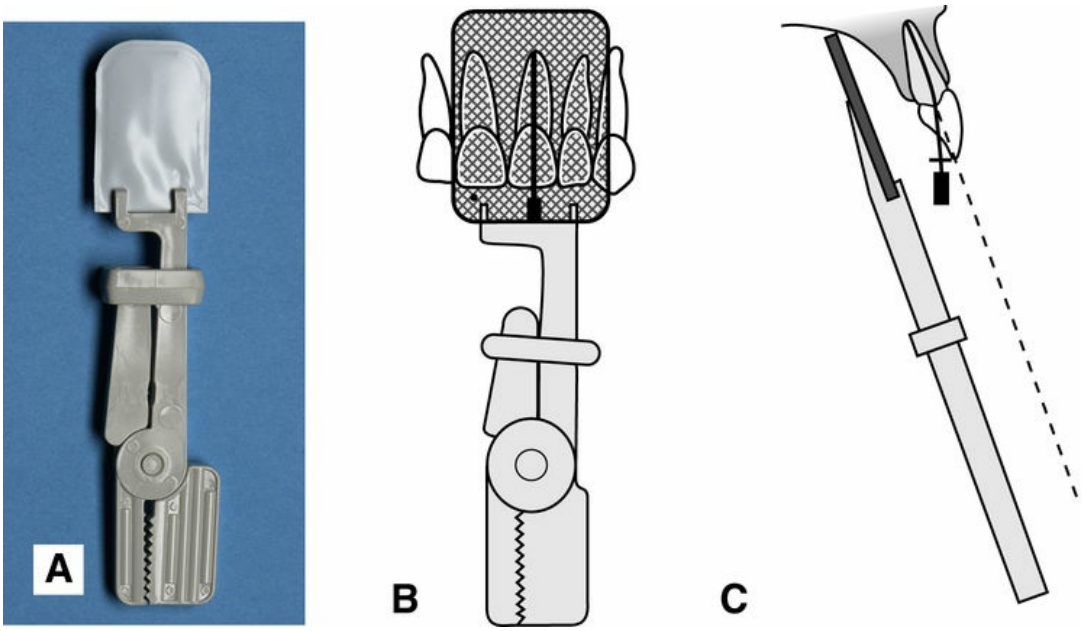


FIG. 9.41 **(A)** The Rinn Eezee-Grip® film/phosphor plate holder. **(B)** and **(C)** Diagrams showing its use in

endodontics.
Note: rubber dam not shown.

- The problems of assessing root canal length can be solved by:
  - Taking an accurate paralleling technique periapical preoperatively and measuring the lengths of the root(s) directly from the radiograph before beginning the endodontic treatment. The amount of distortion on subsequent films can then be assessed.
  - Calculating mathematically the actual length of a root canal from a distorted bisected angle technique periapical taken with the diagnostic instrument within the root canal at the clinically assessed apical *stop.*

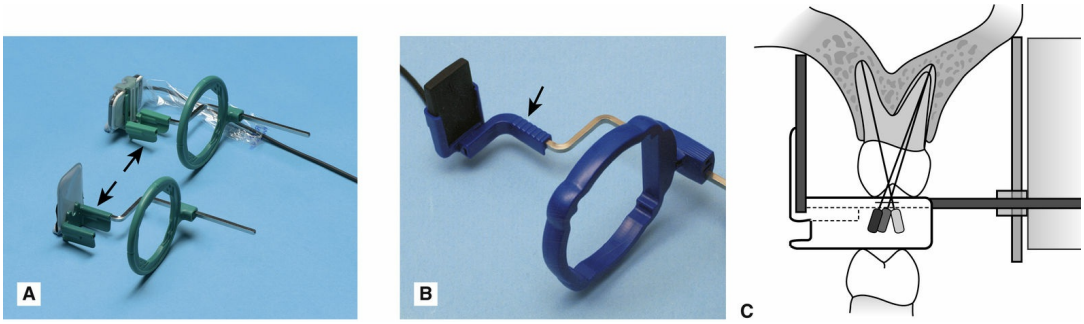


FIG. 9.42 Specially designed image receptor holders and beam-aiming devices for use during endodontics. (A) Rinn Endoray® suitable for film packets and digital phosphor plates and solid–state digital sensors. (B) Anterior Planmeca solid-state digital sensor holder. Note the modified designs of the biteblocks (arrowed) to accommodate the handles of the endodontic instruments. Colour coding of instruments by some manufacturers is now used to facilitate clinical use. (C) Diagram of the Rinn Endoray® in place.

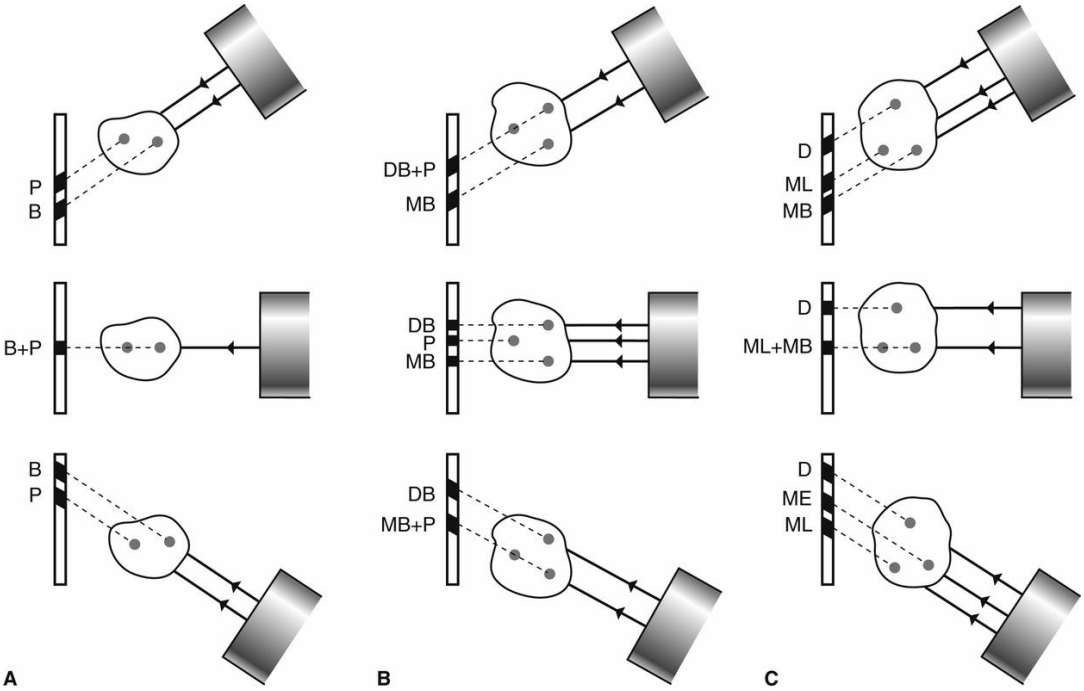


FIG. 9.43 Diagrams showing the effect of different horizontal X-ray tubehead positions on root separation for **(A)** maxillary premolars, **(B)** maxillary first molars and **(C)** mandibular first molars. (The images of the canals are designated: P = palatal, B = buccal, MB = mesiobuccal, DB = distobuccal, ML = mesiolingual and D = distal.)

The calculation is done as follows (see Fig. 9.44):

1. Measure:
    a. The radiographic tooth length
    b. The radiographic instrument length
    c. The actual instrument length
2. Substitute the measurements into the formula:

$$\text{Actual Tooth Length} = \frac{\text{Radiographic Tooth Length} \times \text{Actual Instrument Length}}{\text{Radiographic Instrument Length}}$$

3. Calculate the *actual tooth length* and adjust the working length of the instrument as necessary.

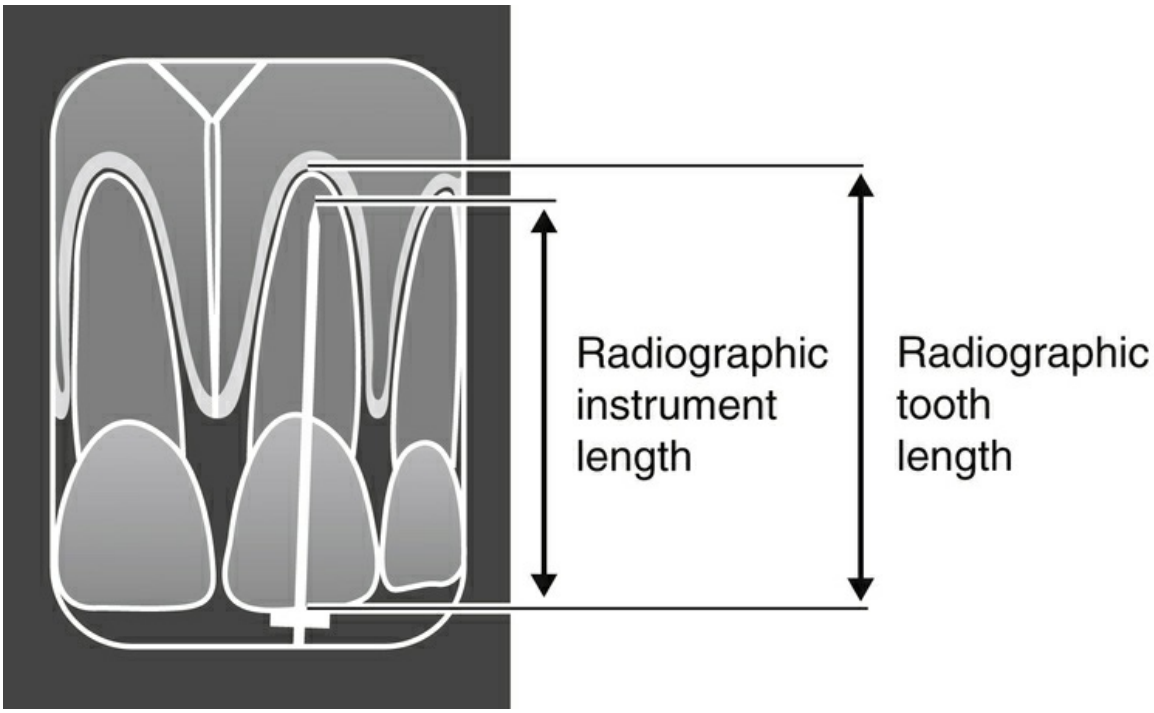


FIG. 9.44 Diagram showing the required radiographic measurements in endodontics to calculate the actual tooth length.

Problems of the Edentulous Ridge

The main difficulty in the edentulous and partially dentate patient is again image receptor placement.

Possible Solutions

These include:

- In edentulous patients, the lack of height in the palate, or loss of lingual sulcus depth, contraindicates the paralleling technique and all periapical radiographs should be taken using a modified bisected angle technique. The long axes of

the image receptor and the alveolar ridge are assessed by observation and the X-ray tubehead position adjusted accordingly (see Fig. 9.45).

- In partially dentate patients, the paralleling technique can usually be used. If the edentulous area causes the image receptor holder to be displaced, the deficiency can be built up by using cotton wool rolls (see Fig. 9.46).

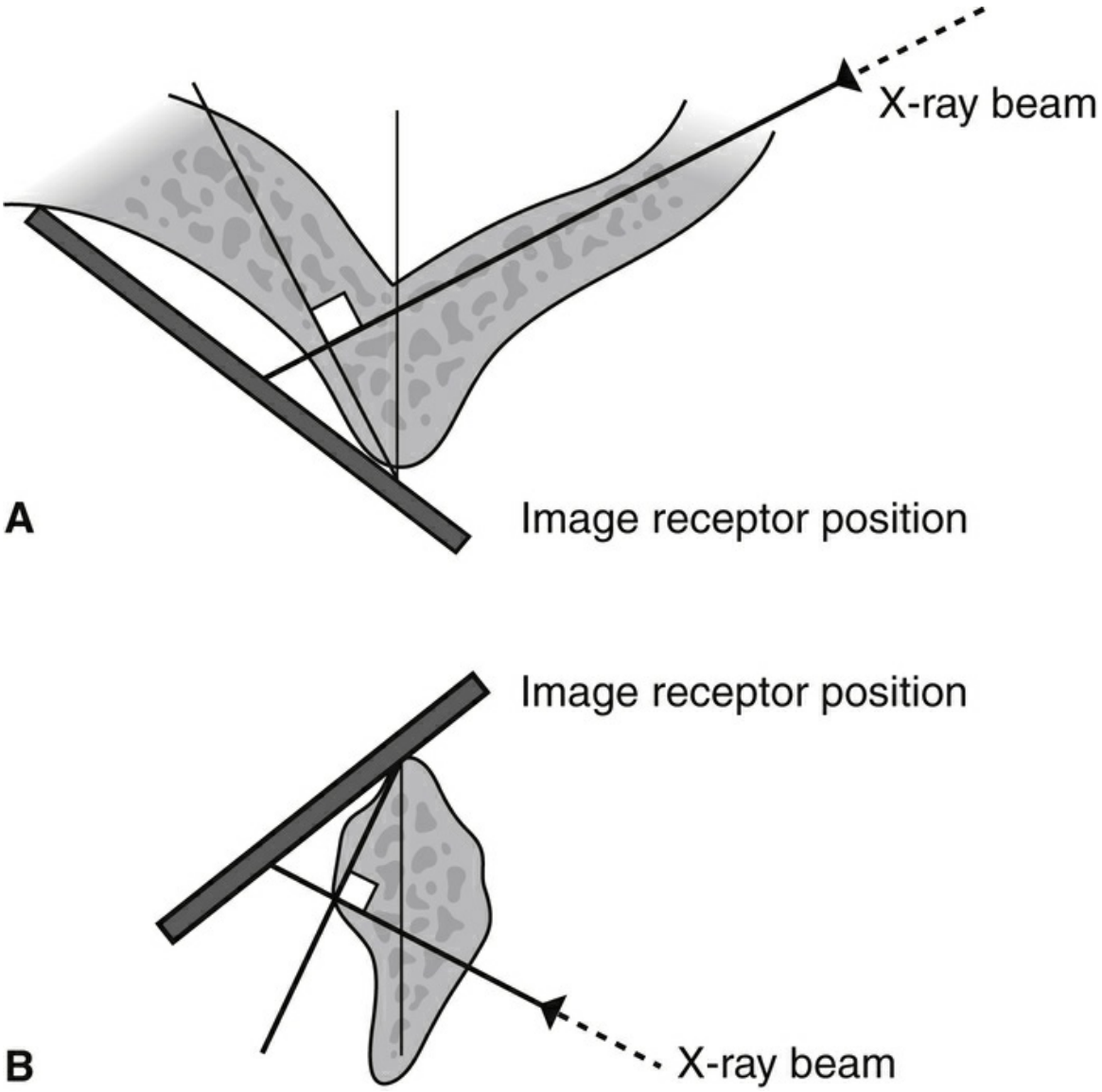


FIG. 9.45 Diagrams showing the relative position of the image receptor and X-ray beam. **(A)** For the molar region of an edentulous maxillary ridge. **(B)** For the molar region of an

edentulous mandibular ridge.

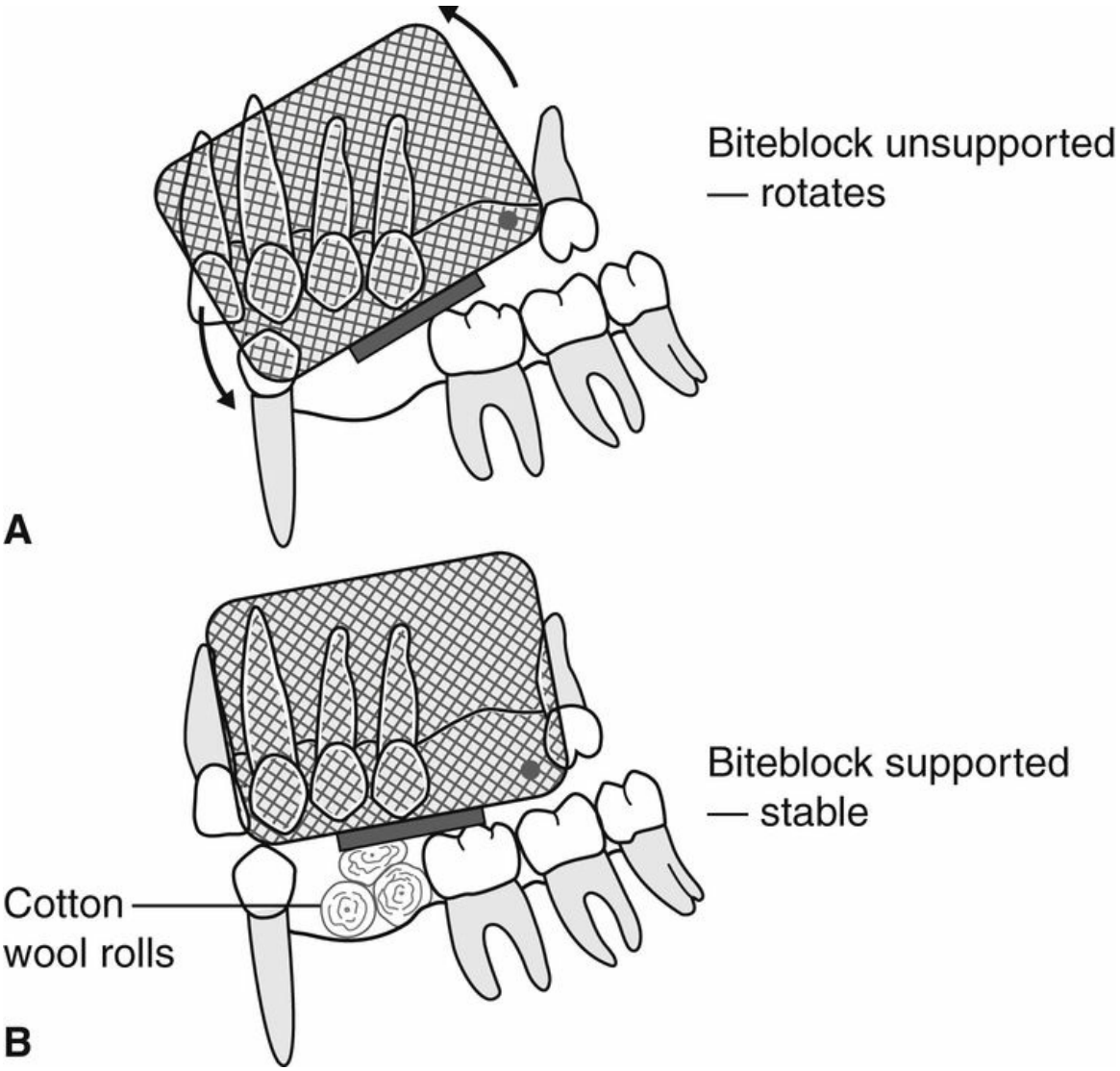


FIG. 9.46 Diagrams showing **(A)** the effect on the position of the image receptor and holder created by an edentulous area, and (B) how the problem can be solved using cotton wool rolls to rebuild the edentulous area, thus supporting the bite block.

Problems Encountered in Children

Once again the main technical problem (as opposed to management

problems) encountered in children is the size of their mouths and the difficulty in placing the image receptor intraorally. The paralleling technique is not possible in very small children, but can often be used (and is recommended) anteriorly, for investigating traumatized permanent incisors. The reproducibility afforded by this technique is invaluable for future comparative purposes.

A modified bisected angle technique is possible in most children, with the image receptor placed flat in the mouth (in the occlusal plane) and the position of the X-ray tubehead adjusted accordingly (see Fig. 9.47).

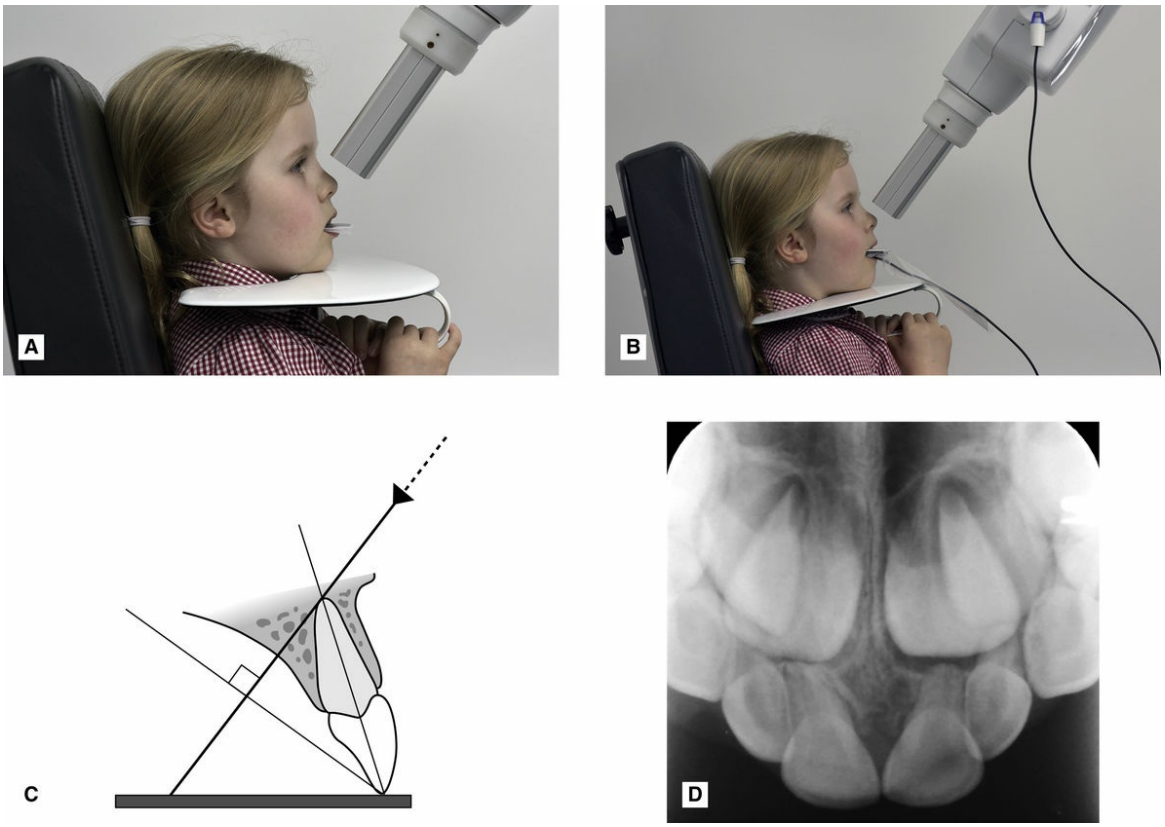


FIG 9.47 Patient positioning for a child's maxillary incisors using **(A)** a phosphor plate or film packet and **(B)** a solid-state digital sensor. Note the use of a thyroid shield. **(C)** Diagram showing the relative positions of the image receptor, in the occlusal plane, the deciduous central incisor and the X-ray beam. **(D)** Resultant radiograph.

Assessment of Image Quality

Assessment of the quality of all radiographic images should be regarded as a routine part of any quality assurance (QA) programme (see Chapter 17). Essentially image quality assessment involves three separate stages, namely:

- Comparison of the image against ideal quality criteria
- Subjective rating of image quality using published standards
- Detailed assessment of rejected radiographs to determine the sources of error.

Ideal Quality Criteria

Irrespective of the type of image receptor or technique being used, typical quality criteria for a periapical radiograph should include:

- The image should have acceptable definition with no distortion or blurring.
- The image should include the correct anatomical area together with the apices of the tooth/teeth under investigation with at least 3–4 mm of surrounding bone.
- There should be no overlap of the proximal surfaces of the teeth.
- The desired density and contrast for film-captured images will depend on the clinical reasons for taking the radiograph, e.g.:
  - to assess *caries, restorations* and the *periapical tissues* films should be well-exposed and show good contrast to allow differentiation between enamel and dentine and between the periodontal ligament space, the lamina dura and trabecular bone
  - to assess the *periodontal status* films should be underexposed to avoid *burnout* of the thin alveolar crestal bone (see Chapter 22).
- The images should be free of *coning off* or *cone cutting* and other film handling errors.

- The images should be comparable with previous periapical images, both geometrically and in density and contrast.

Subjective Rating and Assessment of Image Quality

Subjective rating of image quality has been advocated for many years. In the UK the latest *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition) recommends a simple two-point rating scale for digital and film captured radiographs. A summary is shown in Table 9.1 . Image quality is discussed in detail, together with a range of errors associated with exposure factors and image processing, in Chapter 17 . Patient preparation and positioning errors in periapical radiography are described below.

Patient Preparation and Positioning (Radiographic Technique) Errors (see Fig. 9.48)

These can include:

- Failure to remove dentures or orthodontic appliances
- Failure to position the image receptor correctly to capture the area of interest, thereby failing to image the apices and periapical tissues
- Failure to position the image receptor correctly, causing it to bend (if flexible) creating geometrical distortion
- Failure to orientate the image receptor correctly and using it back to front
- Failure to align the X-ray tubehead correctly in the horizontal plane, either
    - Too far anteriorly or posteriorly (*coning off* or *cone cutting*)
    - Not aimed through the contact areas at right angles to the teeth and the image receptor causing overlapping of the contact areas

- Failure to align the X-ray tubehead correctly in the vertical plane, either
  - Too far superiorly or inferiorly (*coning off* or *cone cutting*)
  - Too steep an angle causing foreshortening and geometrical distortion
  - Too shallow an angle causing elongation and geometrical distortion
- Failure to instruct the patient to remain still during the exposure with subsequent movement resulting in blurring
- Failure to set correct exposure settings (see Chapter 17)
- Careless inadvertent use of the image receptor twice.

NOTE: Many of these technique errors can be avoided by using the paralleling technique using image receptor holders with beam-aiming devices.

Table 9.1

Subjective quality rating criteria for digital and film captured images based on the latest UK *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment,* (second edition.)

Quality	Basis
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction and of sufficient image quality to answer the clinical question
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction which render the image diagnostically unacceptable



FIG. 9.48 A selection of patient preparation and positioning (radiographic technique) errors. **(A)** Image receptor not positioned sufficiently apically to cover the area of interest – apices and periapical tissues not shown. **(B)** Failure to remove an orthodontic appliance. **(C)** Image receptor positioned incorrectly and bent during exposure – image geometrically distorted. **(D)** Failure to align the X-ray tubehead correctly in the vertical plane – *coning off* of the inferior part of the image. **(E)** X-ray tubehead positioned at too steep an angle in the vertical plane – foreshortening and geometrical distortion of the image. **(F)** X-ray tubehead

positioned at too shallow an angle in the vertical plane – elongation and geometrical distortion of the image. **(G)** Failure to instruct the patient to remain still – image blurred as a result of movement. **(H)** Image receptor (film packet) incorrectly placed back to front – pattern of the lead foil is evident. **(I)** Image receptor (phosphor plate) incorrectly placed back-to-front – circular shadow of magnet is evident.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

10

Bitewing Radiography

Bitewing radiographs take their name from the original technique which required the patient to *bite* on a small *wing* attached to an intraoral film packet (see Fig. 10.1). Modern techniques use holders, as shown later, which have eliminated the need for the wing (now termed a *tab),* and digital image receptors (solid-state or phosphor plate) can be used instead of film, but the terminology and clinical indications have remained the same. An individual image is designed to show the crowns of the premolar and molar teeth on one side of the jaws.

Main Indications

These include:

- Detection of carious lesions



FIG. 10.1 A traditional intraoral barrier-wrapped film packet with a *wing* or *tab* attached.

- Monitoring the progression of dental caries
- Assessment of existing restorations
- Assessment of the periodontal status.

Ideal Technique Requirements

These include:

- An appropriate image receptor holder with beam-aiming device should be used and is recommended in the UK in the latest *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition).
- The image receptor should be positioned centrally within the holder with the upper and lower edges of the image receptor parallel to the bite-platform.

- The image receptor should be positioned with its long axis horizontally for a *horizontal bitewing* or vertically for a *vertical bitewing* (see Fig. 10.2).
- The posterior teeth and the image receptor should be in contact or as close together as possible.
- The posterior teeth and the image receptor should be parallel – the shape of the dental arch may necessitate two separate image receptor positions to achieve this requirement for both the premolar and the molar teeth (see Fig. 10.3).
- The beam-aiming device should ensure that in the horizontal plane, the X-ray tubehead is aimed so that the beam meets the teeth and the image receptor at right angles, and passes directly through all the contact areas (see Fig. 10.3).
- The beam-aiming device should ensure that in the vertical plane, the X-ray tubehead is aimed downwards (approximately 5°–8° to the horizontal) to compensate for the upwardly rising curve of Monson (see Fig. 10.4).

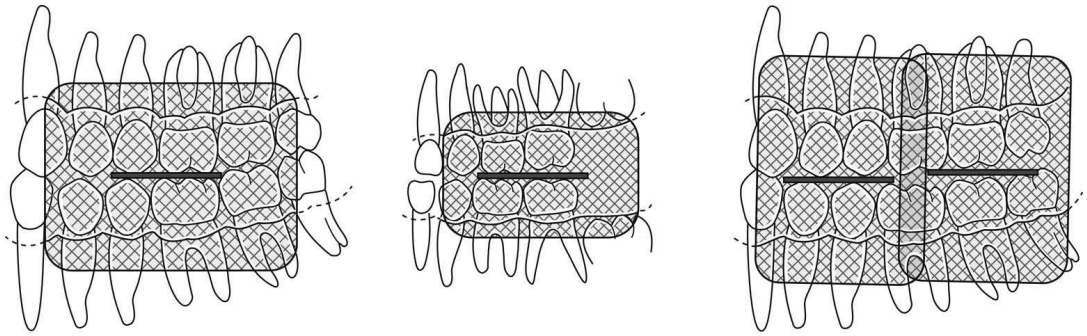


FIG. 10.2 Diagrams showing the ideal image receptor positions for different types of bitewings.

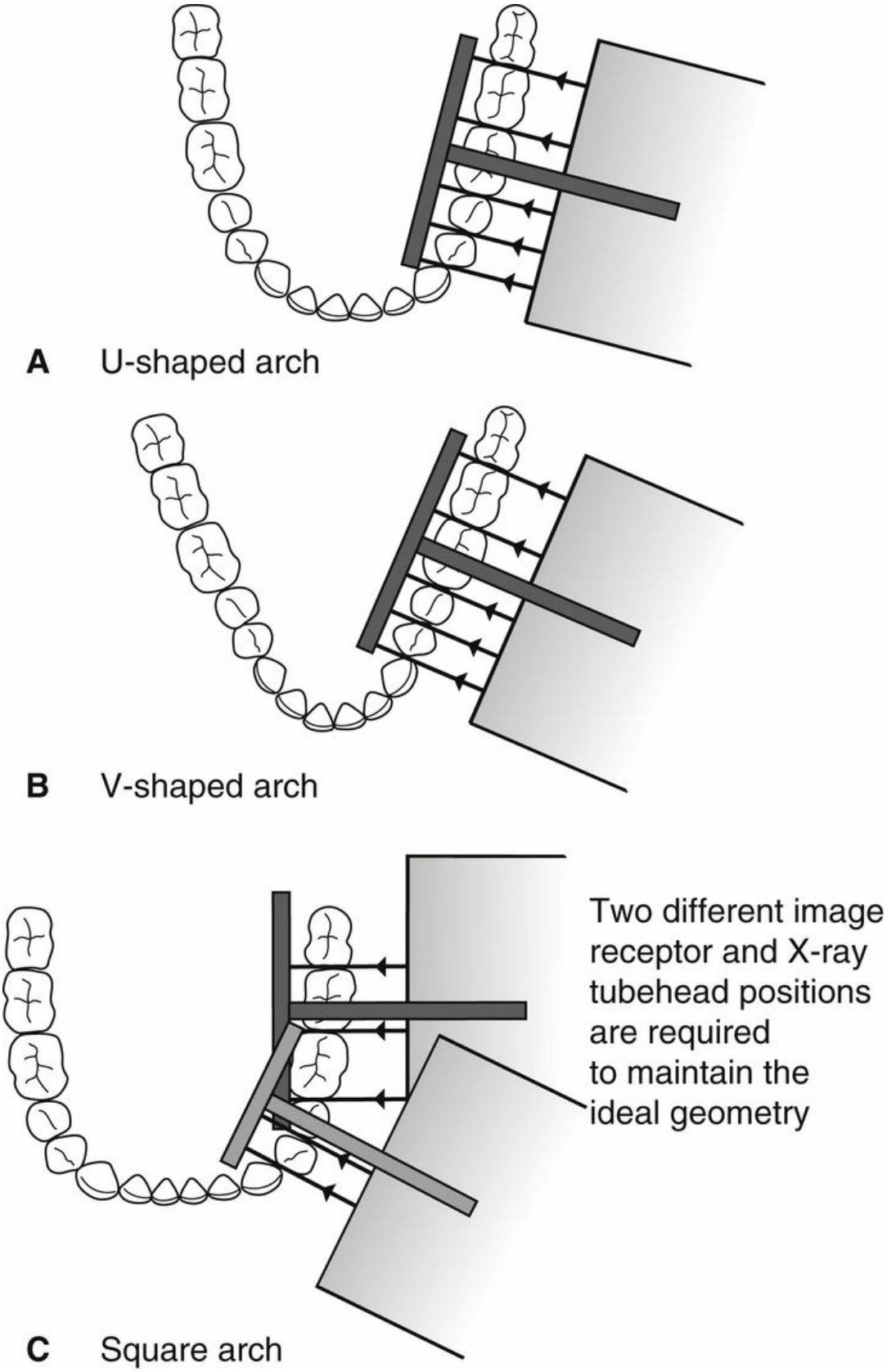


FIG. 10.3 Diagrams showing the ideal image receptor

and X-ray tubehead positions (determined by the beam-aiming device) for different arch shapes.

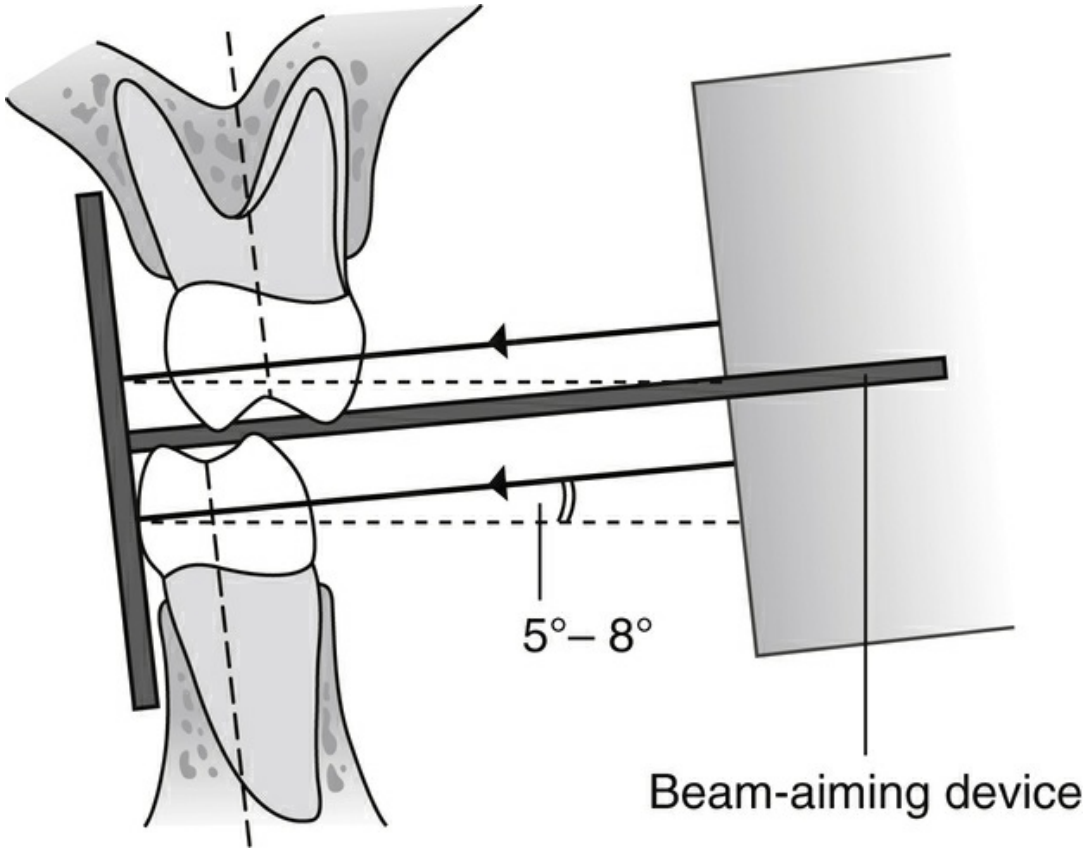


FIG. 10.4 Diagram showing the ideal image receptor position and the approximate 5°–8° downward vertical angulation of the X-ray beam (determined by the beam-aiming device) compensating for the curve of Monson.

- The positioning should be reproducible.

It is sometimes not possible to use an image receptor holder (with beam-aiming device) and achieve these ideal technical requirements – particularly in children. Clinicians therefore still need to be aware of the original technique of using a tab attached to the film packet or phosphor plate and aligning the X-ray tubehead by eye.

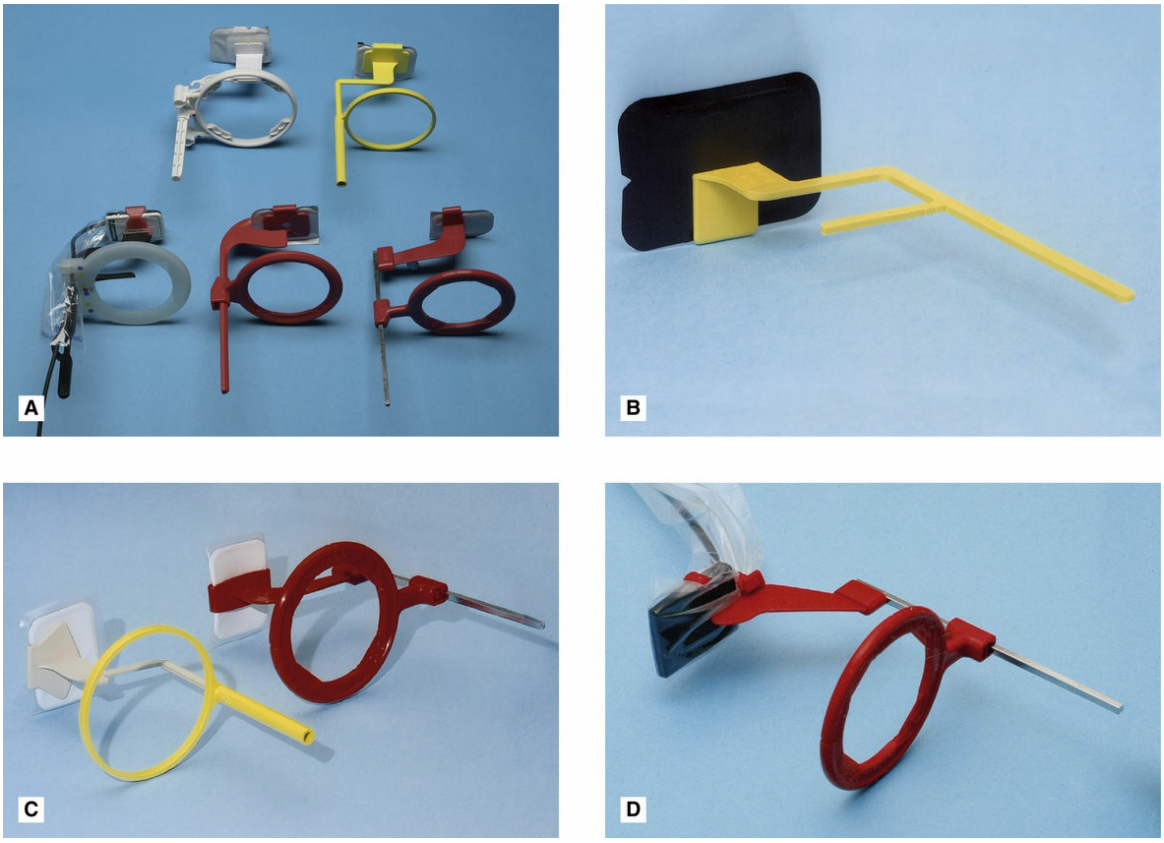


FIG. 10.5 Bitewing image receptor holders with beam-aiming devices. (A) A selection of different holders for use with different image receptors. (B) The simple yellow Hawe-Neos Kwikbite™ horizontal holder. (C) Vertical holders – the red Rinn® XCP holder and the yellow Hawe-Neos Paro-Bite™. (D) The red Rinn® XCP-DS solid-state sensor holder.

Positioning Techniques

Using Image Receptor Holders With Beam-aiming Devices

Several image receptor holders with different beam-aiming devices have been produced for use with digital phosphor plates or film packets and with digital solid-state sensors, held either horizontally or vertically. A selection of different holders is shown in Fig. 10.5 . As in periapical radiography, the choice of holder is a matter of personal preference and dependent upon the type of image receptors being

used. The various holders vary in cost and design but essentially consist of the same three basic components that make up periapical holders (see Chapter 9), namely:

- A mechanism for holding the image receptor parallel to the teeth
- A bite-platform that replaces the original wing
- An X-ray beam-aiming device.

The radiographic technique can be summarized as follows:

1. The desired holder is selected together with an appropriate-sized image receptor – typically a 31 × 41 mm phosphor plate or film packet or the equivalent-sized solid-state sensor.
2. The patient is positioned with the head supported and with the occlusal plane horizontal.
3. The holder is inserted carefully into the lingual sulcus opposite the posterior teeth.
4. The anterior edge of the image receptor should be positioned opposite the distal aspect of the lower canine – in this position the image receptor extends usually just beyond the mesial aspect of the lower third molar (see Fig. 10.6).
5. The patient is asked to close the teeth firmly together onto the bite-platform. (Note: Extra care needs to be taken of solid-state sensor cables.)
6. The X-ray tubehead is aligned accurately using the beam-aiming device to achieve optimal horizontal and vertical angulations (see Fig. 10.7).
7. The exposure is made.
8. If required, the procedure is repeated for the premolar teeth with a new image receptor and X-ray tubehead position.

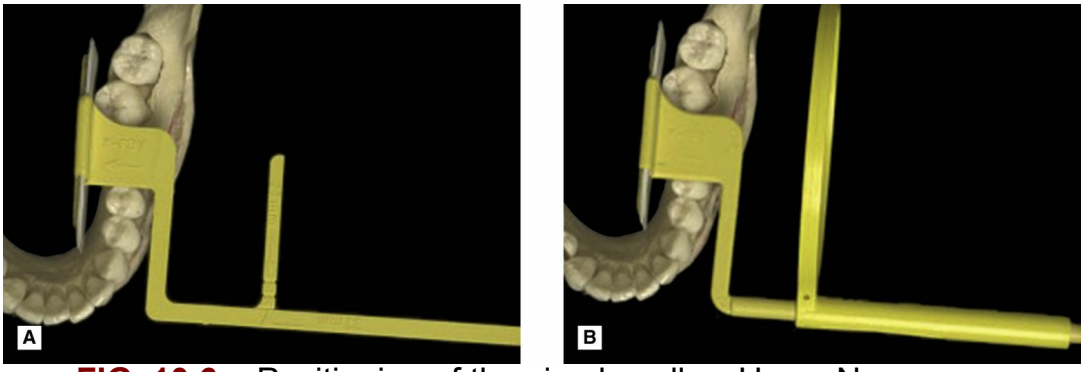


FIG. 10.6 Positioning of the simple yellow Hawe-Neos Kwikbite™ holder in relation to the teeth (A) without and (B) with the circular beam-aiming device.

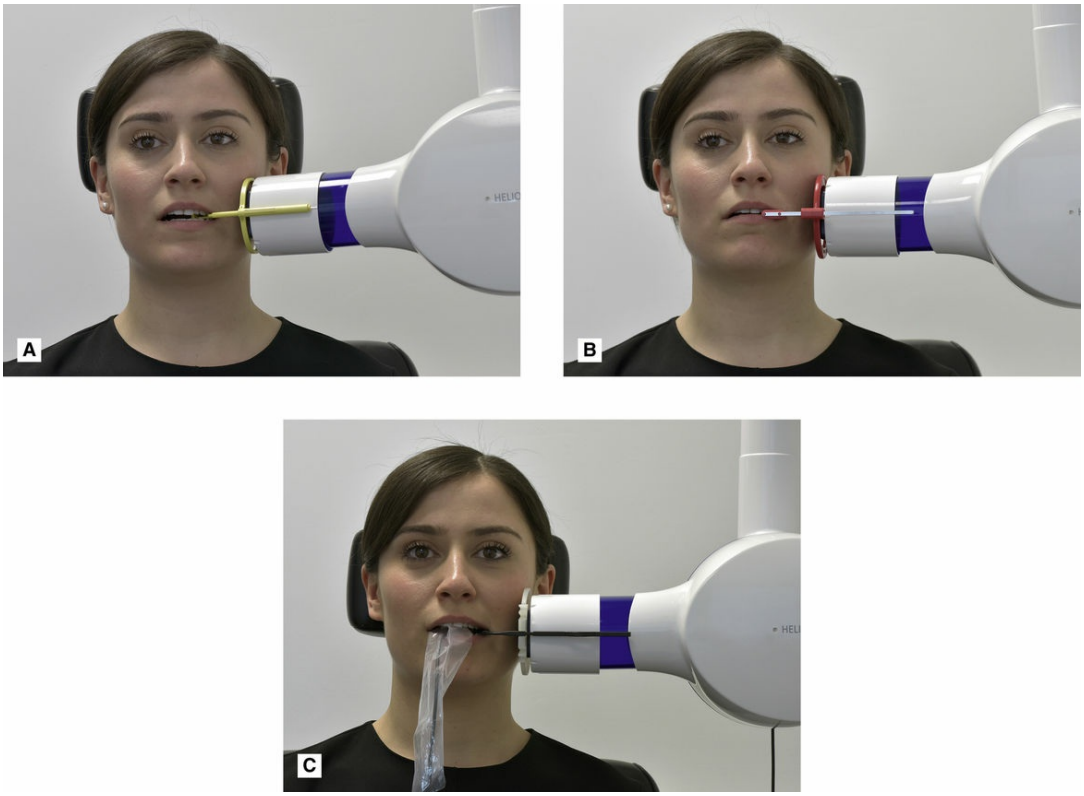


FIG. 10.7 Clinical positioning for the (A) Simple yellow Hawe-Neos Kwikbite™ holder with circular beam-aiming device, (B) Rinn® XCP holder using phosphor plate or film and (C) Kimera Trollbyte holder using a solid-state sensor.

Advantages

- Relatively simple and straightforward.
- Image receptor is held firmly in position and cannot be displaced by the tongue.
- Position of X-ray tubehead is determined by the beam-aiming device so assisting the operator in ensuring that the X-ray beam is always at right angles to the image receptor.
- Avoids *coning off* or *cone cutting* of the anterior part of the image receptor.
- Holders are sterilizable or disposable.

Disadvantages

- Position of the holder in the mouth is operator-dependent, therefore images are not 100% reproducible, so not absolutely ideal for monitoring progression of caries.
- Positioning of the film holder and image receptor can be uncomfortable for the patient, particularly when using solid-state digital sensors.
- Some holders are relatively expensive.
- Holders are not usually suitable for children.

Using a Tab Attached to the Image Receptor

The traditional bitewing technique is particularly suitable when using film packets or digital phosphor plates as the image receptor. Although, as explained below, the technique is very operator-dependent and not recommended for adults, it is still widely used for children.

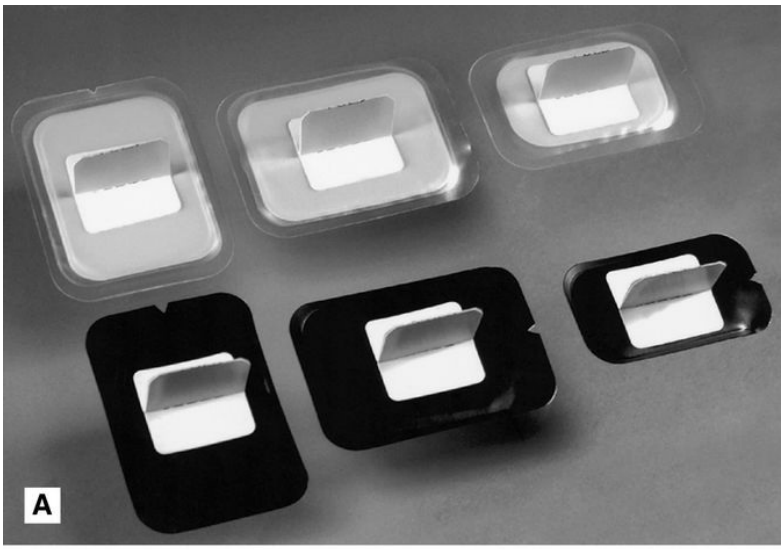
The radiographic technique can be summarized as follows:

1. The appropriate sized phosphor plate or barrier-wrapped film packet is selected and the tab attached, orientated appropriately for *horizontal* or *vertical* projections, as shown in

Fig. 10.8A :

a. Large phosphor plates/film packets (31 × 41 mm) for adults.
b. Small phosphor plates/film packets (22 × 35 mm) for children under 12 years of age. Once the second permanent molars have erupted the adult size is required.
c. Occasionally a long phosphor plate/film packet (53 × 26 mm) is used for adults.

2. The patient is positioned with the head supported and with the occlusal plane horizontal.
3. The shape of the dental arch and the number of films required are assessed.


A


B

FIG. 10.8 (A) Different sized film packets and phosphor plates with tabs attached suitable for vertical and horizontal bitewings. (B) The ideal positioning in relation to the teeth of a phosphor plate or film packet with tab attached.

4. The operator holds the tab between thumb and forefinger and inserts the image receptor into the lingual sulcus opposite the posterior teeth.
5. The anterior edge of the image receptor should again be positioned opposite the distal aspect of the lower canine – in this position, the posterior edge of the image receptor extends usually just beyond the mesial aspect of the lower third molar (see Fig. 10.8B).
6. The tab is placed onto the occlusal surfaces of the lower teeth.
7. The patient is asked to close the teeth firmly together on the tab.
8. As the patient closes the teeth, the operator pulls the tab firmly between the teeth to ensure that the image receptor and teeth are in contact.
9. The operator releases the tab.
10. The operator assesses the horizontal and vertical angulations and positions the X-ray tubehead so that the X-ray beam is aimed directly through the contact areas, at right angles to the teeth and the image receptor, with an approximately 5°-8° downward vertical angulation (see Fig. 10.9A–B).
11. The exposure is made.
12. If required, the procedure is repeated for the premolar teeth with a new image receptor and X-ray tubehead position.

NOTE : When positioning the X-ray tubehead, after the patient has closed the mouth, the film can no longer be seen. To ensure that the anterior part of the image receptor is exposed and to avoid *coning off* and *cone cutting* , a simple guide to remember is that the front edge of the open-ended spacer cone should be positioned adjacent to the corner of the mouth.

Advantages

- Simple.
- Inexpensive.
- The tabs are disposable, so no extra cross-infection control procedures required.
- Can be used easily in children.

Disadvantages

- Arbitrary, operator-dependent assessment of horizontal and vertical angulations of the X-ray tubehead.
- Images not accurately reproducible, so not ideal for monitoring the progression of caries.

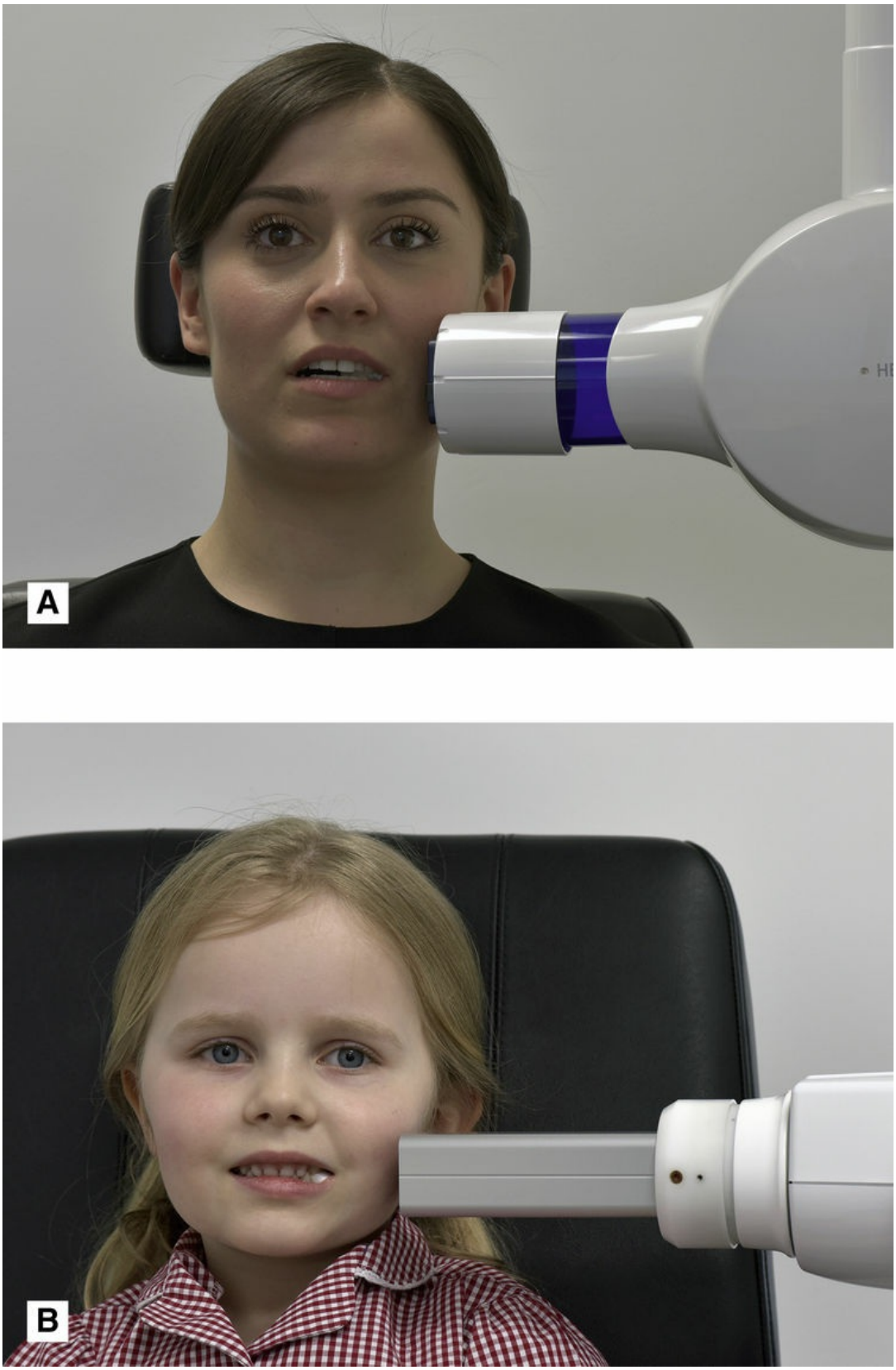


FIG. 10.9 (A) Adult patient and X-ray tubehead positioning for a left bitewing. (B) Positioning for a child.

- *Coning off* or *cone cutting* of anterior part of image receptor is common.
- Not compatible with using solid-state digital sensors.
- The tongue can easily displace the image receptor.

Resultant Radiographs

Whichever radiographic technique is used, the resultant radiographic images and the anatomical structures they show are very similar – it is their accuracy that varies. Examples are shown in Figs 10.10 –10.12 .

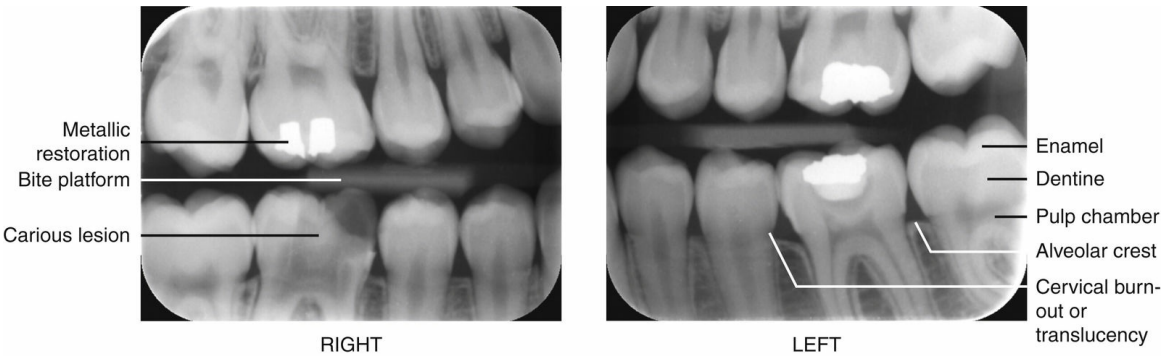


FIG. 10.10 Examples of typical RIGHT and LEFT horizontal adult bitewing radiographs, suitable for the assessment of caries and restorations, with the main radiographic features indicated.

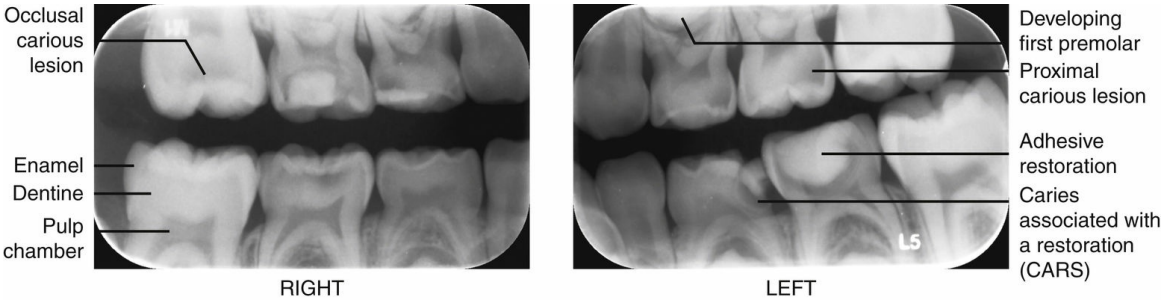


FIG. 10.11 Examples of typical RIGHT and LEFT bitewing radiographs of a child with the main radiographic features

indicated.

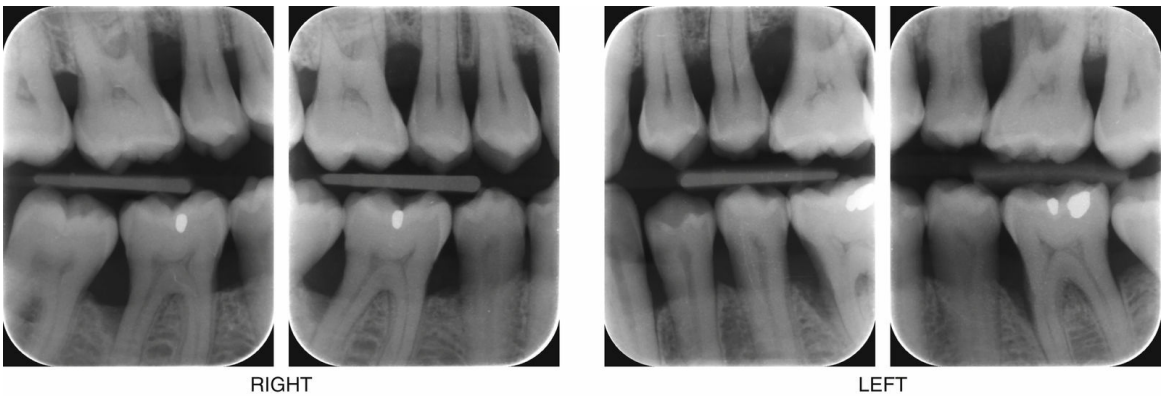


FIG. 10.12 Examples of typical RIGHT and LEFT vertical adult bitewing radiographs. Note that two image receptors are used on each side to image both the premolars and molars.

Assessment of Image Quality

As described in Chapter 9 , image quality assessment essentially involves three separate stages, namely:

- Comparison of the image against ideal quality criteria
- Subjective rating of image quality using published standards
- Detailed assessment of rejected films to determine the source of error.

Ideal Quality Criteria

Irrespective of the type of image receptor being used, typical quality criteria for a bitewing radiograph should include:

- The image should have acceptable definition with no distortion or blurring.
- The image should include from the mesial surface of the first premolar to the distal surface of the second molar – if the third

molars are erupted then the 7/8 contact should be included.

- The occlusal plane/bite-platform should be in the middle of the image so that the crowns and coronal parts of the roots of the maxillary teeth are shown in the upper half of the image and the crowns and coronal parts of the roots of the mandibular teeth are shown in the lower half of the image, and the buccal and lingual cusps should be superimposed.
- The maxillary and mandibular alveolar crests should be shown.
- There should be no overlap of the proximal surfaces of the teeth.
- The desired density and contrast for film-captured images will depend on the clinical reasons for taking the radiograph, e.g.
  - to assess *caries* and *restorations* films should be well exposed and show good contrast to allow differentiation between enamel and dentine and to allow the enamel–dentine junction to be seen.
  - to assess the *periodontal status* films should be underexposed to avoid *burn-out* of the thin alveolar crestal bone (see Chapter 22).
- The image should be free of *coning off* or *cone cutting* and other film handling errors.

TABLE 10.1

Subjective quality rating criteria for digital and film captured images based on the latest UK's *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment*, (second edition)

Quality	Basis
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction and of sufficient image quality to answer the clinical question
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction which render the image diagnostically unacceptable

- The image should be comparable with previous bitewing

images both geometrically and in density and contrast.

Subjective Rating and Assessment of Image Quality

The simple two-point subjective rating scale published in the latest *Guidance Notes* was introduced in Chapter 9 and is discussed in detail, together with the errors associated with exposure factors and image processing, in Chapter 17 . A summary is shown again in Table 10.1 . Patient preparation and positioning errors in bitewing radiography are described here.

Patient Preparation and Positioning (Radiographic Technique) Errors (see Fig. 10.13)

These can include:

- Positioning the image receptor too far posteriorly in the mouth thereby failing to image the premolar teeth.
- Failure to insert the image receptor correctly into the lingual sulcus between the tongue and posterior teeth allowing the tongue to displace the image receptor.
- Failure to align the X-ray tubehead correctly in the horizontal plane, either
  - Too far posteriorly *(coning off* or *cone cutting)*
  - Too far anteriorly – rarely (*coning off* or *cone cutting)*
  - Not aimed through the contact areas at right angles to the line of the arch and the image receptor causing overlapping of the contact areas.
- Failure to align the X-ray tubehead correctly in the vertical plane thereby not superimposing the buccal and lingual cusps.
- Failure to set correct exposure settings.
- Failure to instruct the patient to remain still during the exposure with subsequent movement resulting in blurring.

NOTE : Many of these positioning errors can be avoided by using image receptor holders with beam-aiming devices but are relatively common when not using a holder and aligning and positioning the X-ray tubehead without a guide.

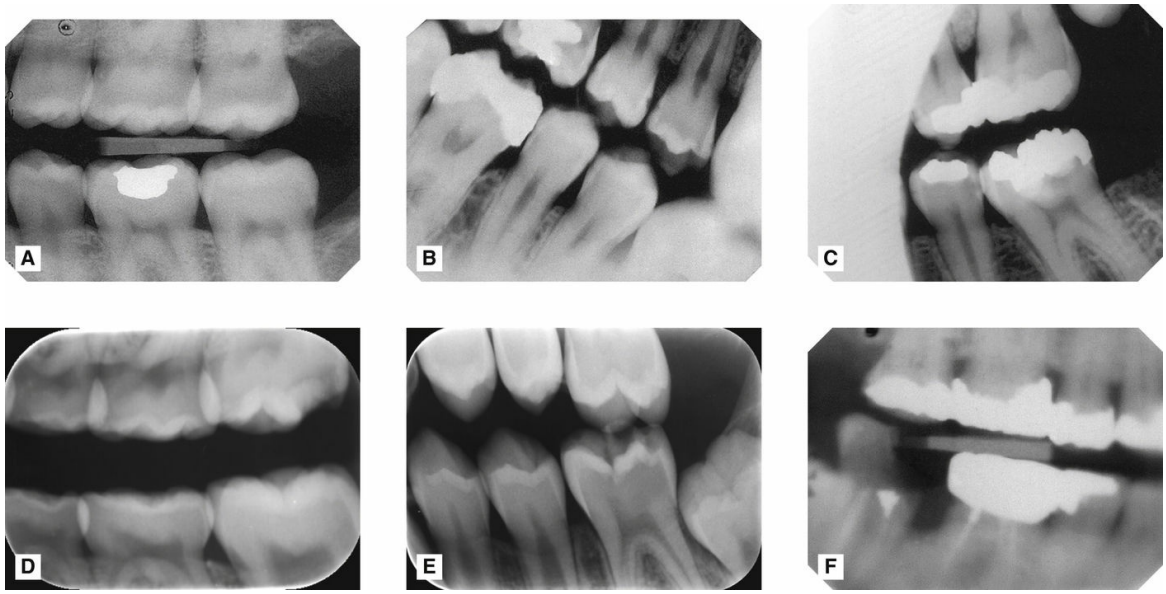


FIG. 10.13 A selection of bitewings showing patient preparation and positioning errors.

(A) Image receptor positioned too far posteriorly – the edentulous area distal to the lower second is imaged but not the premolar teeth.
(B) Image receptor displaced by tongue – occlusal plane not horizontal.
(C) Failure to align the X-ray tubehead correctly in the horizontal plane – *coning off* of the anterior part of the image.
(D) Failure to align the X-ray tubehead correctly in the horizontal plane – overlapping of the contact areas.
(E) Failure to align the X-ray tubehead correctly in the vertical plane – buccal and lingual cusps not superimposed and distortion of the teeth.
(F) Failure to instruct the patient to remain still – image blurred as a result of movement.

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11

Occlusal Radiography

Introduction

Occlusal radiography is defined as those intraoral radiographic techniques taken using a dental X-ray set where the image receptor (digital phosphor plate or film packet – 5.7 × 7.6 cm) is placed in the occlusal plane. Suitable-sized solid-state digital sensors are not currently available. This chapter provides an overview of various occlusal radiographs, including their classification, the clinical indications for each projection, how the images are taken and the anatomical structures shown.

Terminology and Classification

The terminology used in occlusal radiography is confusing with different terms being preferred in different countries and within different institutions.

The terminology preferred by the authors and used here is an attempt to make the terms explicit, straightforward and practical so that often the name of the view indicates how it is taken.

Maxillary Occlusal Projections

- Upper standard (or anterior) occlusal
- Upper oblique occlusal

Mandibular Occlusal Projections

- Lower 90° (or true) occlusal
- Lower 45° (or anterior) occlusal
- Lower oblique occlusal

Upper Standard (or Anterior) Occlusal

This projection shows the anterior part of the maxilla and the upper anterior teeth.

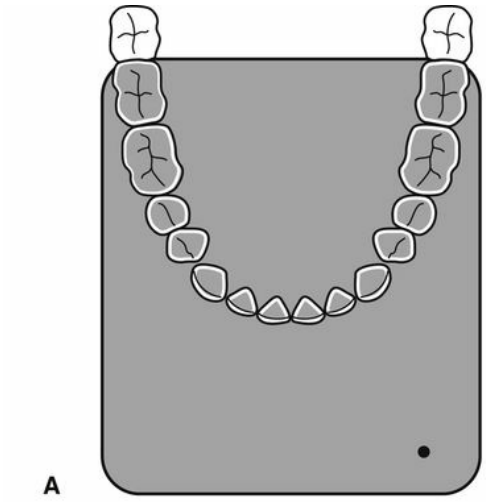
Main Clinical Indications

- Periapical assessment of the upper anterior teeth, especially in children, but also in adults unable to tolerate periapical holders
- Detecting the presence of unerupted canines, supernumeraries and odontomes
- As the midline view, when using the parallax method for determining the bucco/palatal position of unerupted canines (see Chapter 24)
- Evaluation of the size and extent of lesions such as cysts or tumours in the anterior maxilla
- Assessment of fractures of the anterior teeth and alveolar bone.

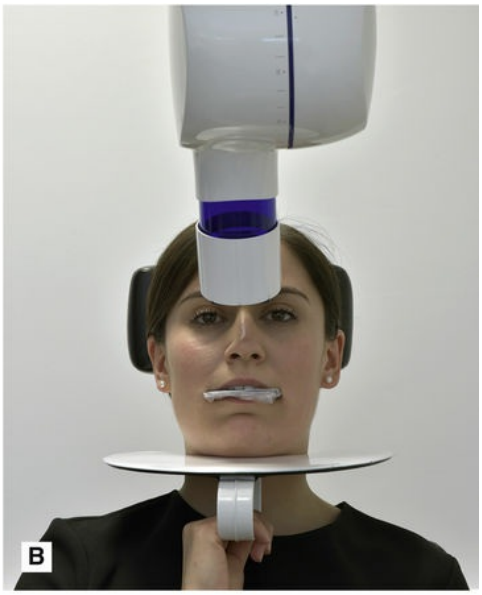
Technique and Positioning

1. The patient is seated with the head supported and with the occlusal plane horizontal and parallel to the floor and is asked to support a protective thyroid shield.
2. The image receptor, suitably barrier-wrapped, is placed flat into the mouth onto the occlusal surfaces of the lower teeth. The patient is asked to bite together gently. The image receptor is placed centrally in the mouth with its long axis anteroposteriorly.

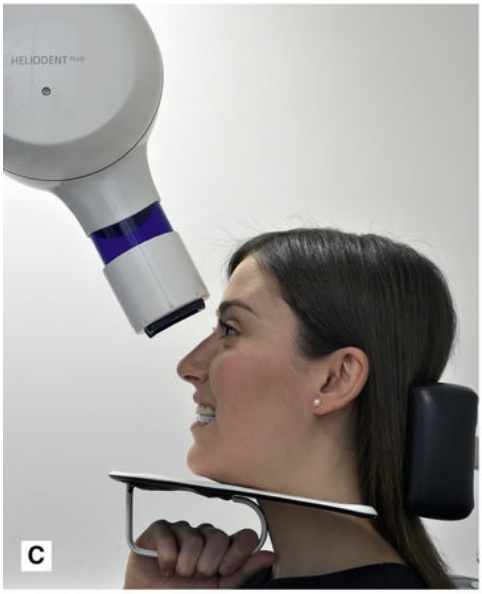
3. The X-ray tubehead is positioned above the patient in the midline, aiming downwards through the bridge of the nose at an angle of 65–70° to the image receptor (see Fig. 11.1).



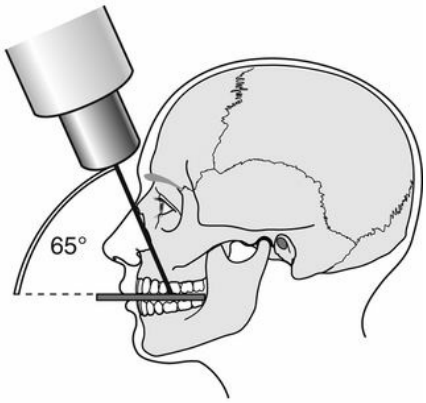
A



B



C



D



E

FIG. 11.1 Upper standard occlusal. **(A)** Diagram showing the position of the image receptor in relation to the lower arch. **(B)** Positioning from the front; note the use of the protective thyroid shield. **(C)** Positioning from the side. **(D)** Diagram showing the positioning from the side. **(E)** The resultant radiograph.

Upper Oblique Occlusal

This projection shows the posterior part of the maxilla and the upper posterior teeth on one side.

Main Clinical Indications

- Periapical assessment of the upper posterior teeth, especially in adults unable to tolerate periapical image receptor holders
- Evaluation of the size and extent of lesions such as cysts, tumours or other bone lesions affecting the posterior maxilla
- Assessment of the condition of the antral floor
- As an aid to determining the position of roots displaced inadvertently into the antrum during attempted extraction of upper posterior teeth
- Assessment of fractures of the posterior teeth and associated alveolar bone including the tuberosity.

Technique and Positioning

1. The patient is seated with the head supported and with the occlusal plane horizontal and parallel to the floor.
2. The image receptor, suitably barrier-wrapped, is inserted into the mouth onto the occlusal surfaces of the lower teeth, with its long axis anteroposteriorly. It is placed to the side of the mouth under investigation, and the patient is asked to bite together gently.

3. The X-ray tubehead is positioned to the side of the patient's face, aiming downwards through the cheek at an angle of 65°–70° to the image receptor, centring on the region of interest (see Fig. 11.2).

NOTE: If the X-ray tubehead is positioned too far posteriorly, the shadow cast by the body of the zygoma will obscure the posterior teeth.

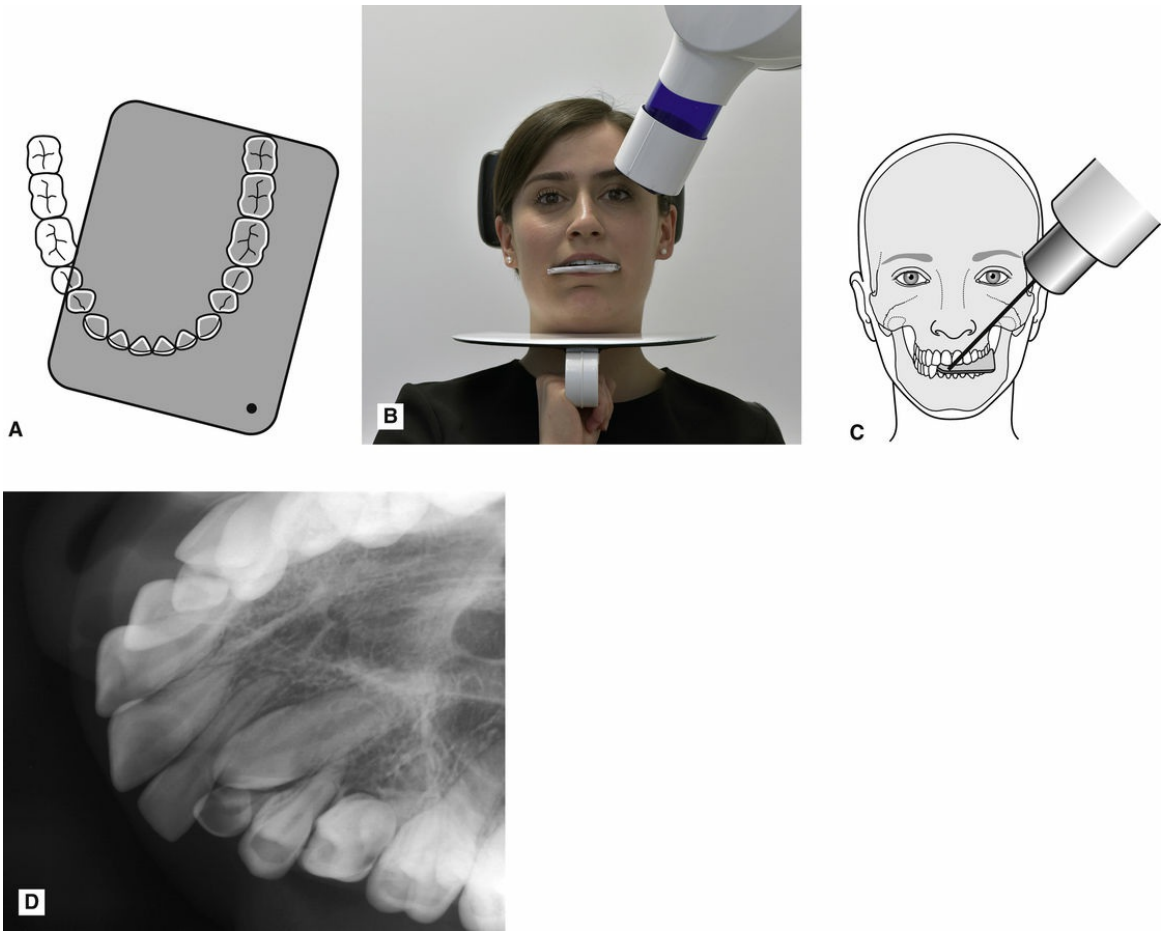


FIG. 11.2 Upper oblique occlusal. **(A)** Diagram showing the position of the image receptor in relation to the lower arch for an image of the LEFT maxillary teeth. **(B)** Positioning from the front; note the use of the protective thyroid shield. **(C)** Diagram showing the positioning from the front. **(D)** The resultant radiograph.

Lower 90° Occlusal

This projection shows a plan view of the tooth-bearing portion of the mandible and the floor of the mouth. A minor variation of the technique is also used to show unilateral lesions.

Main Clinical Indications

- Detection of the presence and position of radiopaque calculi in the submandibular salivary ducts
- Assessment of the buccolingual position of unerupted mandibular teeth
- Evaluation of the buccolingual expansion of the body of the mandible by cysts/tumours
- Assessment of fracture displacement of the anterior mandible in the horizontal plane
- Assessment of mandibular width prior to implant placement.

Technique and Positioning

1. The image receptor, suitably barrier-wrapped and facing downwards, is placed centrally into the mouth, onto the occlusal surfaces of the lower teeth, with its long axis anteroposteriorly. The patient is asked to bite together gently.
2. The patient *then* leans forwards and *then* tips the head backwards as far as is comfortable, where it is supported.
3. The X-ray tubehead, with circular collimator fitted, is placed below the patient's chin, in the midline, centring on an imaginary line joining the first molars, at an angle of 90° to the image receptor (see Fig. 11.3).

Variation of Technique

To show a particular part of the mandible, the image receptor is placed in the mouth with its long axis anteroposteriorly over the area of interest. The X-ray tubehead, still aimed at 90° to the image receptor, is centred below the body of the mandible in that area.

NOTE: The lower 90° occlusal is mounted as if the examiner were looking into the patient's mouth. Radiographic film is therefore mounted with the embossed dot pointing *away* from the examiner and phosphor plate images need to be flipped.

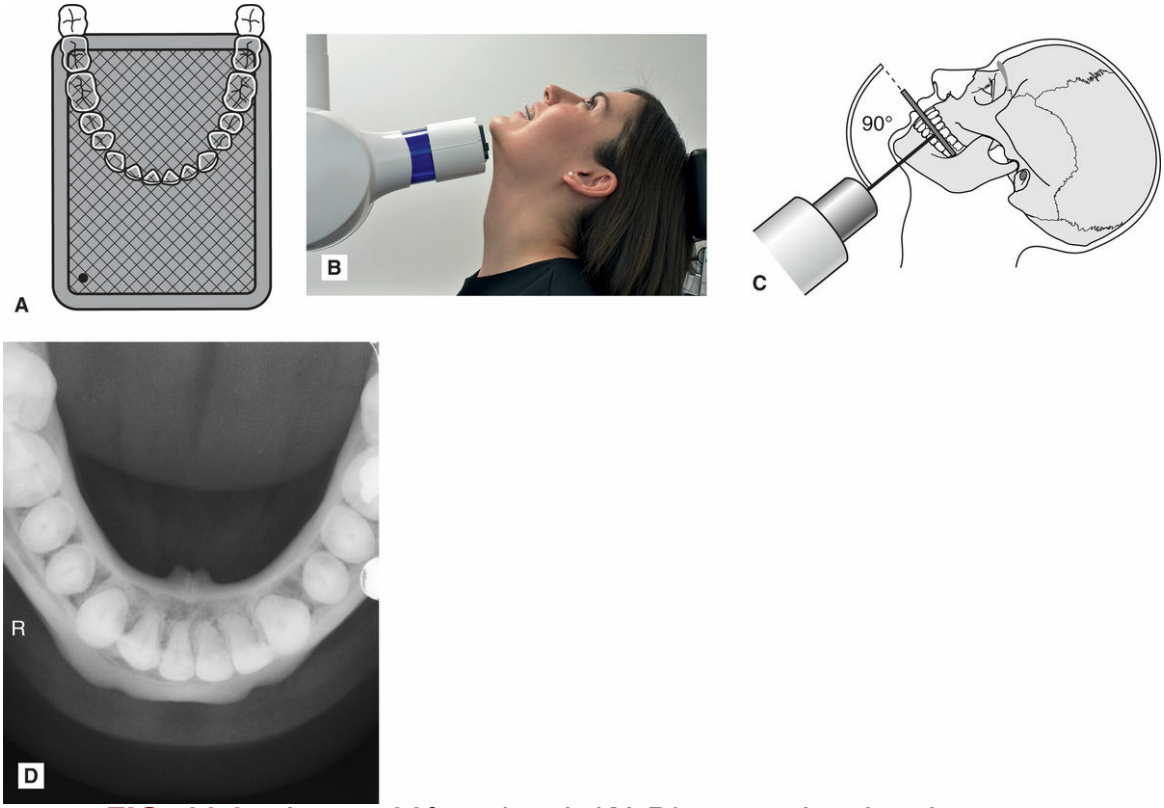


FIG. 11.3 Lower 90° occlusal. **(A)** Diagram showing the position of the image receptor (facing downwards) in relation to the lower arch. **(B)** Positioning from the side. **(C)** Diagram showing the positioning from the side. **(D)** The resultant radiograph.

Lower 45° (or Anterior) Occlusal

This projection is taken to show the lower anterior teeth and the anterior part of the mandible (see Fig. 11.4). The resultant radiograph resembles a large bisected angle technique periapical of this region.

Main Clinical Indications

- Periapical assessment of the lower incisor teeth, especially useful in adults and children unable to tolerate periapical image receptor holders
- Evaluation of the size and extent of lesions such as cysts or

tumours affecting the anterior part of the mandible
- Assessment of fracture displacement of the anterior mandible in the vertical plane.

Technique and Positioning

1. The patient is seated with the head supported and with the occlusal plane horizontal and parallel to the floor.
2. The image receptor, suitably barrier-wrapped and facing downwards, is placed centrally into the mouth, onto the occlusal surfaces of the lower teeth, with its long axis anteroposteriorly, and the patient is asked to bite gently together.
3. The X-ray tubehead is positioned in the midline, centring through the chin point, at an angle of 45° to the image receptor.

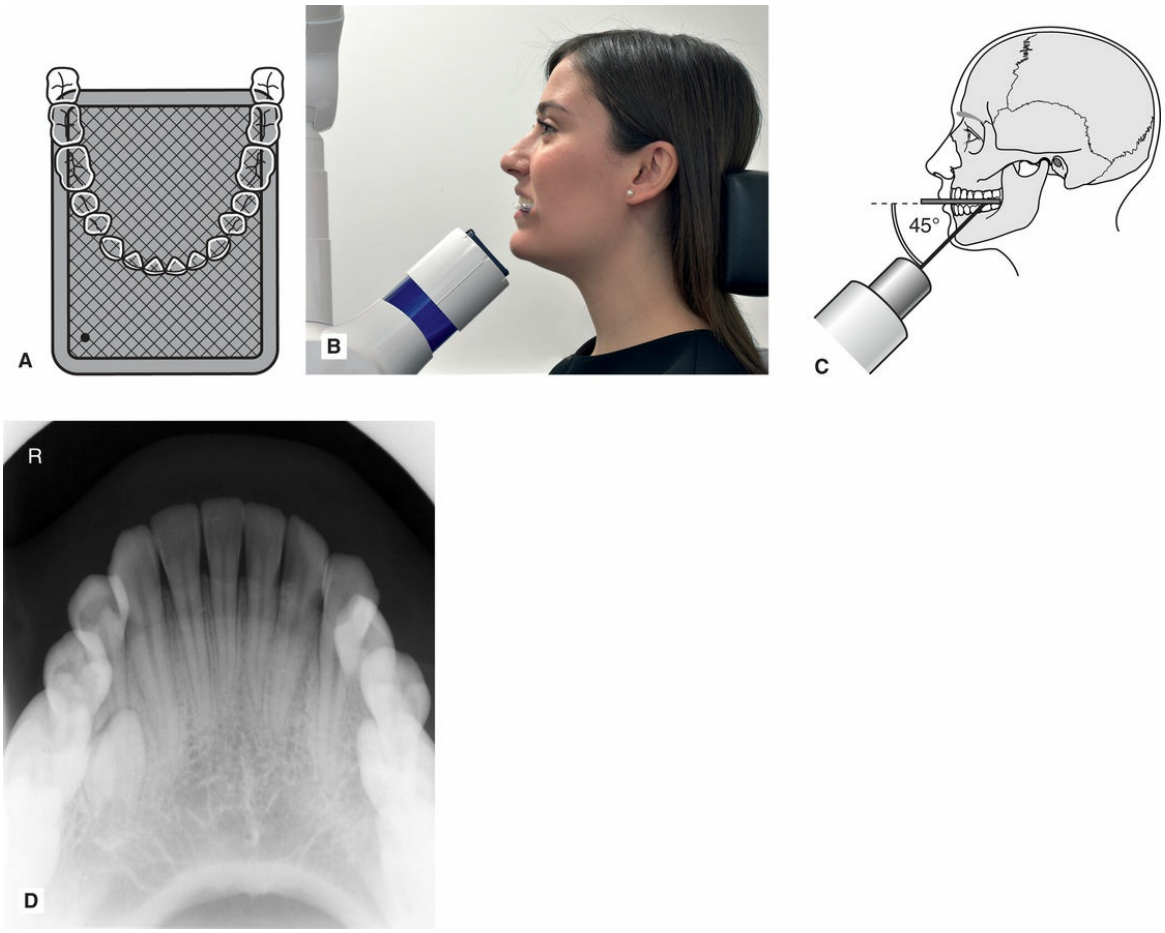


FIG. 11.4 Lower 45° occlusal. **(A)** Diagram showing the position of the image receptor (facing downwards) in relation to the lower arch. **(B)** Positioning from the side. **(C)** Diagram showing the positioning from the side. **(D)** The resultant radiograph.

Lower Oblique Occlusal

This projection is designed to allow the image of the submandibular salivary gland, on the side of interest, to be projected onto the image receptor (see Fig. 11.5). However, because the X-ray beam is oblique, all the anatomical tissues shown are distorted.

Main Clinical Indications

- Detection of radiopaque calculi in the submandibular salivary gland of interest
- Assessment of the buccolingual position of unerupted lower wisdom teeth
- Evaluation of the extent and expansion of cysts, tumours or other bone lesions in the posterior part of the body and angle of the mandible.

Technique and Positioning

1. The image receptor, suitably barrier-wrapped, and facing downwards, is inserted into the mouth, onto the occlusal surfaces of the lower teeth, over to the side under investigation, with its long axis anteroposteriorly. The patient is asked to bite together gently.
2. The patient's head is supported, then rotated away from the side under investigation and the chin is raised. This rotated positioning allows the subsequent positioning of the X-ray tubehead.
3. The X-ray tubehead with circular collimator is aimed upwards and forwards towards the image receptor, from below and behind the angle of the mandible and parallel to the lingual surface of the mandible (see Fig. 11.5).

NOTE: The radiographic film is mounted with the embossed dot pointing away from the examiner and phosphor plate images need to be flipped.

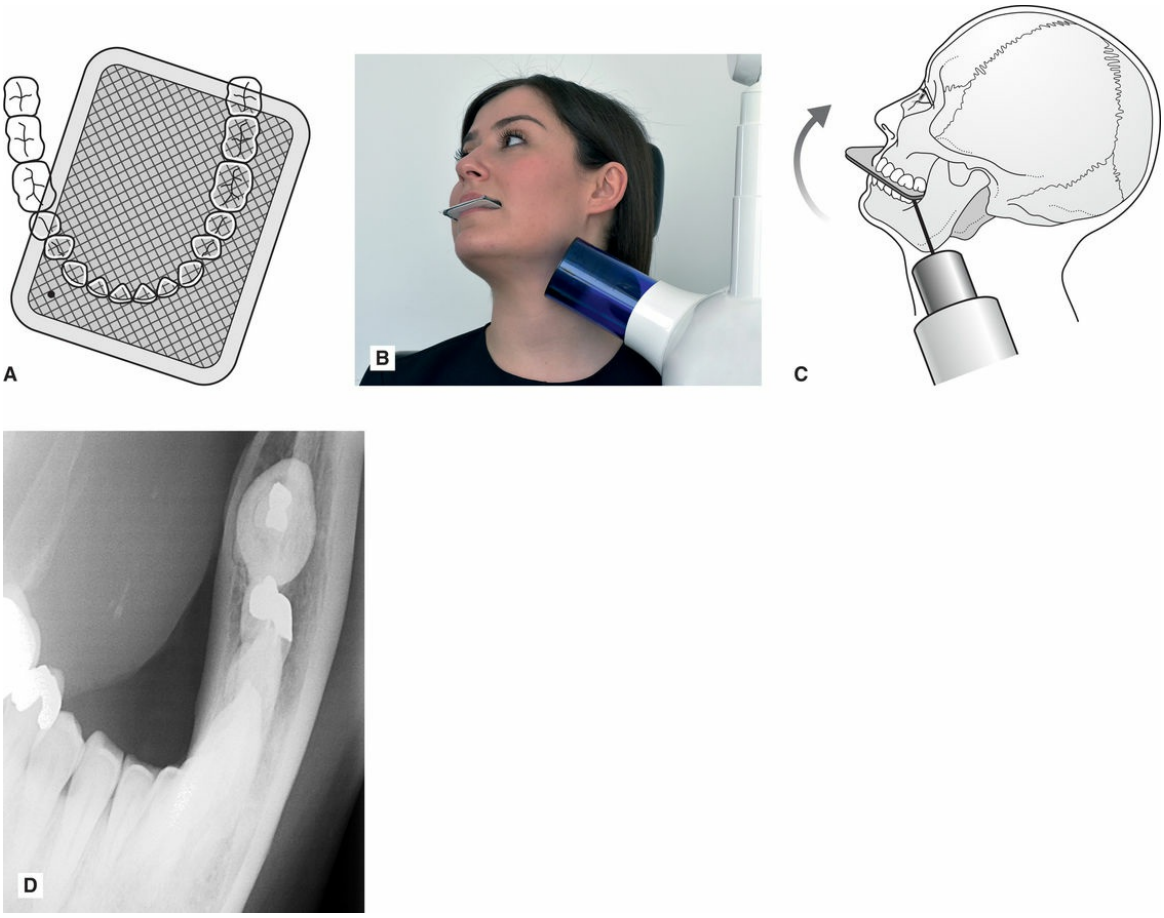
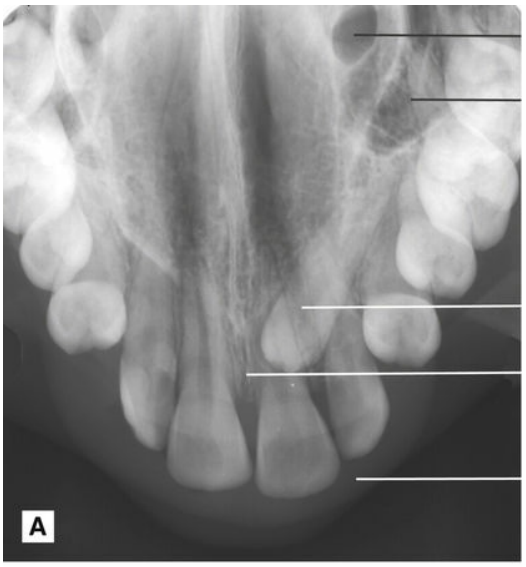
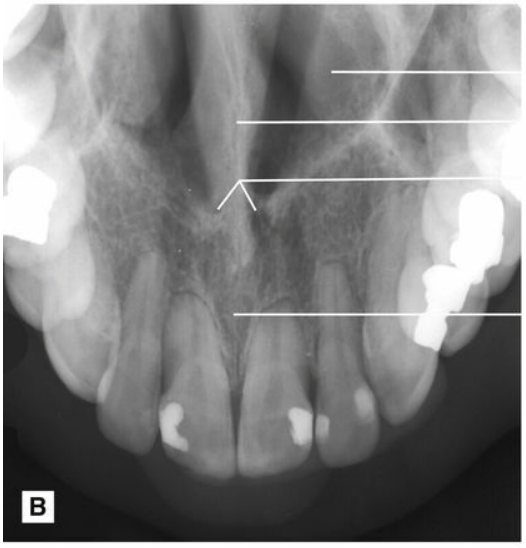


FIG. 11.5 Lower oblique occlusal. **(A)** Diagram showing the position of the image receptor (facing downwards) in relation to the lower arch for an image of the LEFT side. **(B)** Positioning from the side. **(C)** Positioning from the side and indicating that the patient's chin is raised and that the head is rotated away from the side under investigation. **(D)** The resultant radiograph.

Anatomy


Nasolacrimal canal
Maxillary antrum
Unerupted canine
Median maxillary suture
Shadow of the nose
A


Inferior turbinate
Nasal septum
Superior foramina of the nasopalatine canal
Incisive foramen
B

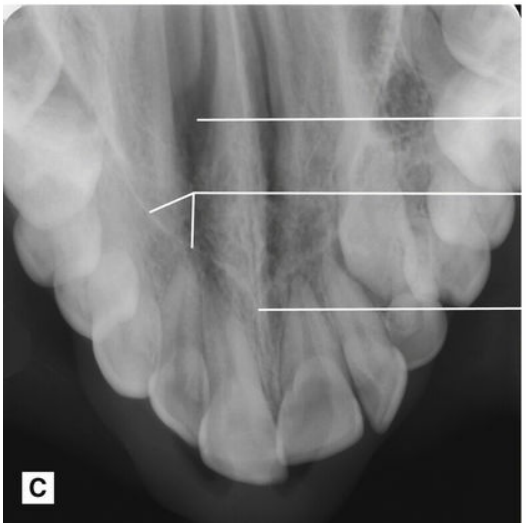
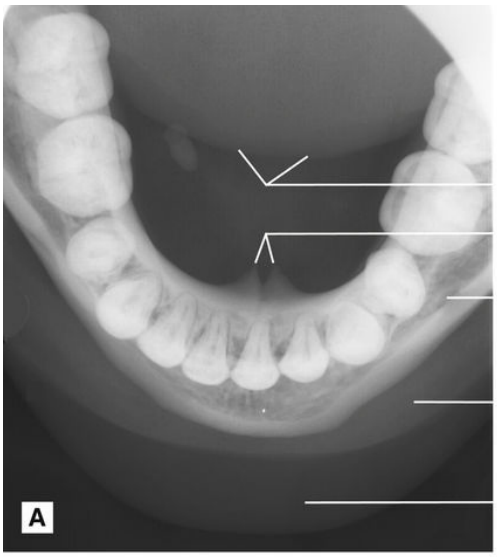
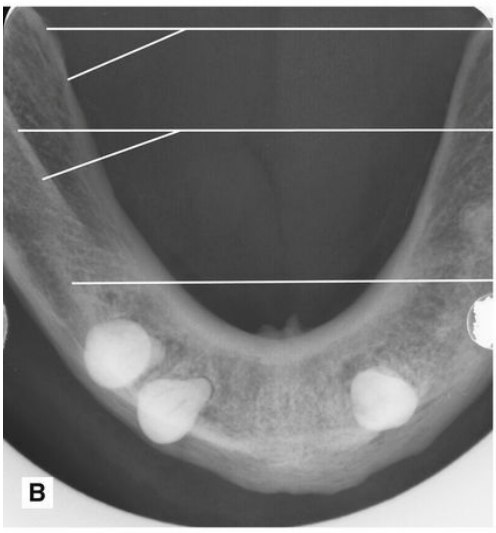

Nasal fossa
Lateral border of the nasal fossa
Anterior nasal spine
C

FIG. 11.6 **(A-C)** Examples of upper standard occlusal radiographs with the main anatomical structures indicated.


Tongue
Genial tubercles
Mental foramen
Soft tissue of lower lip
Soft tissue of chin
A


Internal oblique ridge
(mylohyoid ridge)
Lingual cortex/plate of the
submandibular fossa
Body of the mandible
B

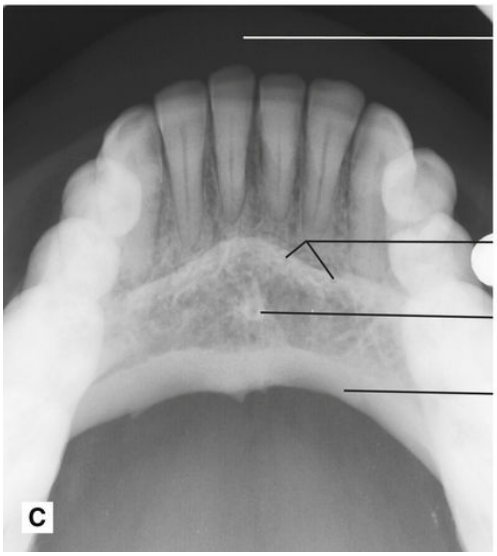

Shadow of lower lip
Mental ridge
Genial tubercles
Lower border of mandible
C

FIG. 11.7 **(A-C)** Examples of lower occlusal radiographs with the main anatomical structures indicated.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

12

Oblique Lateral Radiography

Introduction

Oblique lateral radiographs are extraoral views of the jaws that can be taken using a dental X-ray set (see Fig. 12.1). Before the development of panoramic equipment, they were the routine extraoral radiographs used both in hospitals and in general practice. In recent years, their popularity has waned, but the limitations of panoramic radiographs (see Chapter 15) have ensured that oblique lateral radiographs still have an important role.



FIG. 12.1 An example of an oblique lateral showing the left molars.

Terminology

Lateral radiographs of the head and jaws are divided into:

- True laterals
- Oblique laterals (the term *bimolar* was used historically to describe the image incorporating two oblique laterals on the same film).

The differentiating adjectives *true* and *oblique* are used to indicate

the relationship of the image receptor, patient and X-ray beam (see Fig. 12.2).

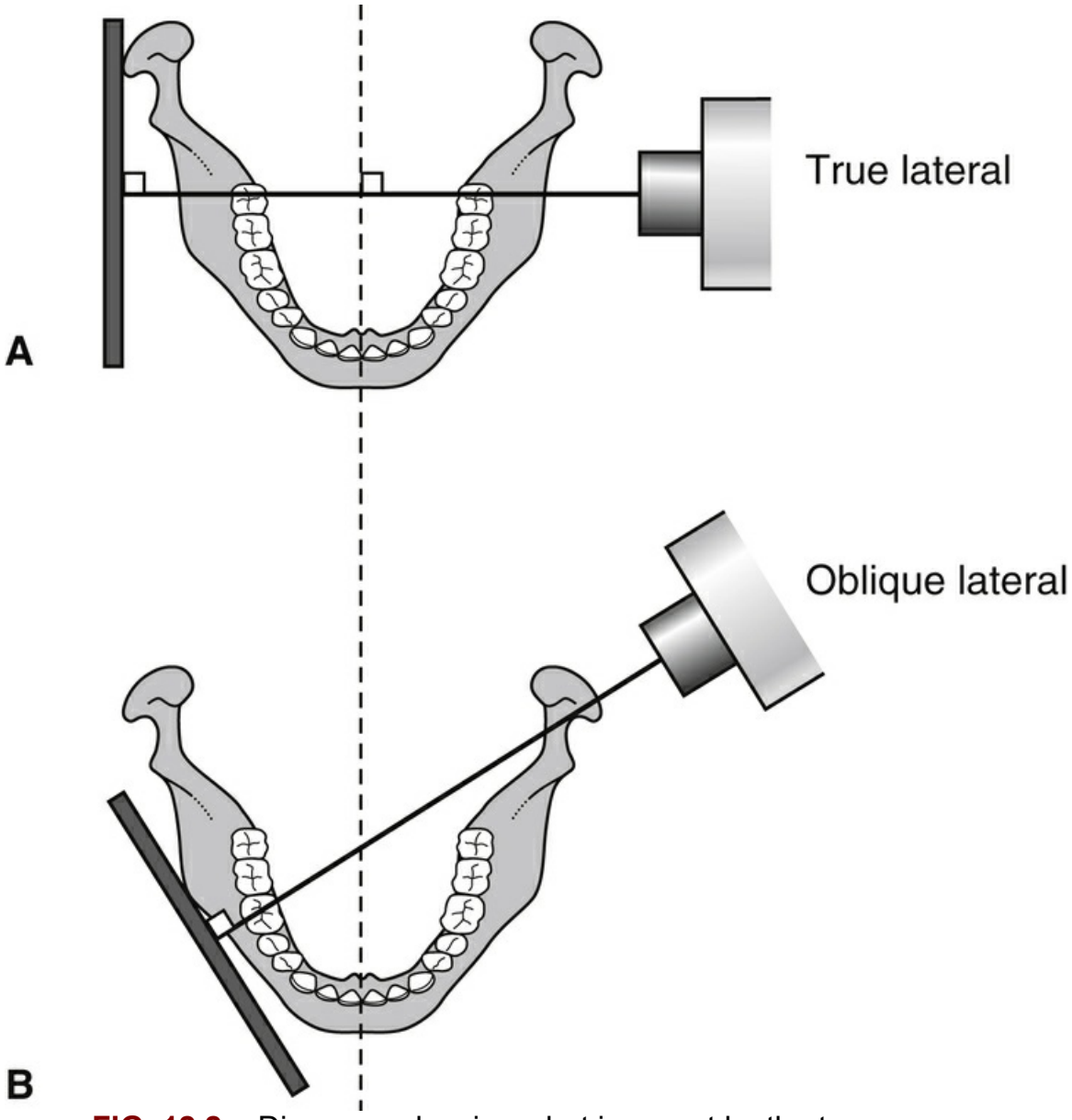


FIG. 12.2 Diagrams showing what is meant by the terms *true* and *oblique* lateral.

True Lateral Positioning

The image receptor and the sagittal plane of the patient's head are

parallel and the X-ray beam is perpendicular to both of them. This is the positioning for the *true lateral skull radiograph* taken in a cephalostat unit described in Chapter 14 .

Oblique Lateral Positioning

The image receptor and the sagittal plane of the patient's head are not parallel. The X-ray beam is aimed perpendicular to the image receptor but is *oblique* to the sagittal plane of the patient. A variety of different *oblique lateral* projections is possible with different head and X-ray beam positions.

Main Indications

The main clinical indications for oblique lateral radiographs include:

- Assessment of the presence and/or position of unerupted teeth
- Detection of fractures of the mandible
- Evaluation of lesions or conditions affecting the jaws including cysts, tumours, giant cell lesions, and other bone lesions
- As an alternative when intraoral views are unobtainable because of severe gagging or if the patient is unable to open the mouth or is undergoing general anaesthesia
- As specific views of the salivary glands or temporomandibular joints.

Basic Technique Principles

As stated, a wide range of different oblique lateral projections of the jaws is possible. However, all the variations require only a dental X-ray set and an extraoral cassette (usually 13 × 18 cm and containing a digital phosphor plate or a film and intensifying screens), and rely on the same basic positioning principles outlined below.

Cassette Position

The cassette is held by the patient against the side of the face overlying the area of the jaws under investigation. The exact position of the cassette is determined by the area of interest.

Patient's Head Position

The patient is normally seated upright in the dental chair and is then instructed to:

1. *Rotate the head to the side of interest.* This is done to bring the contralateral ramus forwards, avoiding its superimposition and to increase the space available between the neck and shoulder in which to position the X-ray set.
2. *Raise the chin.* This is done to increase the triangular space between the back of the ramus and the cervical spine (the so-called *radiographic keyhole;* see Fig. 12.3) through which the X-ray beam will pass.

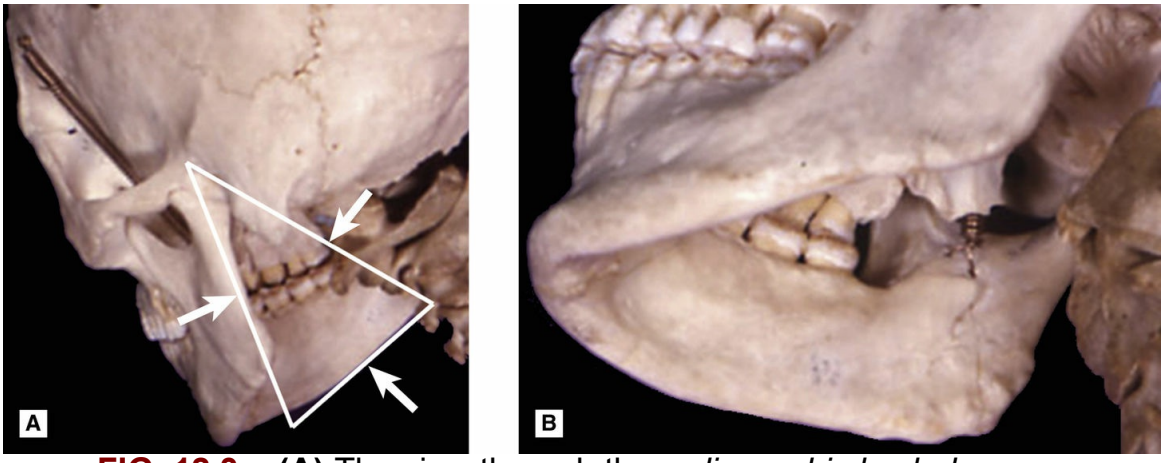


FIG. 12.3 **(A)** The view through the *radiographic keyhole* (arrowed) showing the right mandibular and maxillary posterior teeth. Note the anterior teeth are obscured by the left ramus of the mandible. **(B)** The view from underneath the left body of the mandible showing the right mandible and right posterior mandibular teeth. Note the right maxillary teeth are obscured by the left body of the mandible.

X-ray Tubehead Position

The X-ray tubehead is positioned on the opposite side of the patient's head to the cassette. There are two basic positions, depending on the area of the jaws under investigation:

- *Behind the ramus aiming through the radiographic keyhole.* The X-ray tubehead is positioned along the line of the occlusal plane, just below the ear, behind the ramus aiming through the *radiographic keyhole* at the particular maxillary **and** mandibular teeth under investigation. The view from this position is illustrated in Fig. 12.3A . As shown, the X-ray beam will not pass directly between the contact areas of the posterior teeth. This may result in some overlapping of the crowns.
- *Beneath the lower border of the mandible.* The X-ray tubehead is positioned beneath the lower border of the contralateral body of the mandible, directly opposite the particular mandibular teeth under investigation, aiming slightly upwards. The view from this position is illustrated in Fig. 12.3B . As shown, the X-ray beam will now pass between the contact areas of the teeth. However, there will still be some distortion of the image in the vertical plane owing to the upward angulation of the X-ray beam. In addition, the shadow of the body of the mandible will be superimposed over the maxillary teeth.

Once these principles are understood, the technique becomes straightforward and can be modified readily for different anatomical regions and clinical situations.

Positioning Examples For Various Oblique Lateral Radiographs

Examples of the required positioning for different oblique laterals and the resultant radiographs are shown in Figs 12.4 –12.7 . Illustrations show the positioning for both adults and children.

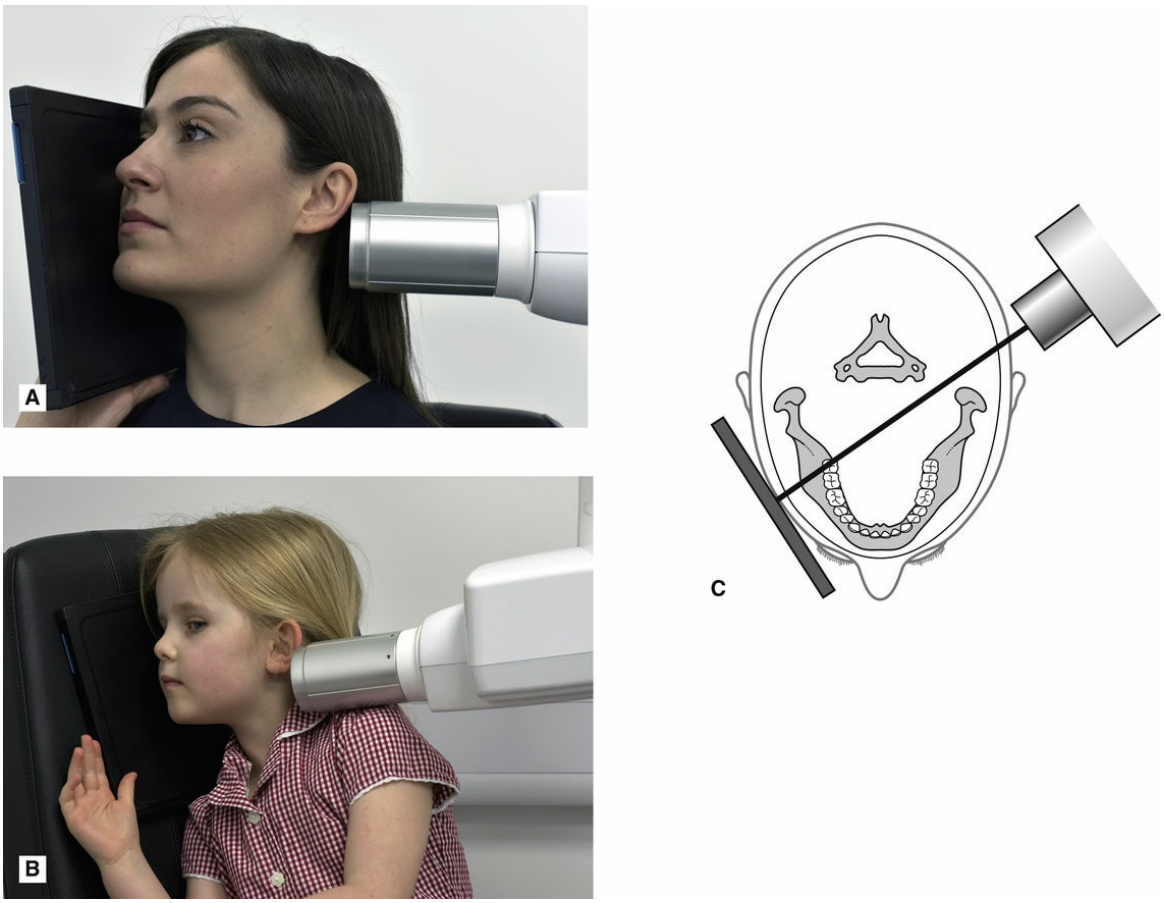


FIG.12.4 Cassette and X-ray tubehead positions to show the RIGHT mandibular and maxillary molars on **(A)** an adult and **(B)** a child. **(C)** Diagram of the positioning from above showing the cassette overlying the molar teeth and the X-ray beam passing between the cervical spine and mandibular ramus.

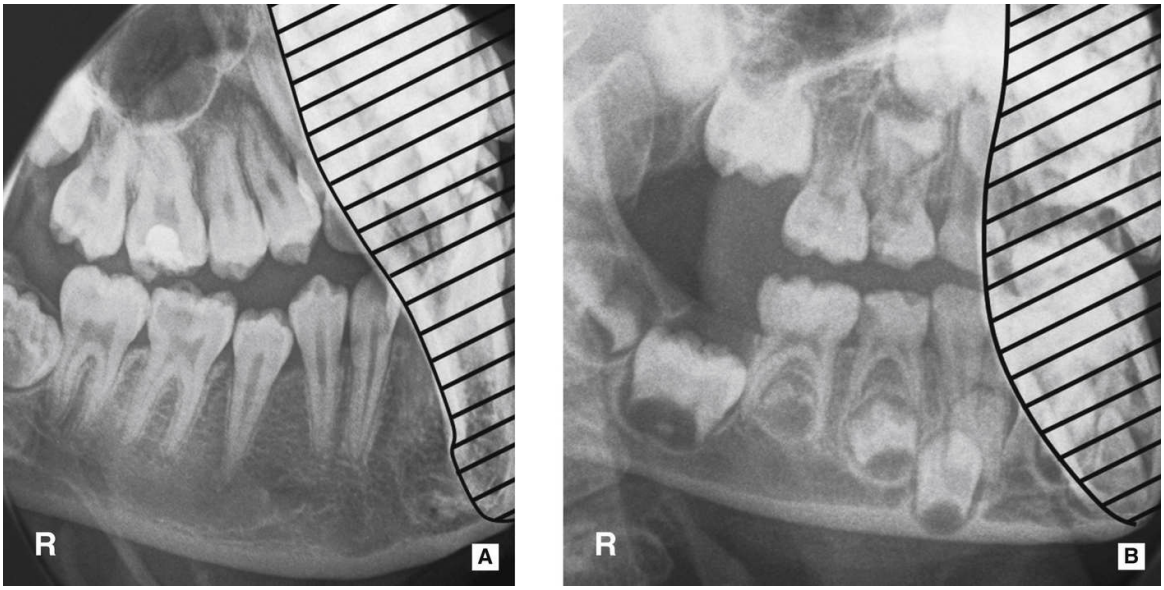


FIG. 12.5 Typical resultant radiographs showing the RIGHT mandibular and maxillary molars of **(A)** an adult and **(B)** a child. In both examples the shadow of the superimposed left ramus has been drawn in to emphasize its position. Compare with Fig. 12.3A . Note the radiographs are mounted and viewed as if the observer is looking at the patient's right side.

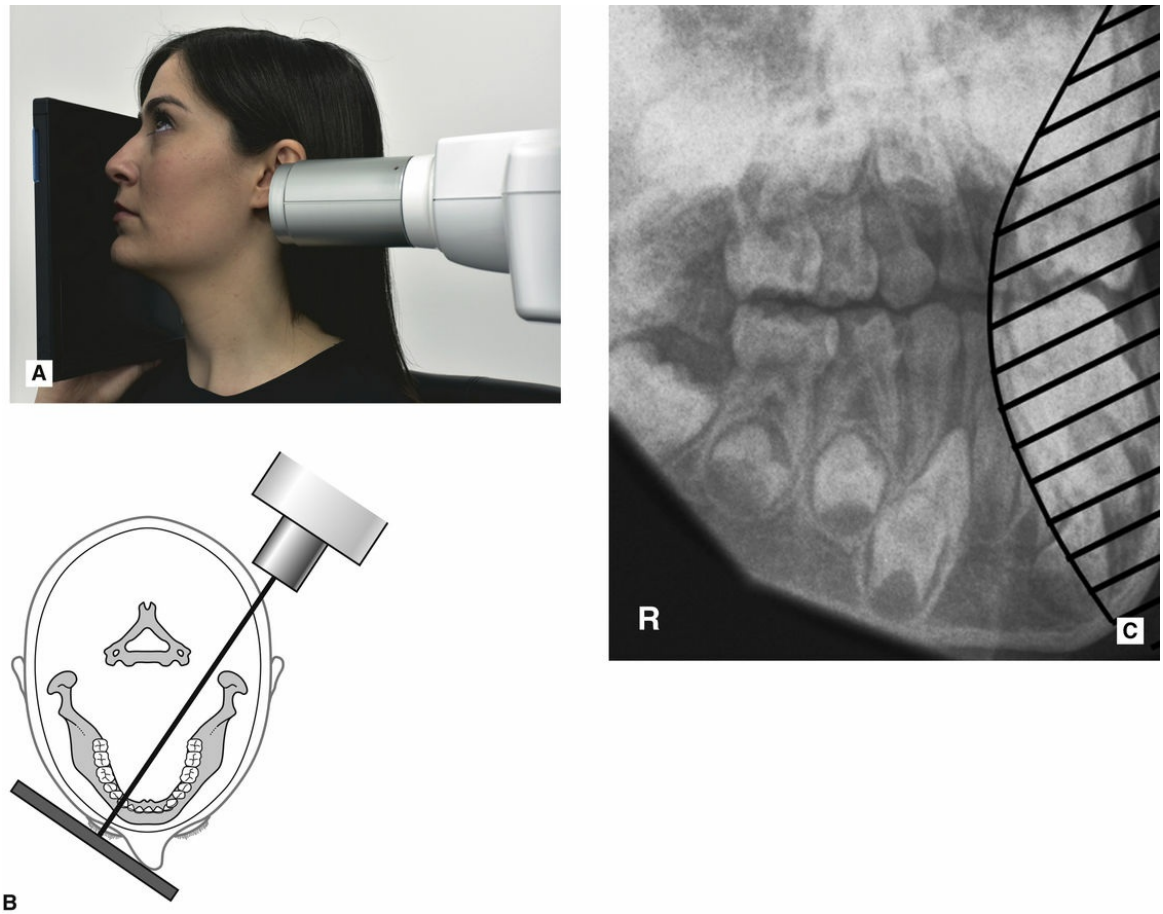
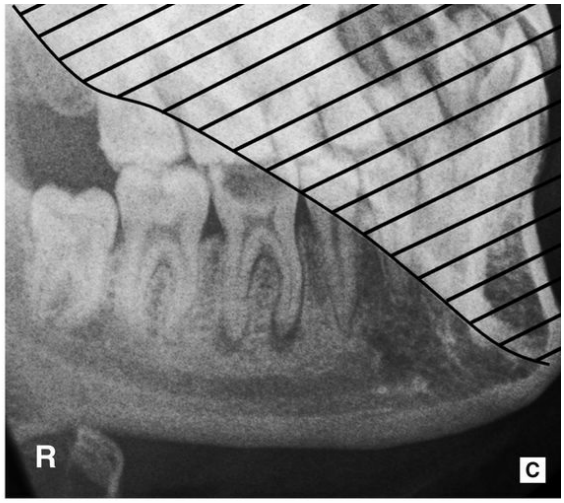


FIG. 12.6 **(A)** Cassette and X-ray tubehead positions for the RIGHT mandibular and maxillary canines. Note the displacement of the nose needed to achieve the desired position for the cassette. **(B)** Diagram of the positioning from above, showing the cassette overlying the canine teeth and the X-ray tubehead aimed through the *radiographic keyhole.* **(C)** A typical resultant radiograph of a patient in the mixed dentition. The shadow of the superimposed left ramus has again been drawn in – it now overlies the lateral incisors. Again note the orientation of the radiograph and how it is viewed.





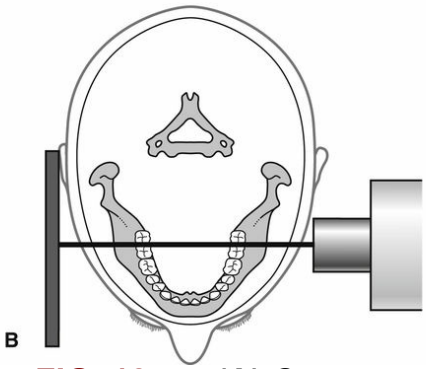


FIG. 12.7 **(A)** Cassette and X-ray tubehead position for the RIGHT mandibular molars. Note the upward angulation of the X-ray tubehead and its position beneath the left body of the mandible. **(B)** Diagram of the positioning from above. Note the position of the X-ray tubehead and compare with Fig. 12.4C . **(C)** A typical resultant radiograph showing the right mandibular molars. The superimposed shadow of the left mandibular body has been drawn in overlying the maxillary molars. Compare with Fig. 12.3B .

Bimolar Technique

As mentioned, *bimolar* is the historical term used for the radiographic projection showing oblique lateral views of the right and left sides of the jaws on the different halves of the same radiograph as shown in Fig. 12.8 .

The technique can be summarized as follows:

1. The patient is positioned with one side of the face in the middle of one-half of the cassette, with the nose towards the midline. The precise positioning depends on which teeth or area of the jaws are being examined (like any other oblique lateral).
2. The other half of the cassette is covered by a lead shield to prevent exposure of this side of the image receptor.
3. The X-ray tubehead is positioned to show the desired area, and the exposure is made.
4. The lead shield is then placed over the other side of the cassette to protect the part of the image receptor already exposed.
5. The patient is then positioned in a similar manner with the cassette held on the other side of the face.
6. The X-ray tubehead is repositioned and a second exposure made.

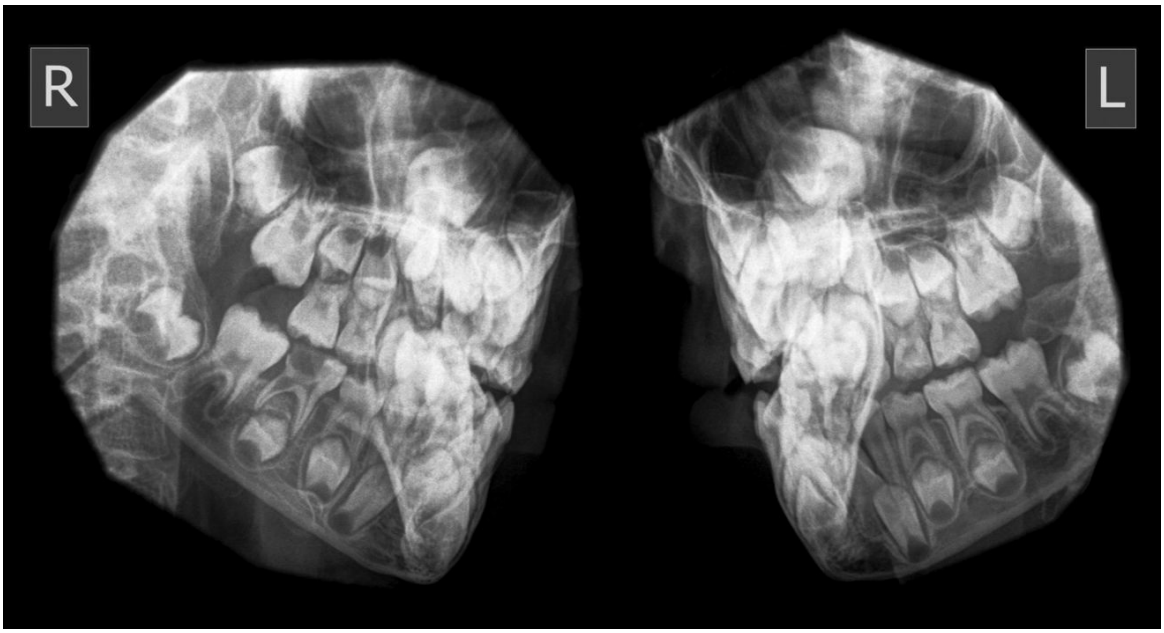


FIG. 12.8 Example of a child's bimolar projection showing the right and left oblique laterals on the same image receptor.

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13

Skull and Maxillofacial Radiography

Radiographs of the whole head were traditionally required for a variety of purposes and because of the complexity of the structure of the maxillofacial skeleton a range of projections was devised. In many cases these techniques have been superseded by computed tomography (see Chapter 18) and cone beam computed tomography (see Chapter 16). However, this sophisticated computed tomography equipment is not universally available. This chapter therefore provides a brief summary of the now somewhat historic main maxillofacial/skull projections, why and how each is taken, what the resultant radiograph looks like and which normal anatomical features are shown.

Equipment, Patient Positioning and Projections

Most skull radiographs were taken using an *isocentric* skull unit such as the Orbix®, often with the patient lying down, or using a conventional skull unit such as the Craniotome® with the patient sitting up (see Fig. 13.1).

The image receptor is commonly a cassette (18 × 24 cm) containing either conventional intensifying screens and indirect-action film or an appropriately sized digital phosphor plate.

Positioning the patient's head for the different projections is facilitated by the *radiographic (orbitomeatal) baseline* – a line representing the base of the skull. It extends from the outer canthus of

the eye to the external auditory meatus and is depicted on the patient's face in subsequent photographs and diagrams.

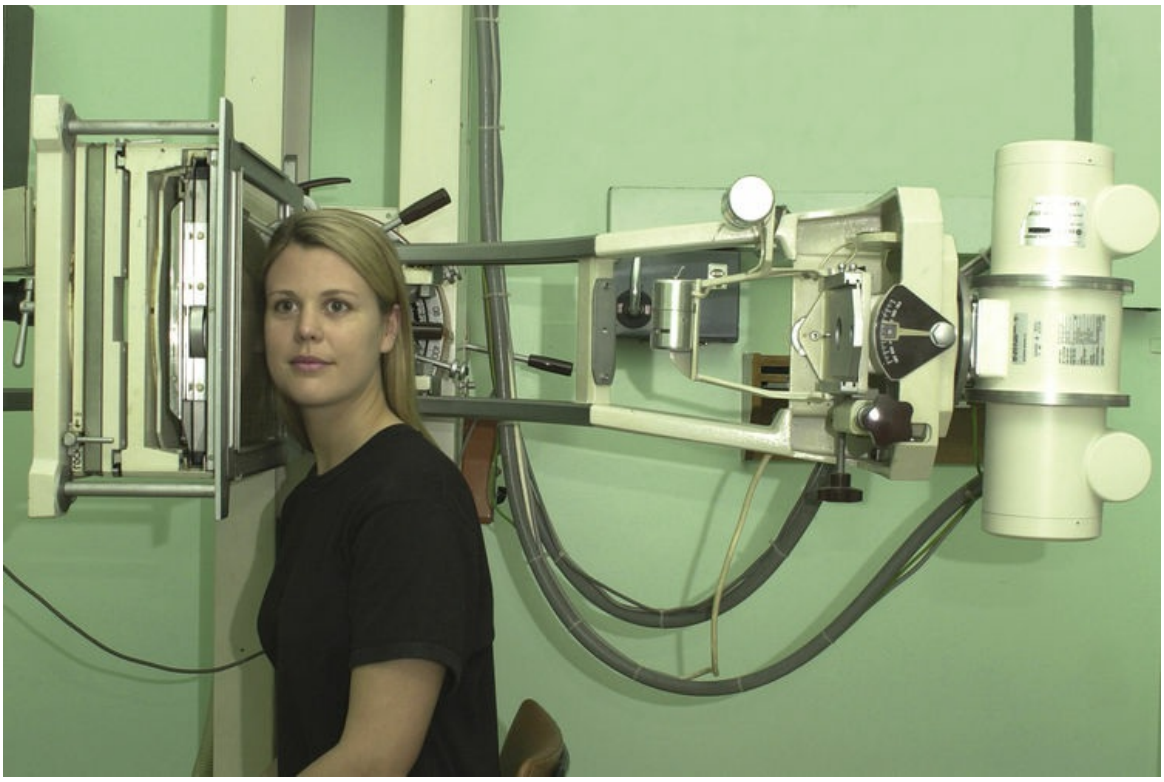


FIG. 13.1 Patient erect in the Craniotome® skull unit positioned to produce a lateral view of the skull.

The main maxillofacial/skull projections are:

- Standard occipitomental (0° OM)
- 30° occipitomental (30° OM)
- Posteroanterior of the skull (PA skull) or occipitofrontal (OF)
- Posteroanterior of the jaws (PA jaws)
- Reverse Towne's
- True lateral skull
- Submentovertex (SMV)

Standard Occipitomental (0° OM)

This projection shows the facial skeleton and maxillary antra, and

avoids superimposition of the dense bones of the base of the skull (see Fig. 13.2).

Main Indications

The main clinical indications include:

- Detecting the following middle third facial fractures (see Chapter 29):
  - Le Fort I
  - Le Fort II
  - Le Fort III
  - Zygomatic complex
  - Naso-ethmoidal complex
  - Orbital blow-out
- Coronoid process fractures
- Investigation of the maxillary antra (see Chapter 31)
- Investigation of the frontal and ethmoidal sinuses
- Investigation of the sphenoidal sinus (projection needs to be taken with the patient's mouth open).

Technique and Positioning

This can be summarized as follows:

1. The patient is positioned facing the image receptor with the head tipped back so the radiographic baseline is at 45° to the image receptor, the so-called *nose–chin* position. This positioning drops the dense bones of the base of the skull downwards and raises the facial bones so they can be seen.
2. The X-ray tubehead is positioned with the central ray horizontal (0°) centred through the occiput (see Fig. 13.3).



FIG. 13.2 An example of a standard occipitomental radiograph.

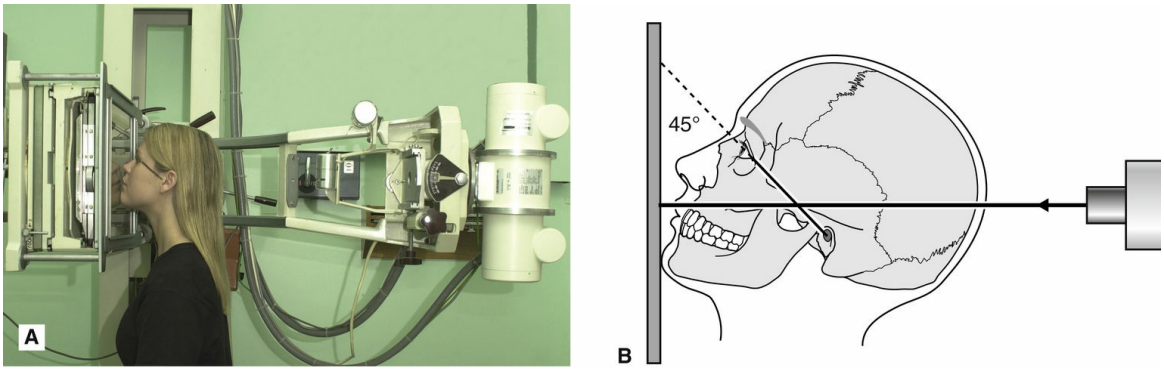


FIG. 13.3 **(A)** Positioning for the standard OM projection – the patient is in the *nose–chin* position and the X-ray beam is horizontal. **(B)** Diagram of the positioning – the radiographic baseline is at 45° to the image receptor, and the X-ray beam is horizontal. The resultant radiograph is shown in Figs. 13.2 and 13.4 .

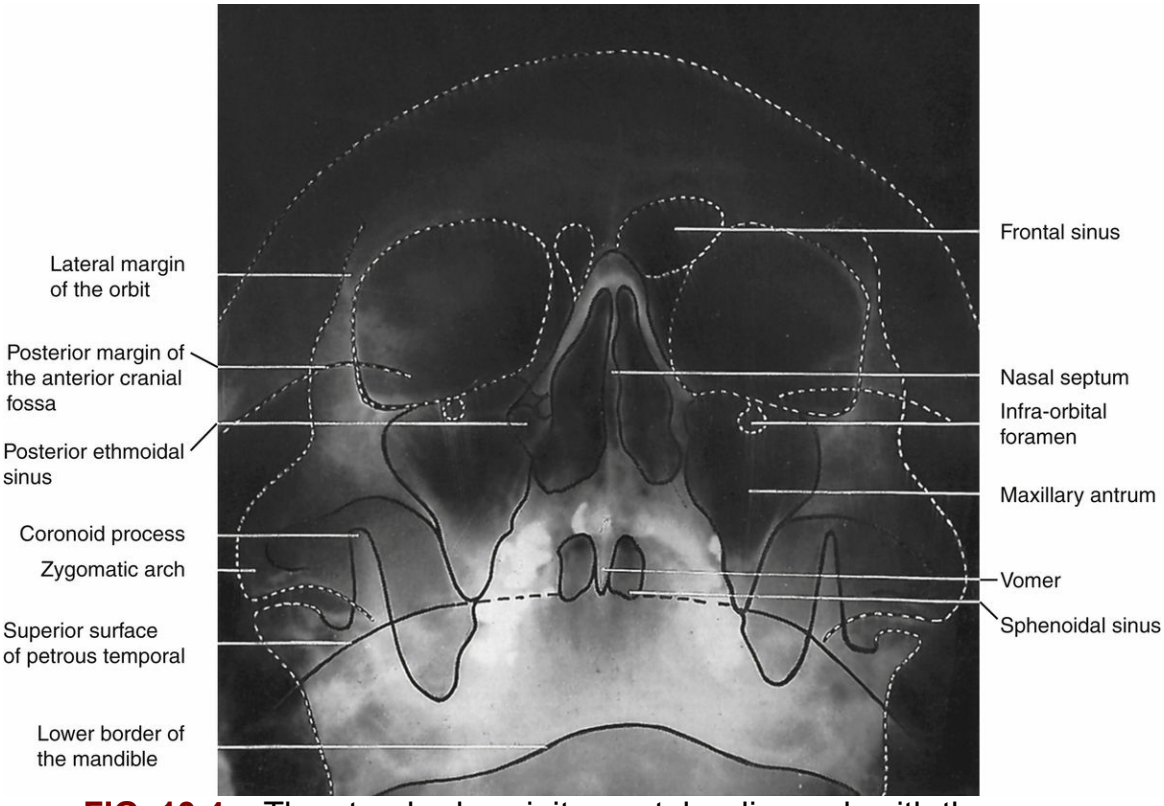


FIG. 13.4 The standard occipitomental radiograph with the major anatomical features drawn in.

The 30° Occipitomental (30° OM)

This projection also shows the facial skeleton, but from a different angle from the 0° OM, enabling certain bony displacements to be detected (see Fig. 13.5).

Main Indications

The main clinical indications include:

- Detecting the following middle third facial fractures:
  - Le Fort I
  - Le Fort II
  - Le Fort III
- Coronoid process fractures.

NOTE: Ideally for fracture diagnosis two views at right angles are required (see Chapter 29), but the 0° OM and 30° OM provide two views of the facial bones at two different angles – therefore in case of suspected facial fracture **both** views are needed.

Technique and Positioning

This can be summarized as follows:

1. The patient is in exactly the same position as for the 0° OM, i.e. the head tipped back, radiographic baseline at 45° to the image receptor, in the *nose–chin* position.
2. The X-ray tubehead is aimed downwards from above the head, with the central ray at 30° to the horizontal, centred through the lower border of the orbit (see Fig. 13.6).

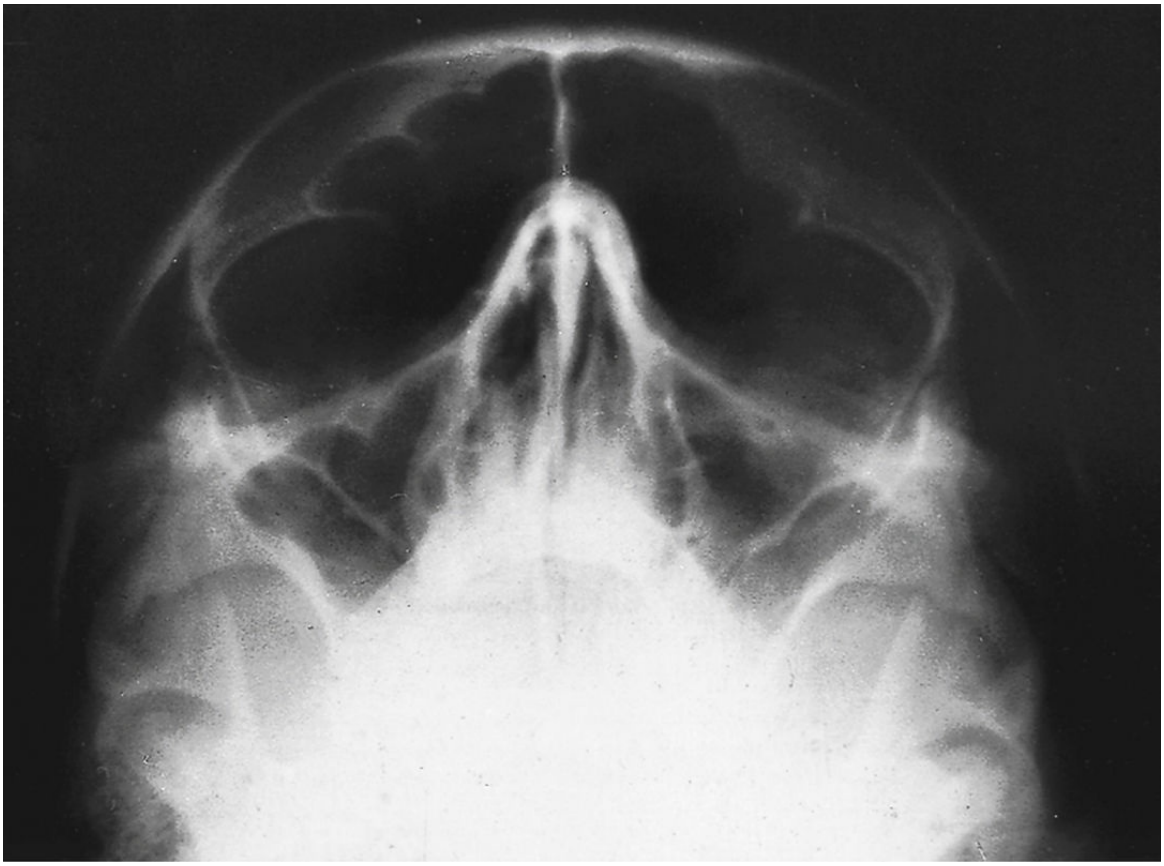


FIG. 13.5 An example of a 30° occipitomental radiograph.

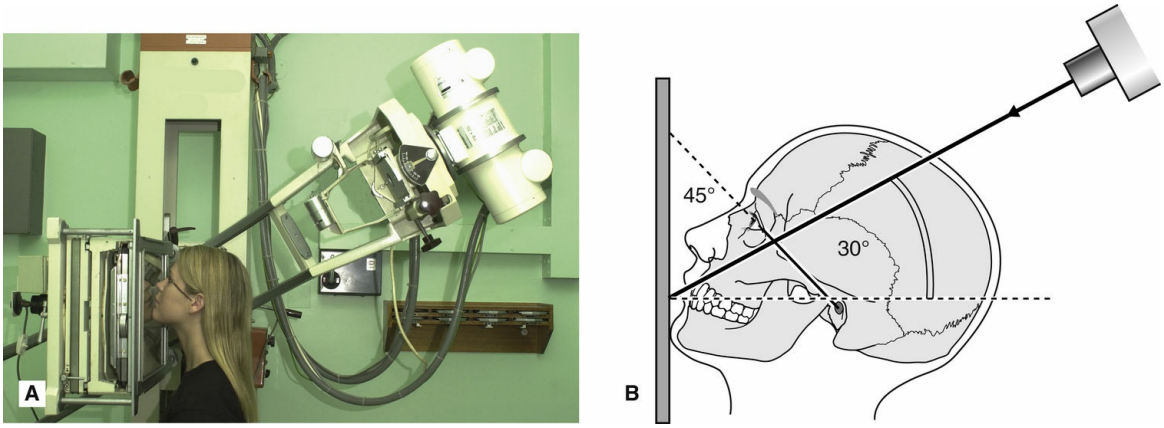


FIG. 13.6 **(A)** Positioning for the 30° occipitomental projection – the patient is in the *nose–chin* position and the X-ray beam is aimed downwards at 30°. **(B)** Diagram of the positioning – the radiographic baseline is at 45° to the image receptor, and the X-ray beam is aimed downwards at 30°. The resultant radiograph is shown in Figs. 13.5 and 13.7 .

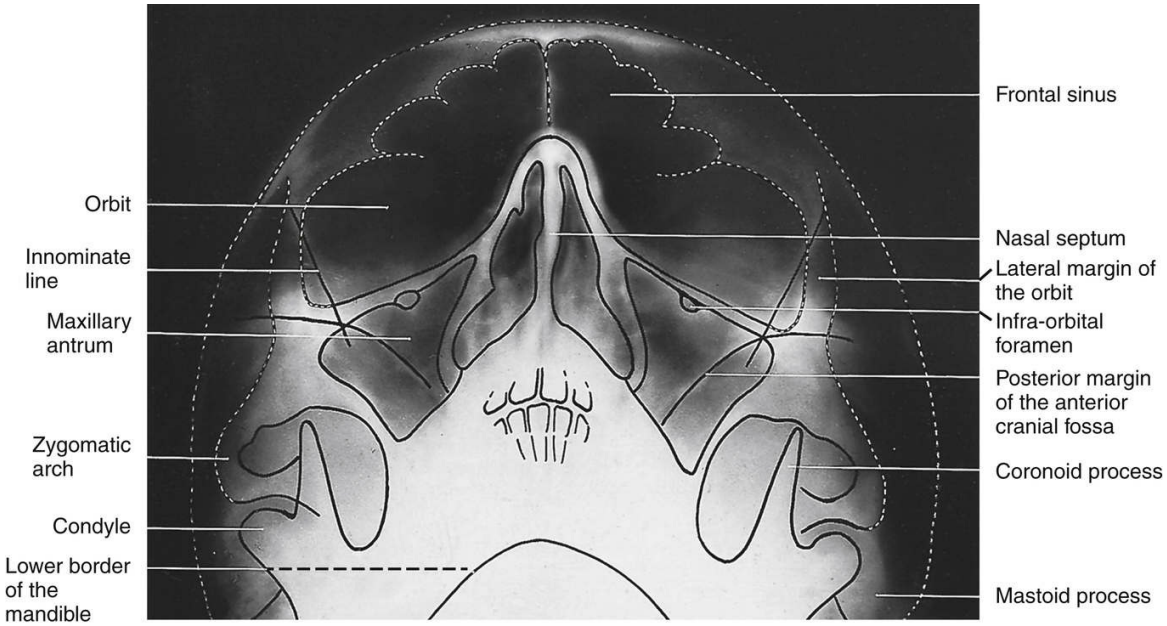


FIG. 13.7 The 30° occipitomental radiograph with the major anatomical features drawn in.

Posteroanterior of the Skull (PA Skull)

This projection shows the skull vault, primarily the frontal bones and the jaws (see Fig. 13.8).

Main Indications

The main clinical indications include:

- Investigation of the frontal sinuses
- Conditions affecting the cranium, particularly:
  - Paget's disease of bone
  - Multiple myeloma
  - Hyperparathyroidism
- Intracranial calcification.

Technique and Positioning

This can be summarized as follows:

1. The patient is positioned facing the image receptor with the head tipped forwards so that the forehead and tip of the nose touch the image receptor – the so-called *forehead–nose* position. The radiographic baseline is horizontal and at right angles to the image receptor. This positioning levels off the base of the skull and allows the vault of the skull to be seen without superimposition.
2. The X-ray tubehead is positioned with the central ray horizontal (0°) centred through the occiput (see Fig. 13.9).

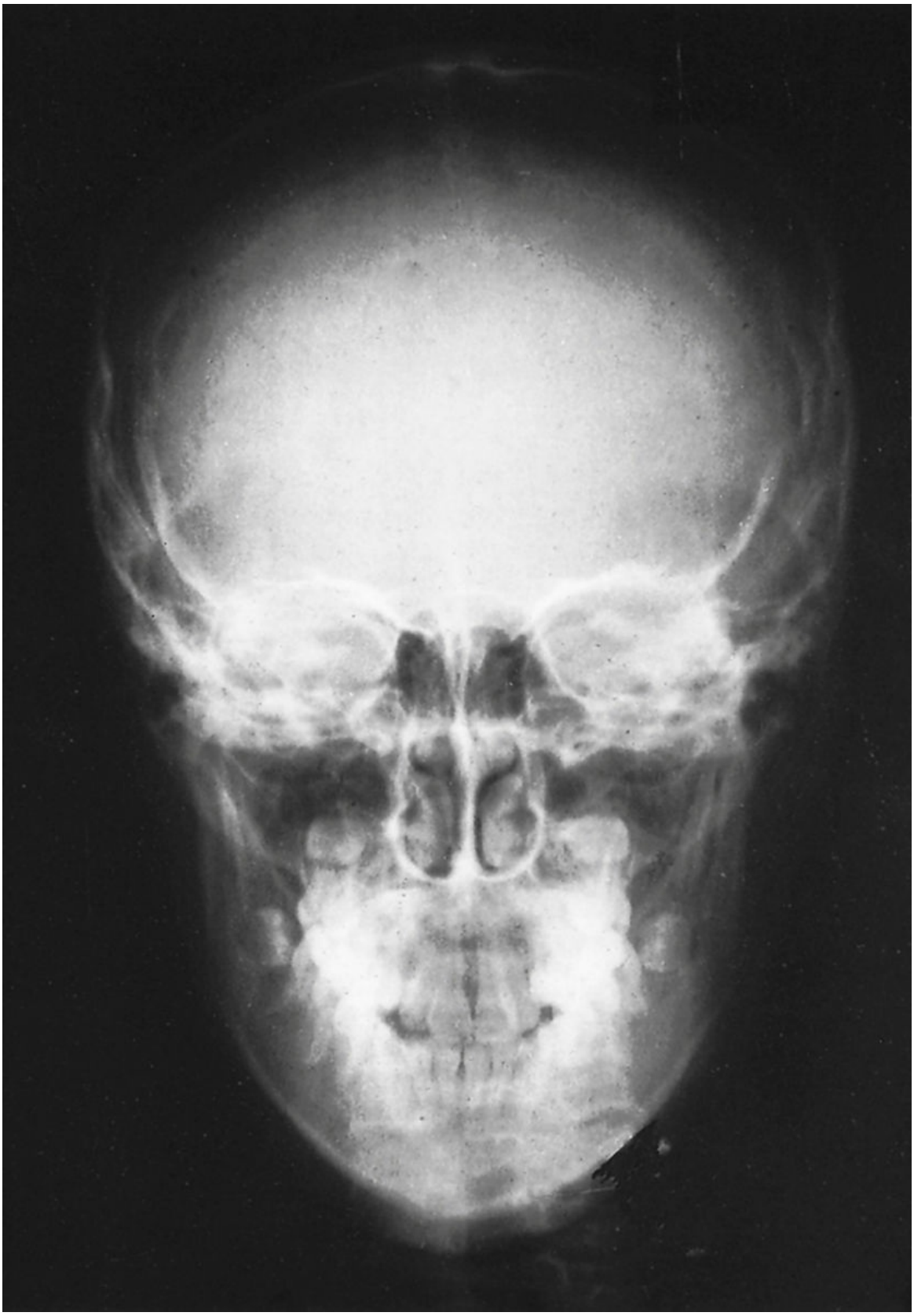


FIG. 13.8 An example of a posteroanterior skull radiograph.

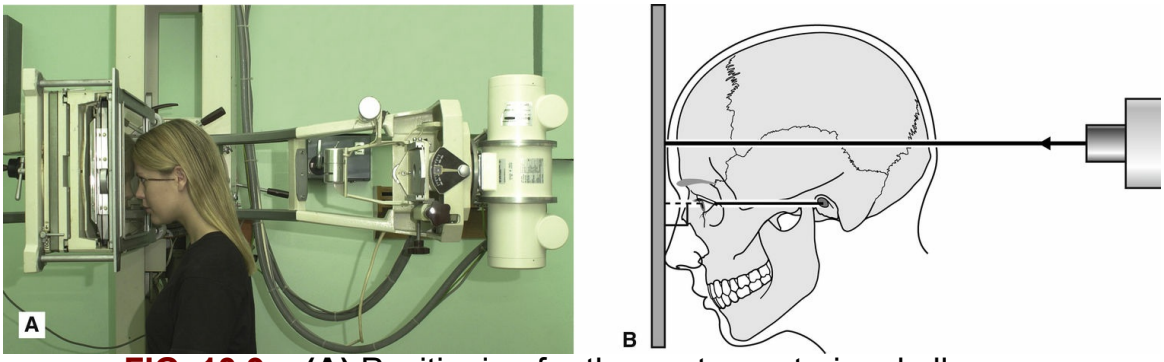


FIG. 13.9 **(A)** Positioning for the posteroanterior skull projection – the patient is in the *forehead–nose* position and the X-ray beam is horizontal. **(B)** Diagram of the positioning – the radiographic baseline is horizontal and perpendicular to the image receptor, and the X-ray beam is also horizontal. The resultant radiograph is shown in Figs. 13.8 and 13.10 .

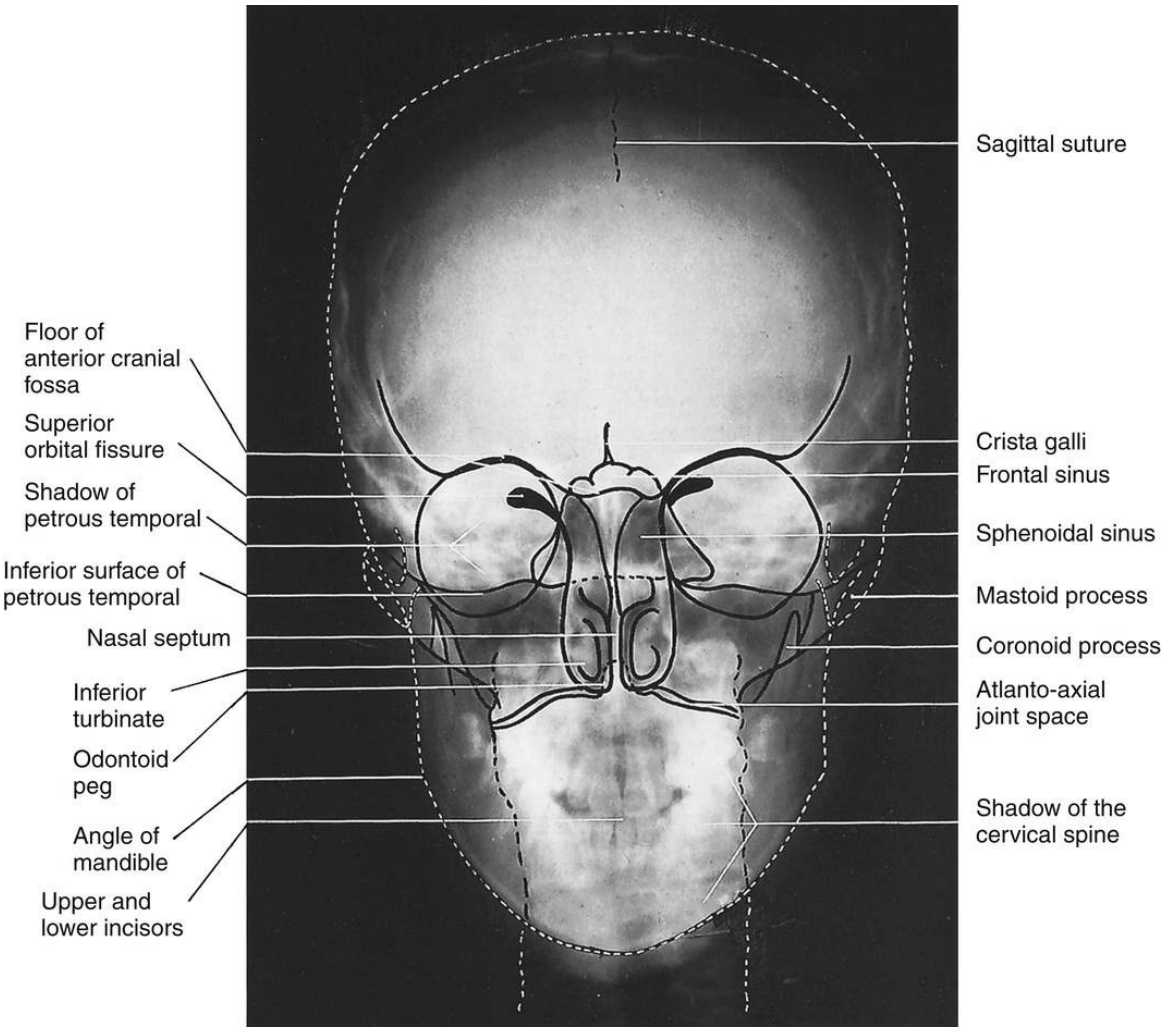


FIG. 13.10 The posteroanterior skull radiograph with the major anatomical features drawn in.

Posteroanterior of the Jaws (PA Jaws/PA Mandible)

This projection shows the posterior parts of the mandible (see Fig. 13.11). It is not suitable for showing the facial skeleton because of superimposition of the base of the skull and the nasal bones.

Main Indications

The main clinical indications include:

- Fractures of the mandible involving the following sites:
  - Posterior third of the body
  - Angles
  - Rami
  - Low condylar necks
- Lesions such as cysts or tumours in the posterior third of the body or rami to note any mediolateral expansion
- Mandibular hypoplasia or hyperplasia
- Maxillofacial deformities.

Technique and Positioning

This can be summarized as follows:

1. The patient is in exactly the same position as for the PA skull, i.e. the head tipped forward, the radiographic baseline horizontal and perpendicular to the image receptor in the *forehead–nose* position.
2. The X-ray tubehead is again horizontal (0°), but now the central ray is centred through the cervical spine at the level of the rami of the mandible (see Fig. 13.12).



FIG. 13.11 An example of a posteroanterior jaws radiograph.

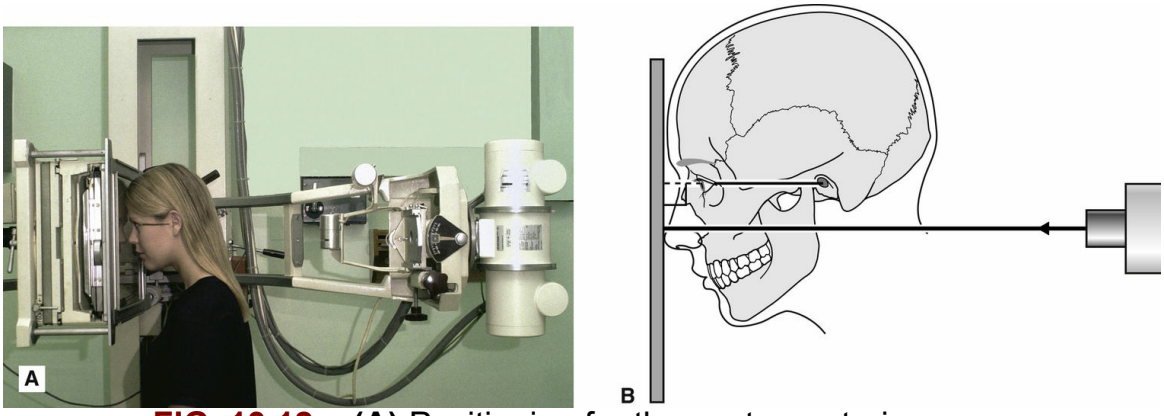


FIG. 13.12 **(A)** Positioning for the posteroanterior jaws/posteroanterior mandible projection – the patient is in the *forehead–nose* position and the X-ray beam is horizontal, centred through the rami. **(B)** Diagram of the positioning – the radiographic baseline is horizontal and perpendicular to the image receptor, and the X-ray beam is also horizontal. The resultant radiograph is shown in Figs. 13.11 and 13.13 .

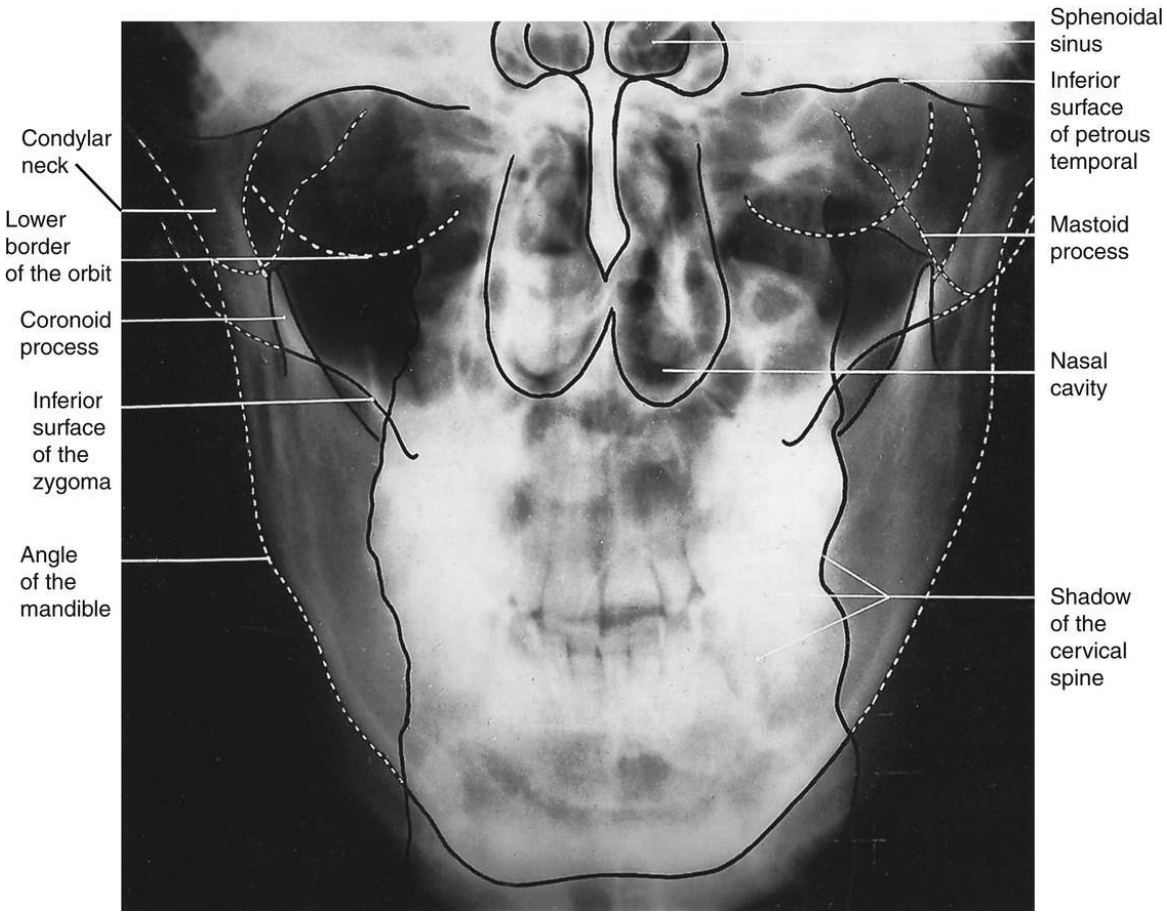


FIG. 13.13 The posteroanterior jaws radiograph with the major anatomical features drawn in.

Reverse Towne's

This projection shows the condylar heads and necks (see Fig. 13.14). The original Towne's view (an anteroposterior projection) was designed to show the occipital region, but also showed the condyles. However, because all skull views used in dentistry are taken conventionally in the posterior–anterior direction, the *reverse Towne's* (a PA projection) is used.

Main Indications

The main clinical indications include:

- High fractures of the condylar necks

- Intracapsular fractures of the temporomandibular joint
- Investigation of the quality of the articular surfaces of the condylar heads in temporomandibular joint disorders
- Condylar hypoplasia or hyperplasia.

Technique and Positioning

This can be summarized as follows:

1. The patient is in the PA position, i.e. the head tipped forwards in the *forehead–nose* position, but in addition the mouth is **open.** The radiographic baseline is horizontal and at right angles to the image receptor. Opening the mouth takes the condylar heads out of the glenoid fossae so they can be seen.
2. The X-ray tubehead is aimed upwards from below the occiput, with the central ray at 30° to the horizontal, centred through the condyles (see Fig. 13.15).



FIG. 13.14 An example of a reverse Towne's radiograph.

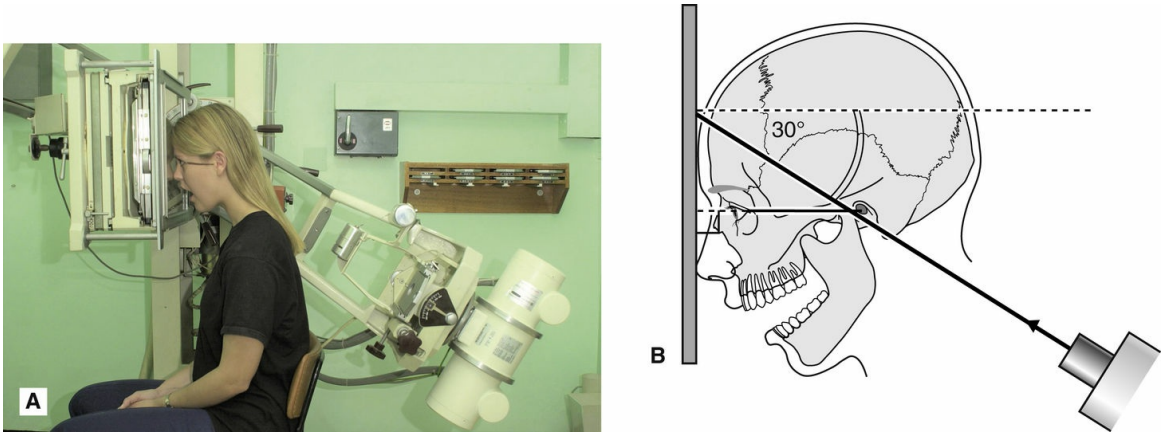


FIG. 13.15 **(A)** Positioning for the reverse Towne's projection – the patient is in the *forehead–nose* position with the mouth open and the X-ray beam is aimed upwards at 30°. **(B)** Diagram of the positioning – the radiographic baseline is horizontal and perpendicular to the image receptor, the mouth is open and the X-ray beam is aimed upwards at 30°. The resultant radiograph is shown in Figs. 13.14 and 13.16 .

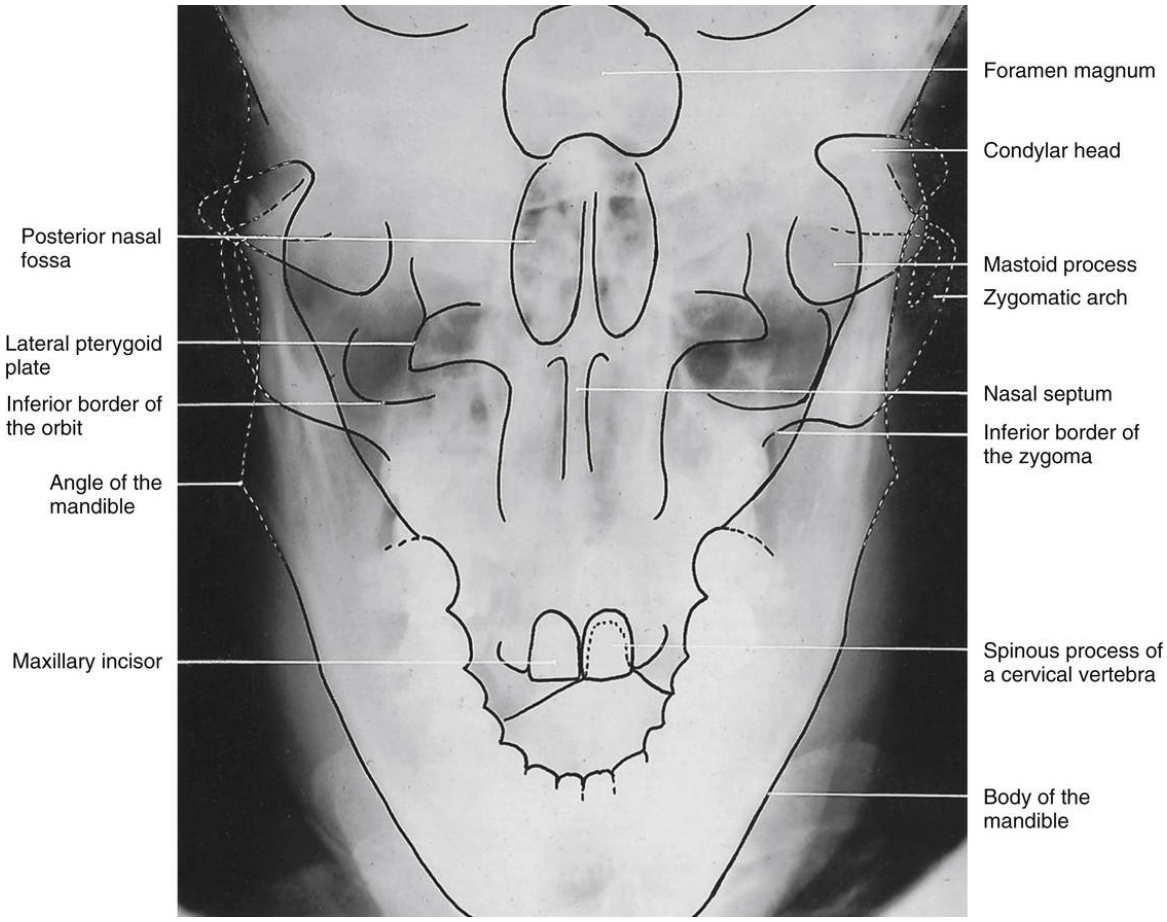


FIG. 13.16 The reverse Towne's radiograph with the major anatomical features drawn in.

True Lateral Skull

This projection shows the skull vault and facial skeleton from the lateral aspect (see Fig. 13.17). The main difference between the *true lateral skull* and the *true cephalometric lateral skull* taken on the cephalostat (see Chapter 14) is that the *true lateral skull* is not standardized or reproducible. This view is used when a single lateral view of the skull is required but not in orthodontics or growth studies.

Main Indications

The main clinical indications include:

- Fractures of the cranium and the cranial base

- Middle third facial fractures, to show possible downward and backward displacement of the maxillae
- Investigation of the frontal, sphenoidal and maxillary sinuses
- Conditions affecting the skull vault, particularly:
  - Paget's disease of bone
  - Multiple myeloma
  - Hyperparathyroidism
- Conditions affecting the sella turcica, such as:
  - Tumour of the pituitary gland in acromegaly.

Technique and Positioning

This can be summarized as follows:

1. The patient is positioned with the head turned through 90°, so the side of the face touches the image receptor. In this position, the sagittal plane of the head is parallel to the image receptor.
2. The X-ray tubehead is positioned with the central ray horizontal (0°) and perpendicular to the sagittal plane and the image receptor, centred through the external auditory meatus (see Fig. 13.18).

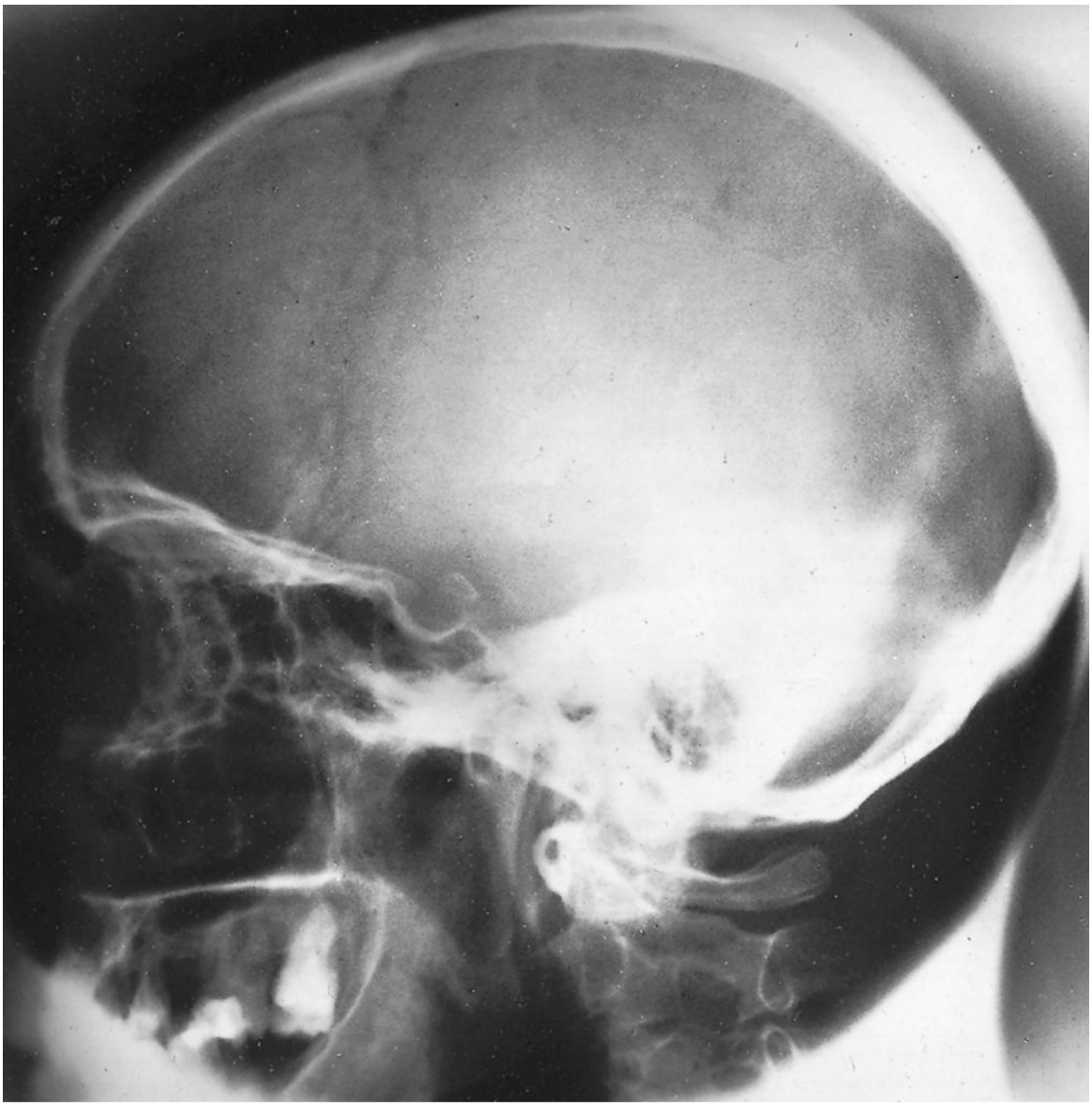


FIG. 13.17 An example of a true lateral skull radiograph.

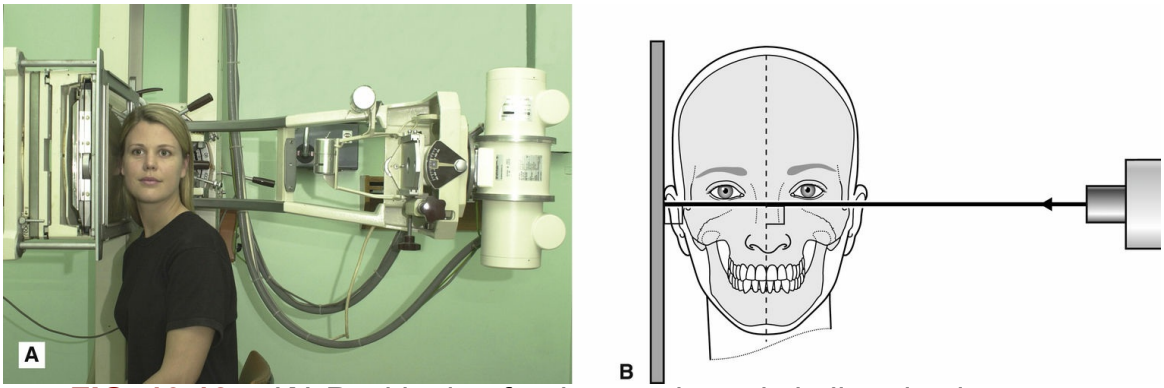


FIG. 13.18 **(A)** Positioning for the true lateral skull projection – the patient's head is turned through 90° and the X-ray beam is horizontal. **(B)** Diagram of the positioning – the sagittal plane of the head is parallel to the image receptor and the X-ray beam is horizontal and perpendicular to the sagittal plane and the image receptor. The resultant radiograph is shown in Figs. 13.17 and 13.19 .

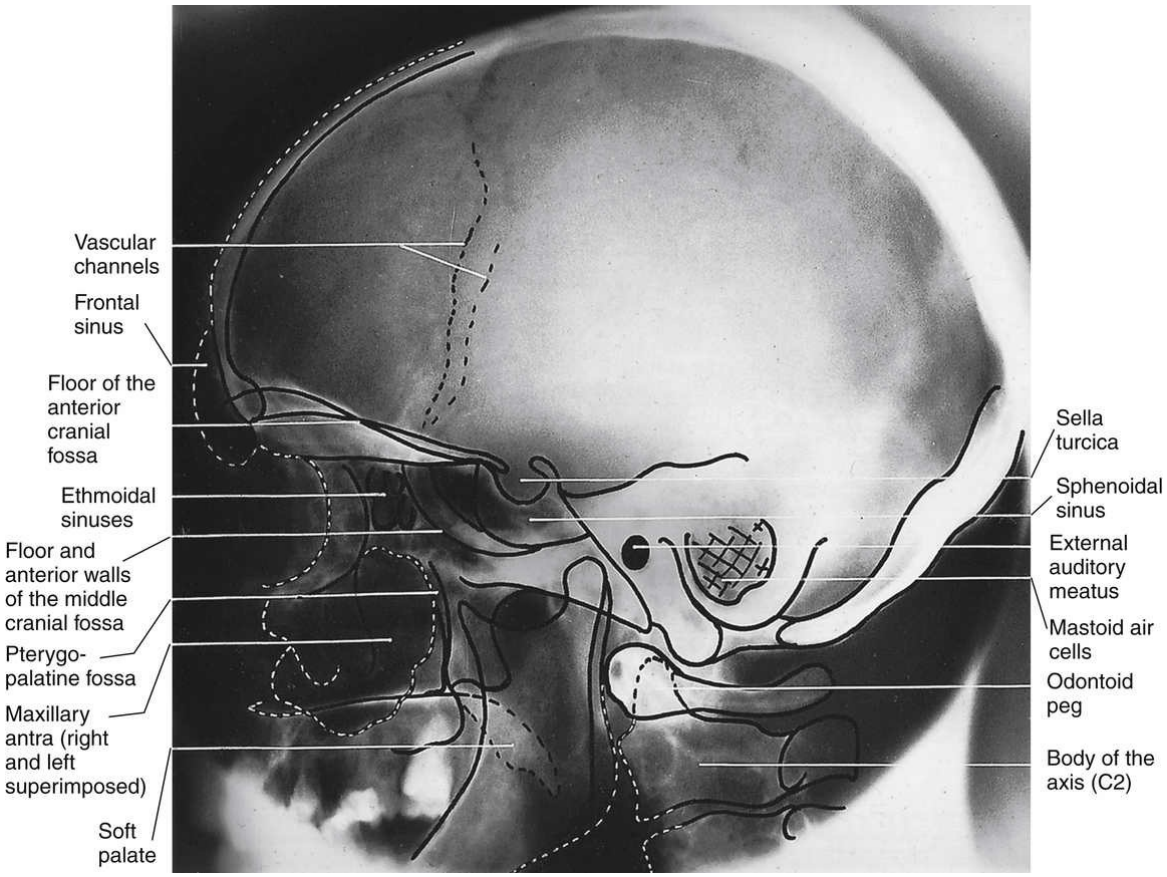


FIG. 13.19 The true lateral skull radiograph with the major anatomical features drawn in.

Submentovertex (SMV)

This projection shows the base of the skull, sphenoidal sinuses and facial skeleton from below (see Fig. 13.20).

Main Indications

The main clinical indications include:

- Investigation of the sphenoidal sinus
- Assessment of the thickness (mediolateral) of the posterior part of the mandible before osteotomy
- Fracture of the zygomatic arches – to show these thin bones the submentovertex is taken with reduced exposure factors

- Investigating the skull base.

Technique and Positioning

This can be summarized as follows:

1. The patient is positioned facing away from the image receptor. The head is tipped backwards as far as is possible, so the vertex of the skull touches the image receptor. In this position, the radiographic baseline is vertical and parallel to the image receptor.
2. The X-ray tubehead is aimed upwards from below the chin, with the central ray at 5° to the horizontal, centred on an imaginary line joining the lower first molars (see Fig. 13.21).

NOTE: The head positioning required for this projection means it is **contraindicated** in patients with suspected neck injuries, especially suspected fracture of the odontoid peg.



FIG. 13.20 An example of a well-exposed submentovertex radiograph.

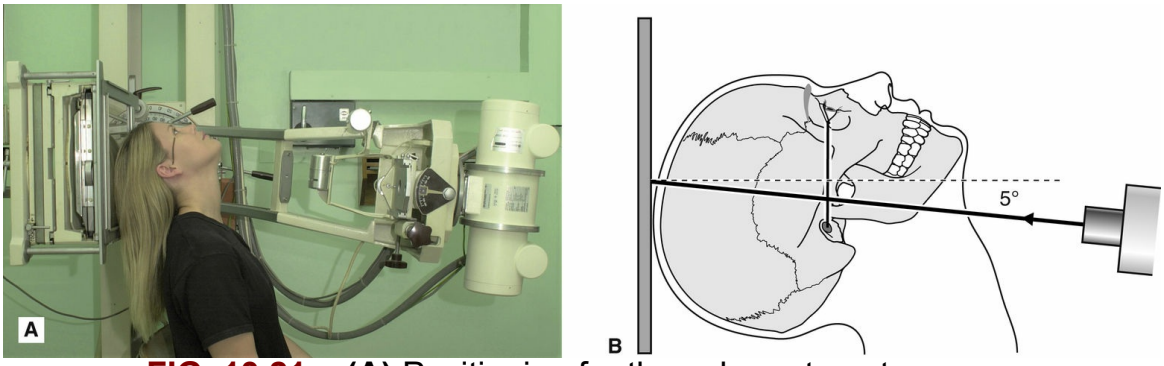


FIG. 13.21 **(A)** Positioning for the submentovertex projection – the patient's head is tipped backwards and the X-ray beam is aimed upwards at 5° to the horizontal. **(B)** Diagram of the positioning – the radiographic baseline is vertical and parallel to the image receptor and the X-ray beam is aimed upwards at 5° to the horizontal. The resultant radiograph is shown in Figs. 13.20 and 13.22 .

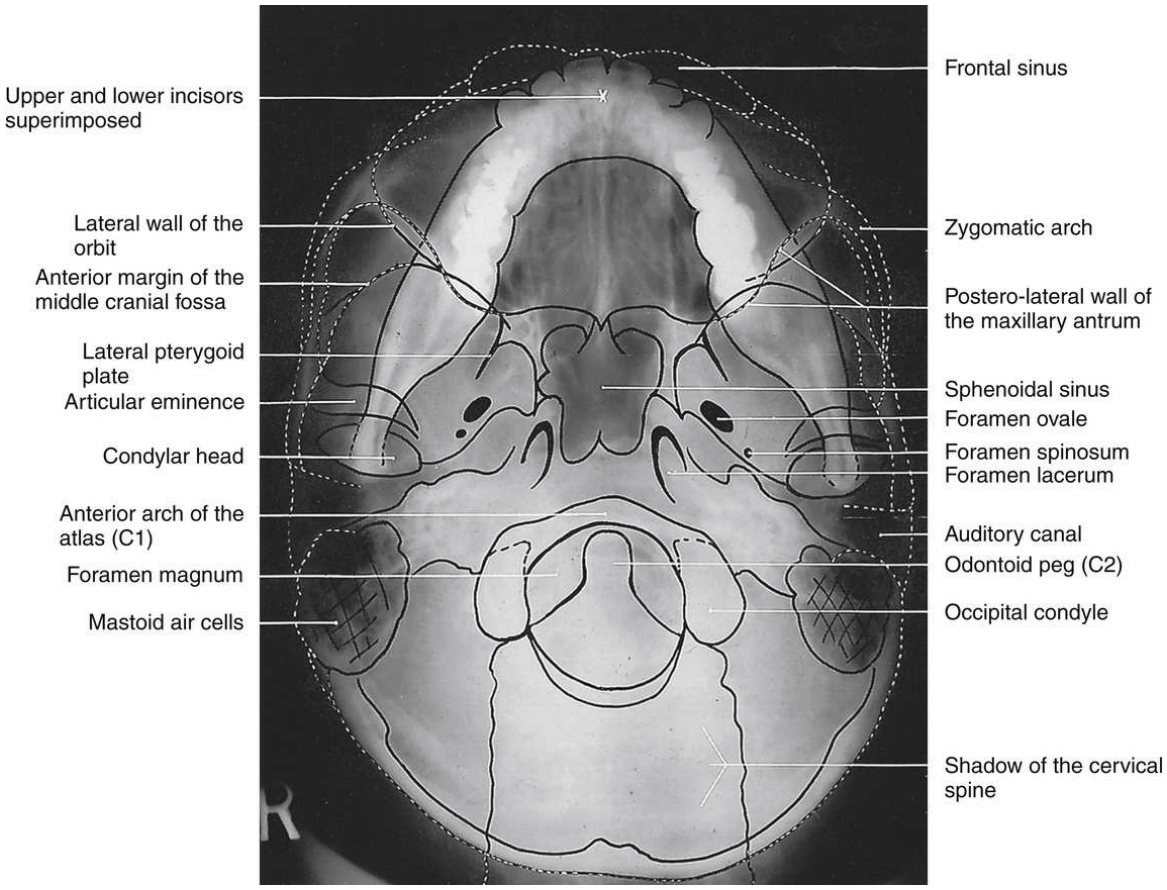


FIG. 13.22 The submentovertex radiograph with the major anatomical features drawn in.

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14

Cephalometric Radiography

Introduction

Cephalometric radiography is a standardized and reproducible form of skull radiography used extensively in orthodontics and maxillofacial surgery to assess the relationships of the teeth to the jaws and the jaws to the rest of the facial skeleton. Standardization was essential for the development of *cephalometry* – the measurement and comparison of specific points, distances and lines within the facial skeleton, which is now an integral part of orthodontic assessment. The greatest value is probably obtained from these radiographs if they are traced or digitized, and this is essential when they are being used for the monitoring of treatment progress.

Main Indications

The main clinical indications can be considered under two major headings – orthodontics and orthognathic surgery.

Orthodontics

- Initial diagnosis – confirmation of the underlying dental skeletal and/or soft tissue abnormalities
- Treatment planning
- Monitoring treatment progress, e.g. to assess anchorage requirements and incisor inclination
- Appraisal of treatment results, e.g. just before the completion of active treatment to ensure that treatment targets can be

achieved and to allow planning of retention.

When considering these indications, it should be remembered that all radiographs must be clinically justified – a legislative requirement in most countries. In the UK, indications and selection criteria for cephalometric radiographs are clearly identified in the British Orthodontic Society's 2015 booklet *Orthodontic Radiographs – Guidelines for the Use of Radiographs in Clinical Orthodontics* (fourth edition) and in the Faculty of General Dental Practice (UK)'s booklet *Selection Criteria for Dental Radiography* (third edition), updated in 2018. These guidelines are designed to assist in the *justification* process so as to avoid the use of unnecessary radiographs.

Orthognathic Surgery

- Preoperative evaluation of skeletal and soft tissue patterns
- Treatment planning
- Postoperative appraisal of the results of surgery and long-term follow-up studies.

Equipment

Cephalometric radiography needs to be reproducible. To achieve this both the patient and the X-ray source need to be in fixed positions. Modern equipment for this purpose is typically combined with a panoramic unit and can be divided into:

- Digital phosphor plate or film-based
- Digital solid-state.

Digital Phosphor Plate or Film-based Equipment (see Fig. 14.1)

This equipment is designed for traditional (sometimes referred to as

one shot) radiography (see Fig. 14.2). The basic components include:

- The panoramic tubehead, which remains stationary during the exposure
- The cephalostat (or craniostat) comprising head positioning and stabilizing apparatus with ear rods to ensure a standardized patient position. Additional positioning guides can include forehead supports and infraorbital guide rods.
- The rigid connector ensuring the tubehead and cephalostat are always located a fixed distance apart so that successive radiographs are reproducible and comparable. To minimise the effect of magnification the tubehead to image receptor distance should ideally be in the range of 1.5–1.8 m.
- An image receptor consisting of a cassette (usually 18 × 24 cm) containing a suitably sized digital phosphor plate or rare earth intensifying screens and indirect action film.

Exposure factors for this type of equipment are typically in the order of 74 kV, 4 mA with an exposure time of 0.8 seconds.

Digital Solid-state Equipment (see Fig. 14.3)

This equipment is designed for *scanning* radiography as shown in Fig. 14.4 . The basic components include:

- The panoramic tubehead incorporating the primary collimator, which moves (usually horizontally) during the exposure creating a very narrow X-ray beam
- The cephalostat (or craniostat) comprising head positioning and stabilizing apparatus with ear rods to ensure a standardized patient position. Additional positioning guides can include forehead supports and infraorbital guide rods.
- The rigid connector ensuring the tubehead and cephalostat are always located a fixed distance apart so that successive radiographs are reproducible and comparable. To minimise the effect of magnification the tubehead to image receptor

distance should ideally again be in the range of 1.5–1.8 m.



FIG. 14.1 An example of a combined panoramic/cephalostat unit – the Planmeca PM 2002 Proline – suitable for digital phosphor plate or film-based imaging.

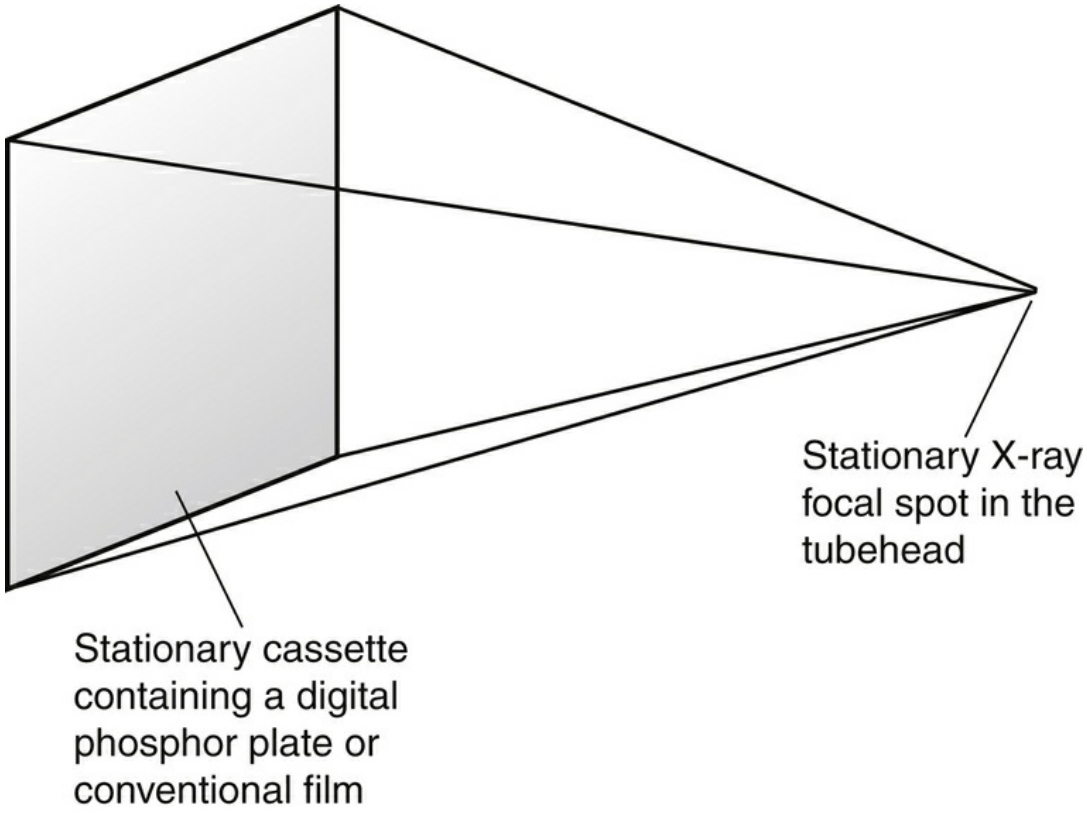


FIG. 14.2 Diagram illustrating the principle of traditional *one shot* radiography used when using digital phosphor plate or film-based imaging. The entire image is captured in a single, fraction of a second, exposure.

- A secondary collimator and solid-state sensor, which move synchronously (usually horizontally) during the exposure so enabling the *scanning* process as shown in Fig. 14.5 . The secondary collimator ensures that the X-ray beam is the same shape as the charge coupled device arrays in the sensor and that they are aligned exactly. The data captured from the two charge coupled device arrays are *stitched* together to create the final image (see Chapter 5).

Exposure factors for this type of scanning equipment are typically in the order of 74 kV, 4 mA with an exposure scanning time of approximately 12 seconds. As with all radiography the patient cannot move during the exposure. To minimize the chance of movement alternative *fast scanning* modes are available using exposure factors in

the order of 74 kV, 8 mA thereby almost halving exposure times to approximately 6.5 seconds.



FIG. 14.3 An example of a combined panoramic/cephalostat unit – the Planmeca Promax – designed for solid-state digital imaging.

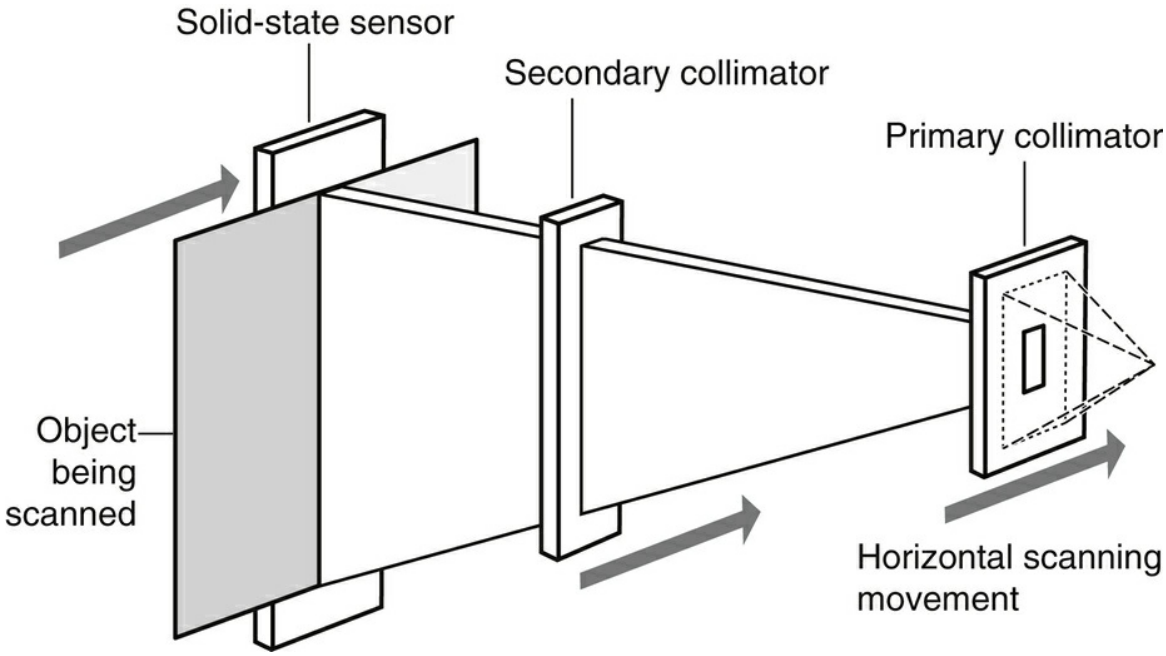


FIG. 14.4 Diagram illustrating the principle of horizontal *scanning* radiography used in solid-state digital imaging. The entire image is captured during an approximately 6 to 12 second exposure.
Courtesy of Mr J. Davies.

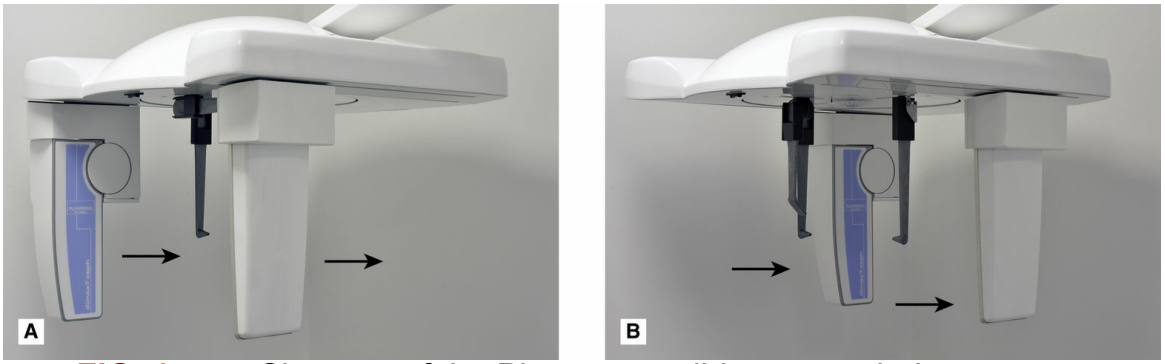


FIG. 14.5 Close-up of the Planmeca solid-state cephalostat and secondary collimator. **(A)** At the start of the exposure and

(B) at the end after the equipment has moved horizontally during the *scanning* process.

Main Radiographic Projections

These include:

- True cephalometric lateral skull
- Cephalometric posteroanterior of the jaws (PA jaws).

True Cephalometric Lateral Skull

As stated in Chapter 12 , the terminology used to describe lateral skull projections is somewhat confusing, the adjective *true,* as opposed to *oblique,* being used to describe lateral skull projections when:

- The image receptor is parallel to the sagittal plane of the patient's head
- The X-ray beam is perpendicular to image receptor and sagittal plane.

In addition, the word cephalometric should be included when describing the *true lateral skull* radiograph taken in the cephalostat. This enables differentiation from the nonstandardized *true lateral skull* projection taken in a skull unit, as described in Chapter 13 . It is now an accepted convention to view orthodontic lateral skull radiographs with the patient facing to the *right,* as shown in Fig. 14.6 .

Patient Positioning

Irrespective of the type of equipment being used, patient positioning is the same and can be summarized as follows:

1. The patient is positioned within the cephalostat, with the sagittal plane of the head vertical and parallel to the image

receptor and with the Frankfort plane horizontal. The teeth should generally be in maximum intercuspation.

2. The head is immobilized carefully within the apparatus with the plastic ear rods being inserted gradually into the external auditory meati.
3. The equipment is designed to ensure that when the patient is positioned correctly, the X-ray beam is horizontal and centred on the ear rods (see Fig. 14.6).

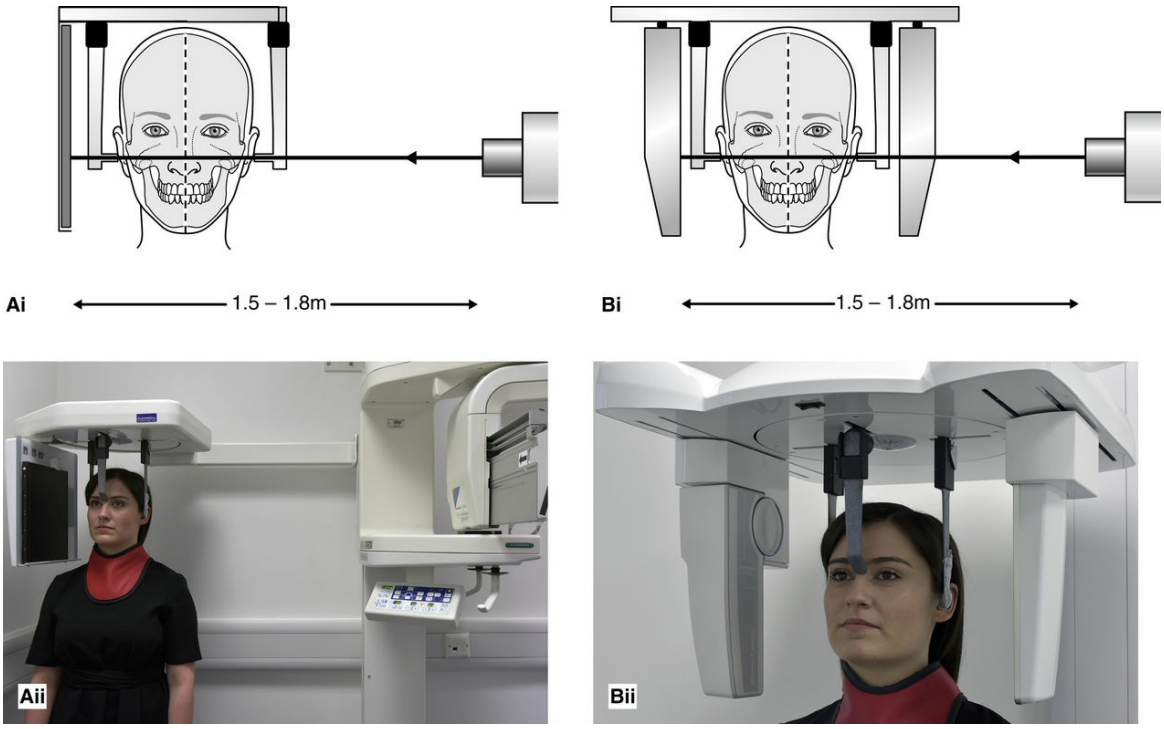


FIG. 14.6 Diagrams and photographs showing similar patient positioning in the cephalostat when using **(A)** phosphor plate/film-based *one shot* or **(B)** solid-state *scanning* equipment.

Cephalometric Tracing/Digitizing

This produces a diagrammatic representation of certain anatomical points or landmarks evident on the lateral skull radiograph (see Fig. 14.7). These points are traced on to an overlying sheet of paper or

acetate or digitally recorded. Either method allows precise measurements to be made. As a basic system these could include:

- The outline and inclination of the anterior teeth
- The positional relationship of the mandibular and maxillary dental bases to the cranial base
- The positional relationship of the dental bases to one another, i.e. the skeletal patterns
- The relationship between the bones of the skull and the soft tissues of the face.

Main Cephalometric Points

The definitions of the main cephalometric points (as indicated in a clockwise direction on the tracing shown in Fig. 14.8) include:

Sella (S). The centre of the sella turcica (determined by inspection).
Orbitale (Or). The lowest point on the infraorbital margin.
Nasion (N). The most anterior point on the frontonasal suture.
Anterior nasal spine (ANS). The tip of the anterior nasal spine.
Subspinale or point A. The deepest midline point between the anterior nasal spine and prosthion.
Prosthion (Pr). The most anterior point of the alveolar crest in the premaxilla, usually between the upper central incisors.
Infradentale (Id). The most anterior point of the alveolar crest, situated between the lower central incisors.
Supramentale or point B. The deepest point in the bony outline between the infradentale and the pogonion.
Pogonion (Pog). The most anterior point of the bony chin.
Gnathion (Gn). The most anterior and inferior point on the bony outline of the chin, situated equidistant from pogonion and menton.
Menton (Me). The lowest point on the bony outline of the mandibular symphysis.
Gonion (Go). The most lateral external point at the junction of the

horizontal and ascending rami of the mandible.



FIG. 14.7 An example of a digitally captured cephalometric lateral skull radiograph.

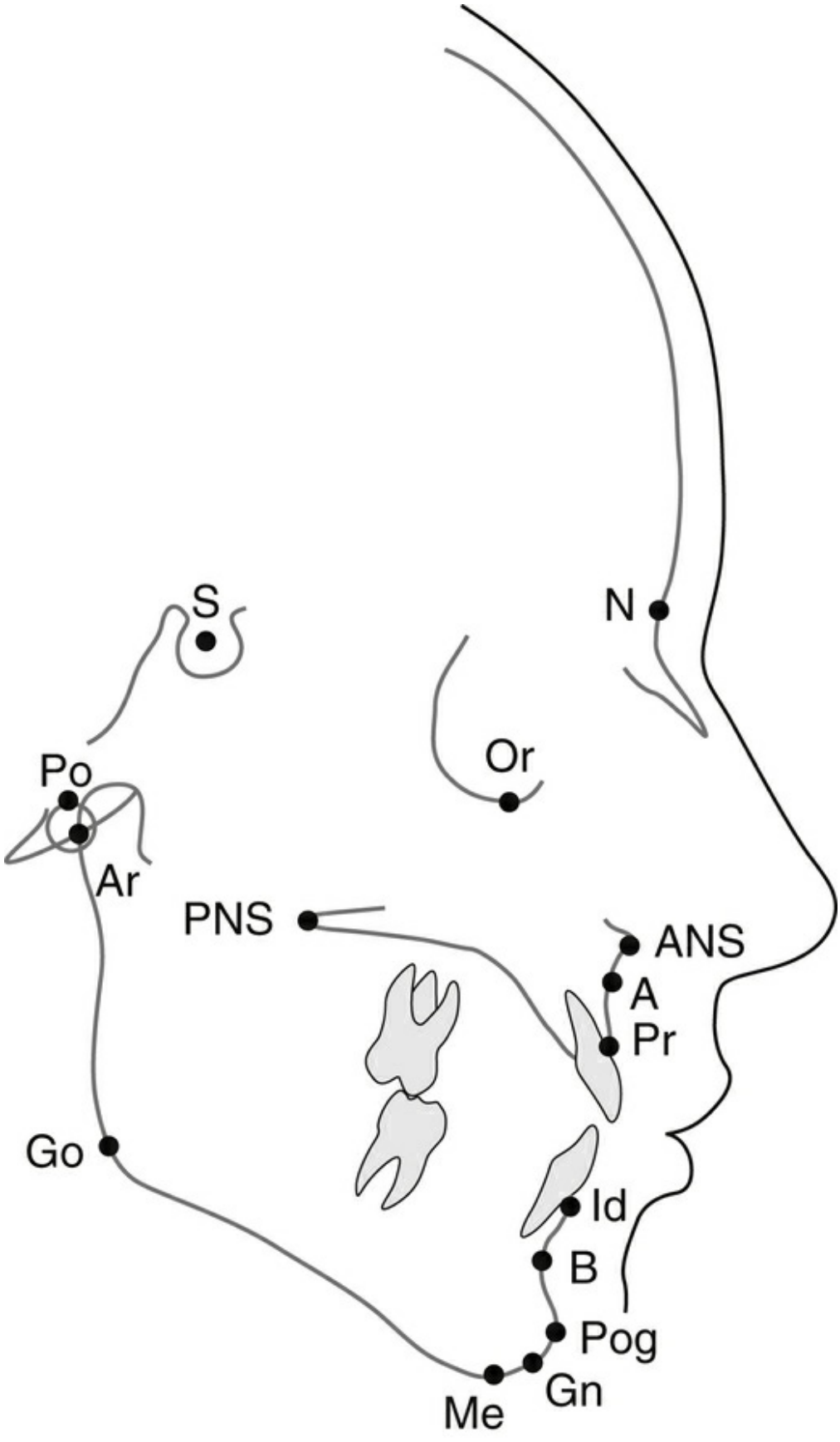

S
N
Or
Po
Ar
PNS
ANS
A
Pr
Go
Id
B
Pog
Gn
Me

FIG. 14.8 A cephalometric tracing of a lateral skull radiograph showing the main cephalometric points.

Note : The gonion is found by bisecting the angle formed by tangents to the posterior and inferior borders of the mandible.

Posterior nasal spine (PNS). The tip of the posterior spine of the palatine bone in the hard palate.

Articulare (Ar). The point of intersection of the dorsal contours of the posterior border of the mandible and temporal bone.

Porion (Po). The uppermost point of the bony external auditory meatus, usually regarded as coincidental with the uppermost point of the ear rods of the cephalostat.

Main Cephalometric Planes and Angles

The definitions of the main cephalometric planes and angles shown in Fig. 14.9 include:

Frankfort plane. A transverse plane through the skull represented by the line joining porion and orbitale.

Mandibular plane. A transverse plane through the skull representing the lower border of the horizontal ramus of the mandible.

There are several definitions:

- A tangent to the lower border of the mandible
- A line joining gnathion and gonion
- A line joining menton and gonion.

Maxillary plane. A transverse plane through the skull represented by a joining of the anterior and posterior nasal spines.

SN plane. A transverse plane through the skull represented by the line joining sella and nasion.

SNA. Relates the anteroposterior position of the maxilla, as

represented by the A point, to the cranial base.

SNB. Relates the anteroposterior position of the mandible, as represented by the B point, to the cranial base.

ANB. Relates the anteroposterior position of the maxilla to the mandible, i.e. indicates the anteroposterior skeletal pattern – class I, II or III.

Maxillary incisal inclination. The angle between the long axis of the maxillary incisors and the maxillary plane.

Mandibular incisal inclination. The angle between the long axis of the mandibular incisors and the mandibular plane.

All the definitions are those specified in the British Standards Institute 2010 *Dentistry. Vocabulary*

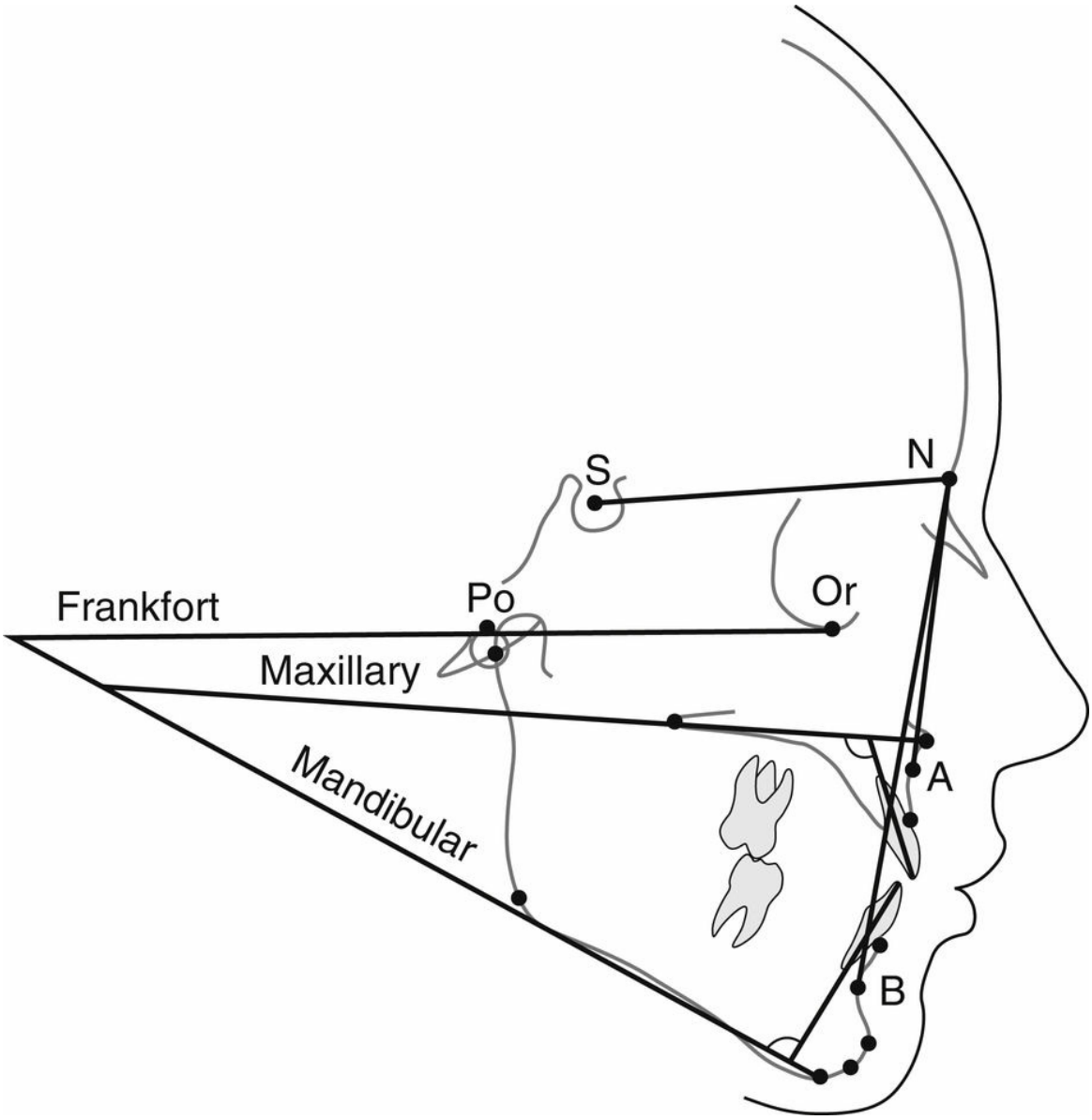


FIG. 14.9 A cephalometric tracing of a lateral skull radiograph showing the main cephalometric planes and angles.

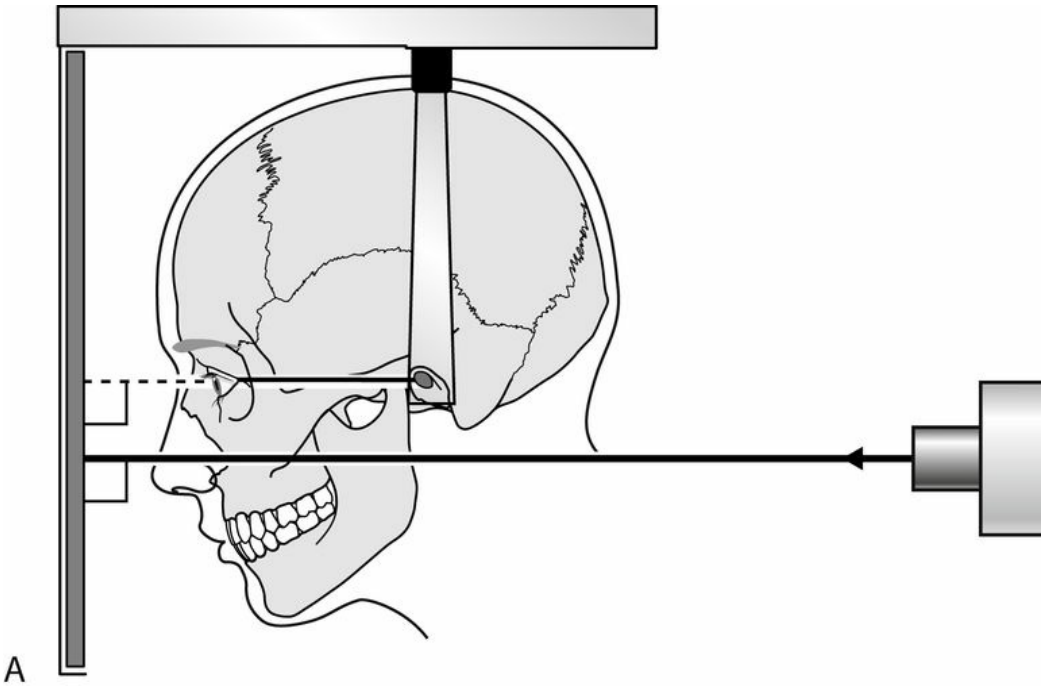
Cephalometric Posteroanterior of the Jaws (PA Jaws)

This projection is identical to the PA view of the jaws described in Chapter 13 , except that it is standardized and reproducible. This

makes it suitable for the assessment of facial asymmetries and for preoperative and postoperative comparisons in orthognathic surgery involving the mandible.

Patient Positioning

This can be summarized as follows:



A

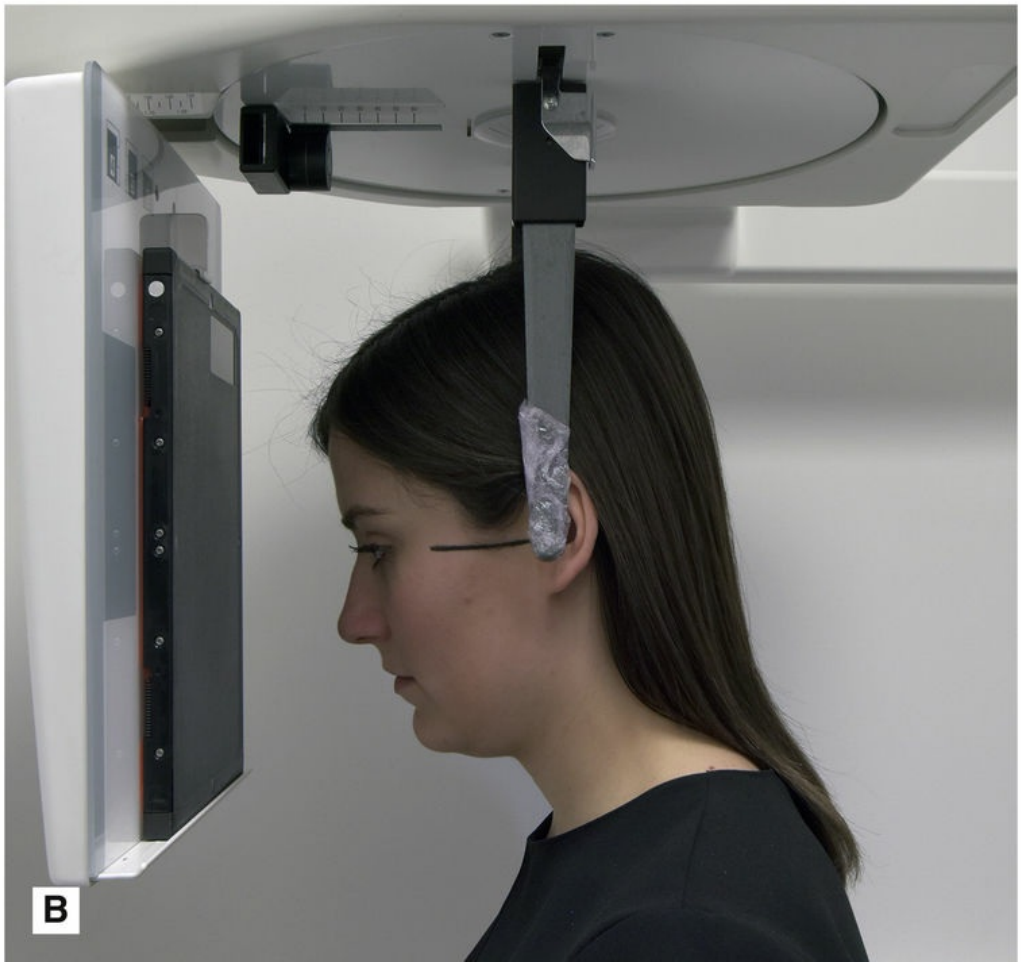


FIG. 14.10 (A) Diagram and (B) photograph showing patient positioning in the cephalostat for the cephalometric posteroanterior jaws. The radiographic baseline is marked on the face.

1. The head-stabilizing apparatus of the cephalostat is rotated through 90°.
2. The patient is positioned in the apparatus with the head tipped forwards and with the radiographic baseline horizontal and perpendicular to the film, i.e. in the *forehead-nose* position.
3. The head is immobilized within the apparatus by inserting the plastic ear rods into the external auditory meati.
4. The fixed X-ray beam is horizontal with the central ray centred through the cervical spine at the level of the rami of the mandible (see Figs. 14.10 –14.11).



FIG. 14.11 An example of a cephalometric posteroanterior jaws radiograph.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

15

Tomography and Panoramic Radiography

Introduction

Conventional *tomography* is a specialized radiographic technique developed originally for producing radiographs that showed only a *section* or *slice* of a patient. A useful analogy is to regard the technique as one that enables the patient to be imaged in slices – like a loaf of sliced bread (see Fig. 15.1). Each individual tomographic image (or *slice*) shows the tissues within that section sharply defined and in focus. The section is thus referred to as the *focal plane* or *focal trough.* Tissues and structures outside the tomographic section or slice are not visible because they are very blurred and out of focus.

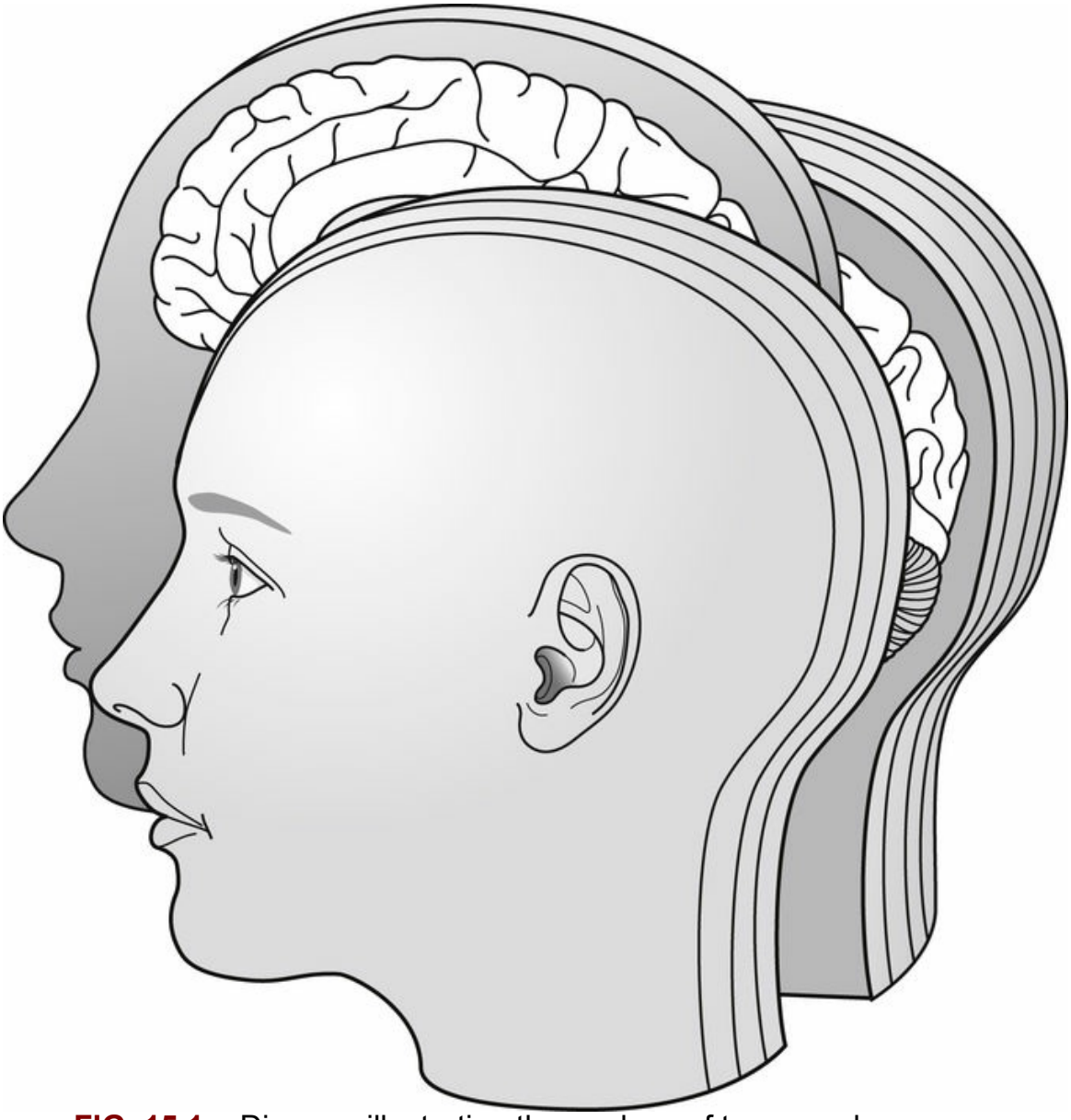


FIG. 15.1 Diagram illustrating the analogy of tomography – the patient is imaged and can be viewed in slices like a loaf of sliced bread.

The production of each traditional tomographic slice required controlled, accurate movement of both the X-ray tubehead and the film during the exposure, thereby making it different from all the routine radiographic techniques described in previous chapters. As will be described later in this chapter, by varying the size of the X-ray beam and the type of equipment movement employed it proved possible to change the shape of the tomographic layer from a straight

(linear) slice (see Fig. 15.2) to a curve, and ultimately to the approximate horseshoe shape of the dental arch, providing an overall panoramic image of all the teeth and their supporting structures – the so-called dental panoramic tomograph (DPT) or panoramic radiograph shown in Fig. 15.3 .

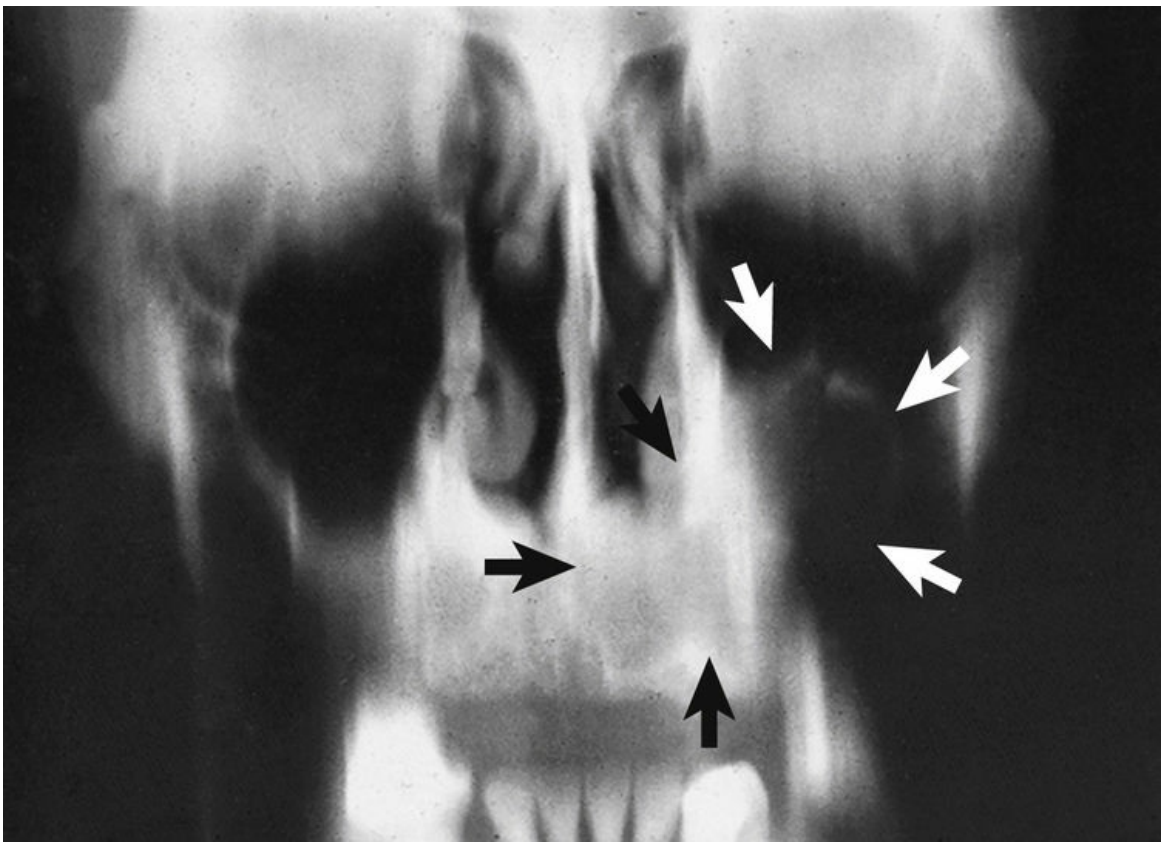


FIG. 15.2 A traditional linear tomograph in the coronal plane. The slice passes through and contains part of the antra and facial skeleton and shows an antral tumour (arrowed).

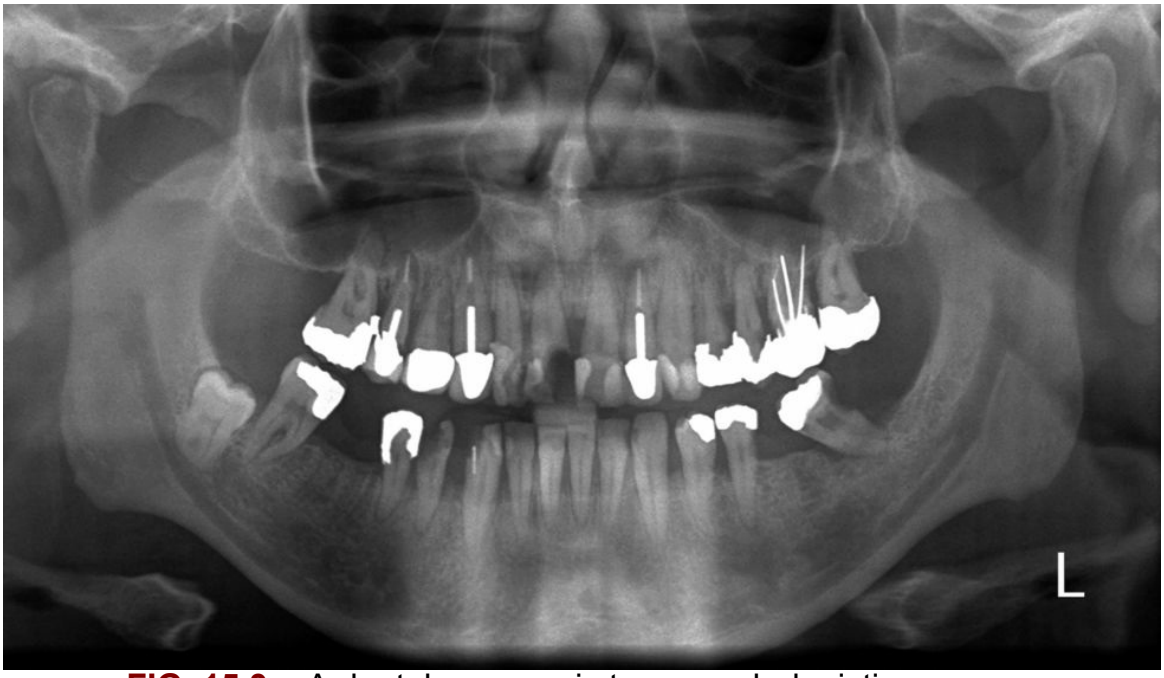


FIG. 15.3 A dental panoramic tomograph depicting a curved, horseshoe-shaped *slice* that is approximately the shape of the dental arch and contains the teeth and their supporting structures. In both this example and Fig. 15.2 the tissues imaged in the tomographic slices are sharply defined and in focus, while the unwanted structures are blurred out.

While panoramic tomography remains very popular, conventional linear tomography has essentially been superseded in radiography by *computed tomography,* which enables computer-generated tomographic sectional images to be created. Cone beam computed tomography is described in Chapter 16 and medical computed tomography is described in Chapter 18 . The concept of tomographic slices or sectional images also forms the basis of many other modern imaging modalities, such as magnetic resonance imaging and ultrasound examinations, which are also described in Chapter 18 .

Tomographic Theory

The theory of panoramic tomography is complicated. Nevertheless, an understanding of how the resultant radiographic image is produced and which structures are in fact being imaged is necessary for a

critical evaluation and the interpretation of this type of radiograph.

As an explanatory introduction to how the approximately horseshoe-shaped, curved tomographic slice or *focal trough* in panoramic tomography is produced, the theory of tomographic movement and three methods for producing linear and curved tomographic slices are first described. These include:

- Linear tomography using a wide or broad X-ray beam
- Linear tomography using a narrow or slit X-ray beam
- Rotational curved tomography using a narrow slit X-ray beam.

Principle of Tomographic Movement

As stated, traditional tomography requires controlled, accurate movement of both the X-ray tubehead and the film. They are therefore linked together. During the exposure, the X-ray tubehead moves in one direction while the film moves in the opposite direction as shown in Fig. 15.4 . The **point** at the centre of this rotating movement will appear in focus on the resultant radiograph, because its shadow will appear in the same place on the film throughout the exposure. All other points will appear blurred or out of focus.

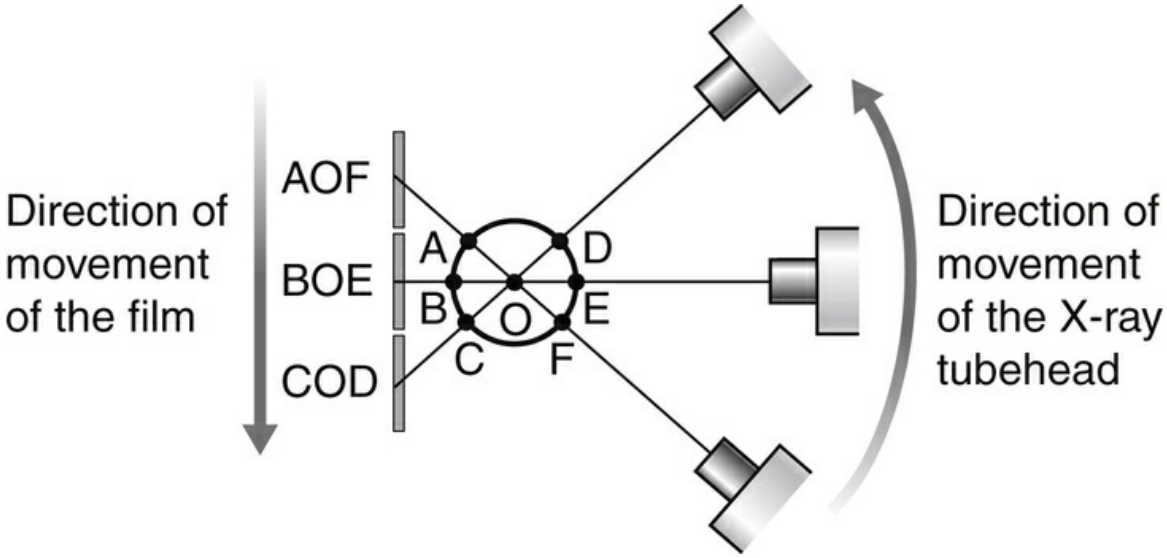


FIG. 15.4 Diagram illustrating the principle of tomographic

movement. The X-ray tubehead moves in one direction while the film moves in the opposite direction. Points A, B, C, D, E and F will all appear on different parts of the film and thus will be blurred out, while point O, the centre of rotation, will appear in the same place on the film throughout the exposure and will therefore be sharply defined.

Broad-beam Linear Tomography

The principle of tomography illustrated in Fig. 15.4 shows a very thin X-ray beam producing one point (O) – the centre of rotation – in focus on the film. To produce a section or slice of the patient in focus, a broad X-ray beam is used. For each part of the beam, there is a separate centre of rotation, all of which lie in the same focal plane. The resultant tomograph will therefore show all these points sharply defined. The principle of broad-beam tomography is illustrated in Fig. 15.5 .

Slit or Narrow-beam Linear Tomography

A similar straight linear tomograph can also be produced by modifying the equipment and using a narrow or slit X-ray beam. The equipment is designed so that the film itself moves such that the narrow beam traverses the film exposing different parts of the film during the tomographic movement. Only by the end of the tomographic movement has the entire film been exposed. The following equipment modifications are necessary:

- The X-ray beam has to be collimated from a broad beam to a narrow beam.
- The film cassette has to be placed behind a protective metal shield. A narrow opening in this shield is required to allow a small part of the film to be exposed to the X-ray beam at any one instant.
- A cassette carrier, incorporating the metal shield, has to be linked to the X-ray tubehead to ensure that they move in the

opposite direction to one another during the exposure. This produces the synchronized tomographic movement in the *vertical* plane.

- Within this carrier, the film cassette itself has to be moved in the **same** direction as the tubehead. This ensures that a different part of the film is exposed to the X-ray beam throughout the exposure.

The principle of narrow-beam linear tomography using this equipment is illustrated in Fig. 15.6 .

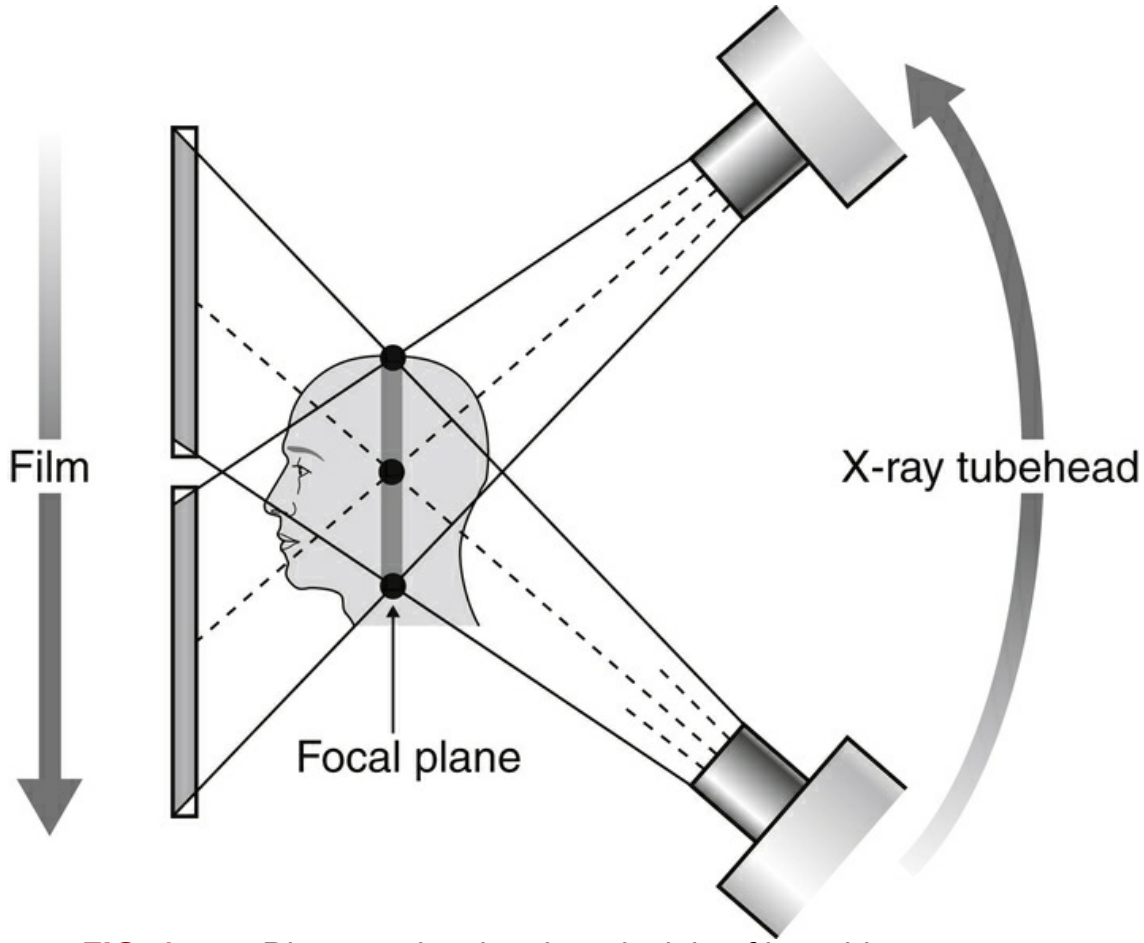


FIG. 15.5 Diagram showing the principle of broad-beam tomography. Using a broad beam there will be multiple centres of rotation (three are indicated: ●) all of which will lie in the shaded zone. As all the centres of rotation will be *in*

focus, this zone represents the *focal plane* or section of the patient that will appear sharply defined on the resultant tomograph.

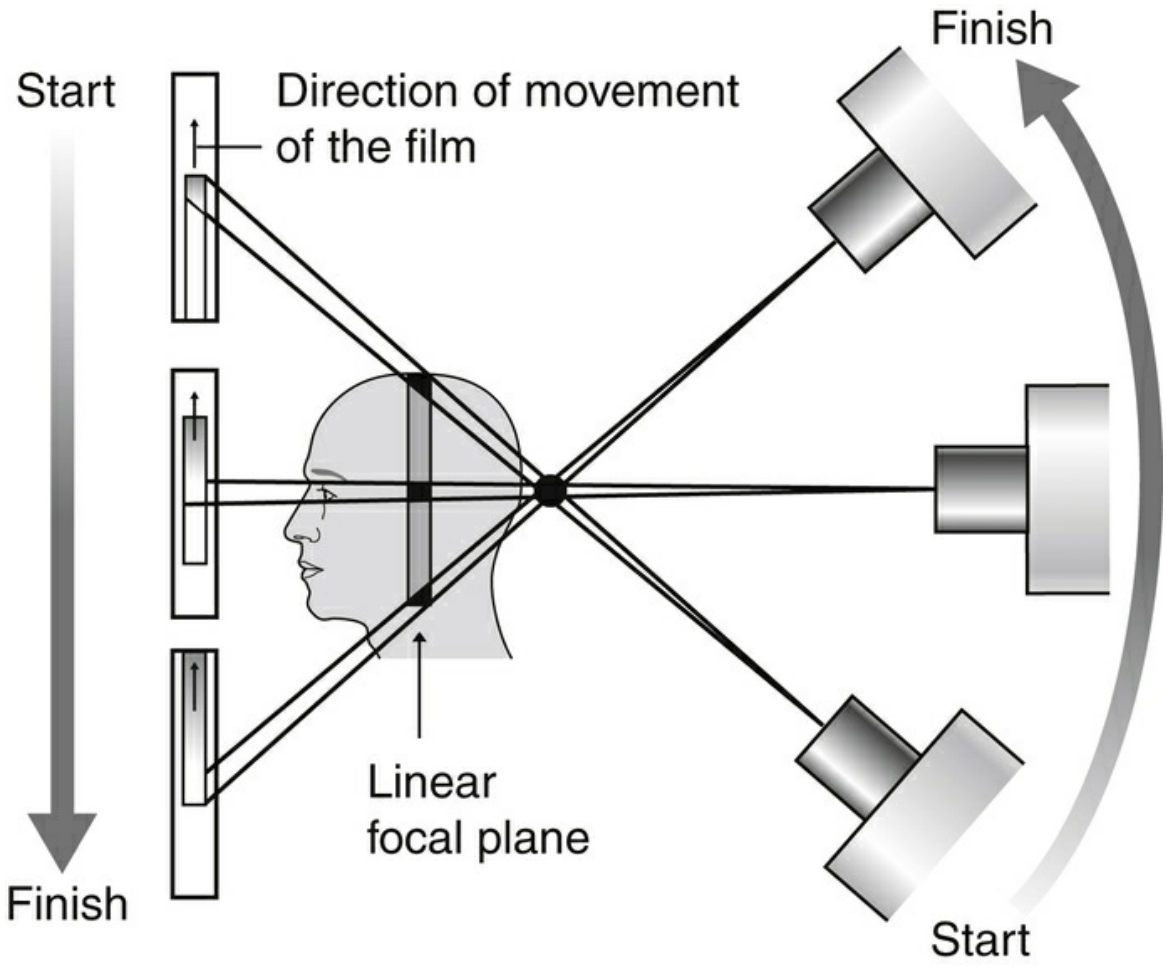


FIG. 15.6 Diagram showing the theory of narrow-beam linear tomography to produce a vertical coronal section. The tomographic movement is produced by the synchronized movement of the X-ray tubehead and the cassette carrier, in the vertical plane. The film, placed behind the metal protective front of the cassette carrier, also moves during the exposure, in the same direction as the X-ray tubehead. The narrow X-ray beam traverses the patient and film, exposing a different part of the film throughout the cycle.

Narrow-beam Rotational Tomography

In this type of tomography, narrow-beam equipment is again used, but the synchronized movement of the X-ray tubehead and the cassette carrier are designed to rotate in the *horizontal* plane, in a *circular* path around the head, with a *single* centre of rotation. The resultant focal trough is curved and forms the arc of a circle as shown in Fig. 15.7 .

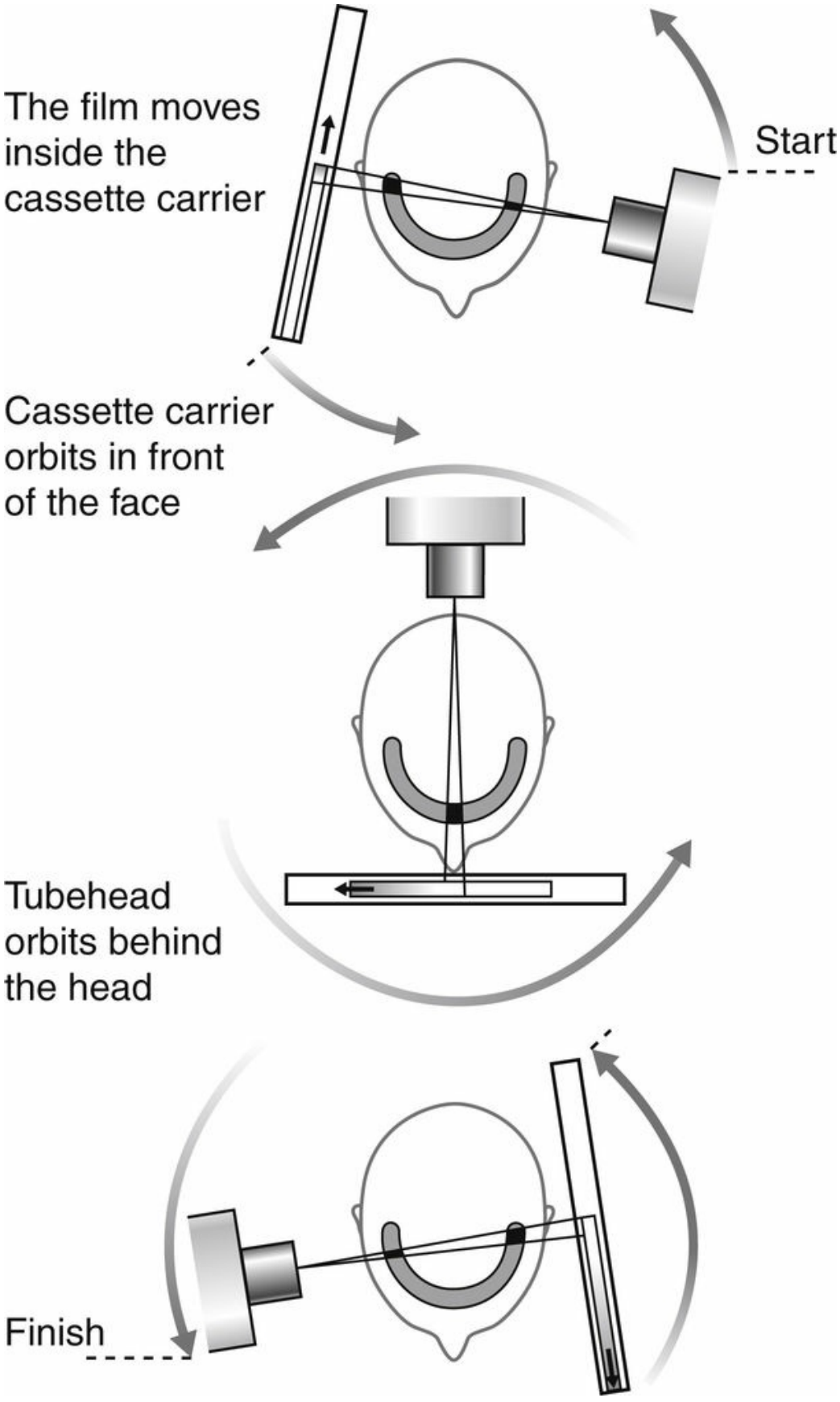

The film moves inside the cassette carrier
Start
Cassette carrier orbits in front of the face
Tubehead orbits behind the head
Finish

FIG. 15.7 Diagrams showing the theory of narrow-beam rotational tomography. The tomographic movement is provided by the circular synchronized movement of the X-ray tubehead in one direction and the cassette carrier in the opposite direction, in the horizontal plane. The equipment has a single centre of rotation. The film also moves inside the cassette carrier so that a different part of the film is exposed to the narrow beam during the cycle; thus, by the end the entire film has been exposed. The focal plane or trough (shaded) is curved and forms the arc of a circle.

Important Points to Note

- The X-ray tubehead orbits around the **back** of the head moving left to right, while the cassette carrier with the film orbits around the **front** of the face moving right to left.
- The film itself moves behind the protective metal shield of the cassette carrier as the equipment orbits around the head ensuring that a different part of the film is exposed to the X-ray beam at any one instant.
- The simple circular rotational movement with a single centre of rotation produces a curved **circular** focal trough.
- As in conventional tomography, shadows of structures not within the focal trough will be out of focus and blurred owing to the tomographic movement.

Panoramic Tomography

The dental arch, though curved, is not the shape of an arc of a circle. To produce the required elliptical, horseshoe-shaped focal trough, panoramic tomographic equipment uses the principle of narrow-beam rotational tomography, but uses two or more centres of rotation.

There are several dental panoramic units available; they all work on the same principle but differ in how the rotational movement is modified to image the elliptical dental arch. Four main methods (see

Fig. 15.8) have been used, including:

- Two stationary centres of rotation, using two separate circular arcs
- Three stationary centres of rotation, using three separate circular arcs
- A continually moving centre of rotation using multiple circular arcs combined to form a final elliptical shape
- A combination of three stationary centres of rotation and a moving centre of rotation.

However the focal troughs are produced, it should be remembered that they are three-dimensional. The focal trough is thus sometimes described as a *focal corridor.* All structures within the corridor, including the mandibular and maxillary teeth, will be in focus on the final radiograph. The vertical height of the corridor is determined by the shape and height of the X-ray beam and the size of the film as shown in Fig. 15.9 .

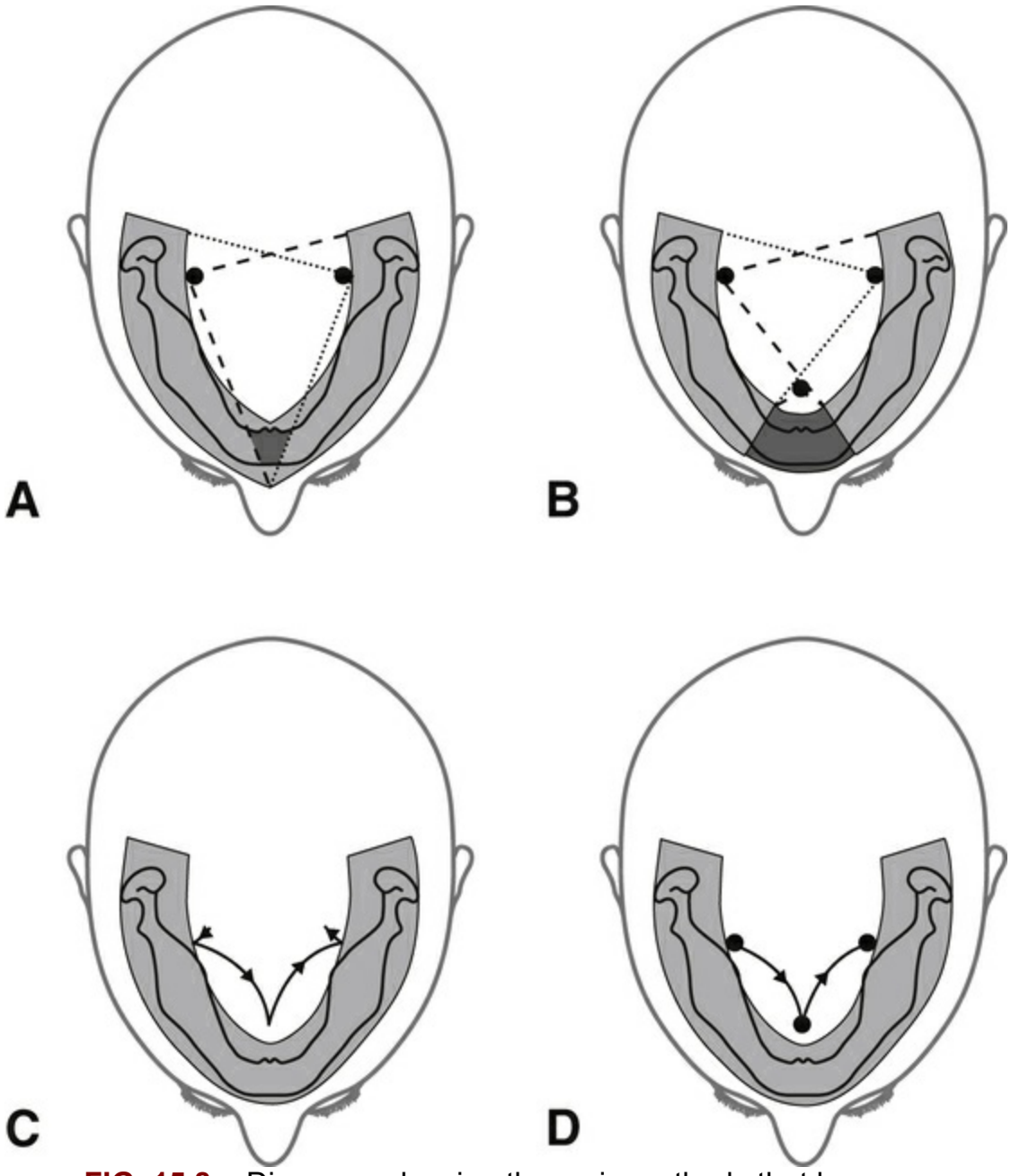


FIG. 15.8 Diagrams showing the main methods that have been used to produce a focal trough that approximates to the elliptical shape of the dental arch using different centres of rotation. **(A)** Two stationary. **(B)** Three stationary. **(C)** Continually moving. **(D)** Combination of three stationary and moving centre.

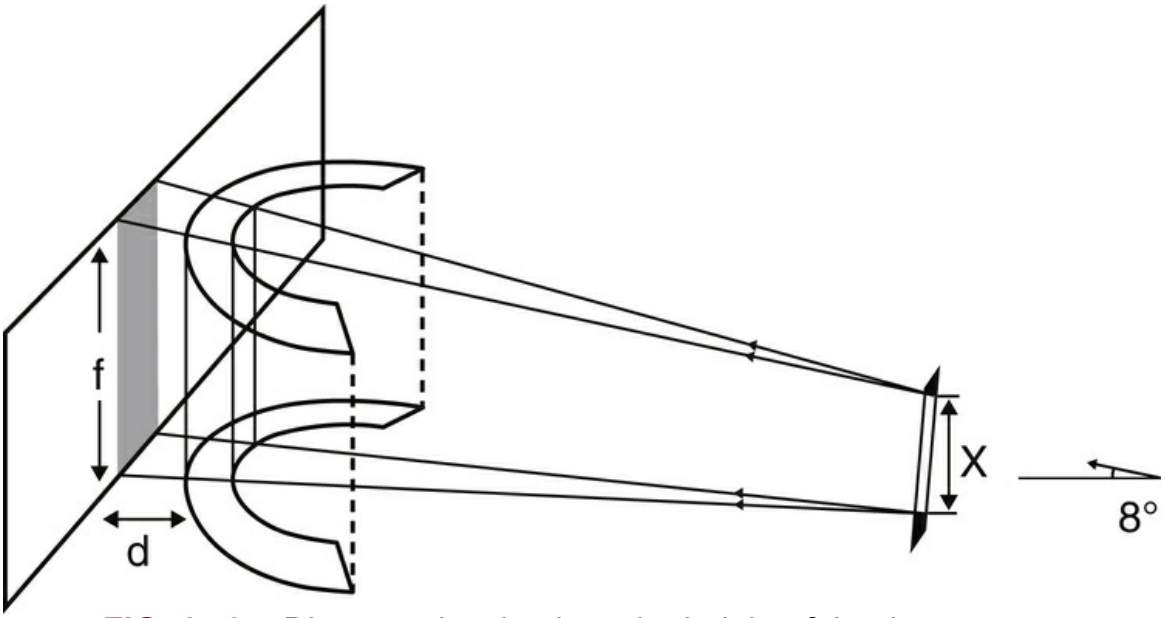


FIG. 15.9 Diagram showing how the height of the three-dimensional focal corridor is determined. The height (X) of the X-ray beam is collimated to just cover the height (f) of the film. The separation of the focal trough and the film (d), coupled with the 8° upward angulation of the X-ray beam, results in the final image being slightly magnified.

As in other forms of narrow-beam tomography a different part of the focal trough is imaged throughout the exposure. The final radiograph is thus built up of sections as shown in Fig. 15.10 , each created separately, as the equipment orbits around the patient's head.

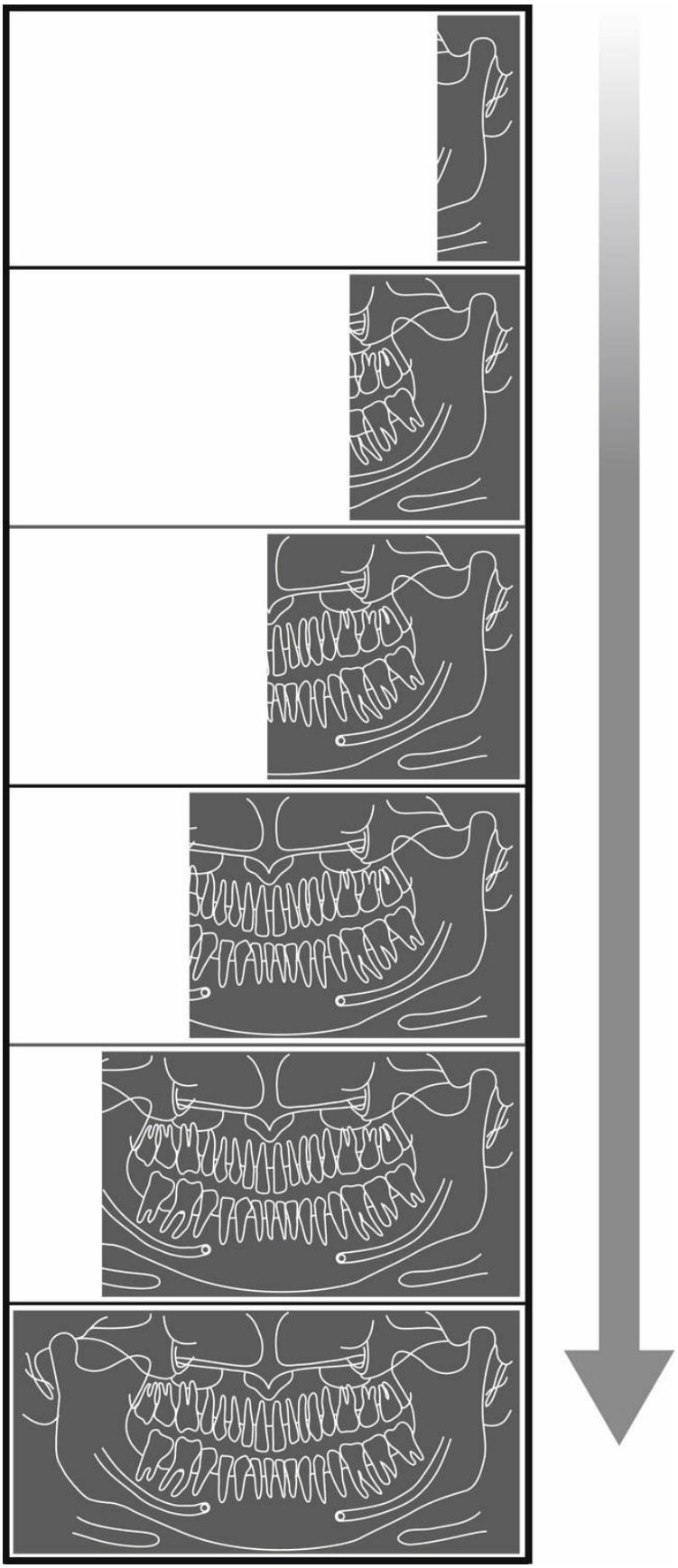


FIG. 15.10 Diagram showing the gradual build-up of a panoramic tomograph over an 18-second cycle, illustrating how a different part of the patient is imaged at different stages in the cycle.

Unfortunately, although the final radiograph shows all the teeth and their supporting structures, the tomographic image quality is generally inferior to that obtained using intraoral radiographic techniques and interpretation is more complicated.

Selection Criteria

In the UK, the *Selection Criteria for Dental Radiography* (third edition) booklet (updated in 2018) suggests panoramic radiography in general practice in the following circumstances:

- Where a bony lesion or unerupted tooth is of a size or position that precludes its complete demonstration on intraoral radiographs
- In the case of a grossly neglected mouth
- As part of an assessment of periodontal bone support often supplemented with periapical radiographs
- For the assessment of wisdom teeth before planned surgical intervention; routine radiography of unerupted third molars is not recommended
- As part of an orthodontic assessment where there is a clinical need to know the state of the dentition and the presence or absence of teeth. The use of clinical criteria to select patients rather than routine screening patients is essential.

In addition, in dental hospitals panoramic radiographs are also used to assess:

- Fractures of all parts of the mandible except the anterior region
- Antral disease – particularly to the floor, posterior and medial

walls of the antra
- Destructive diseases of the articular surfaces of the temporomandibular joint
- Vertical alveolar bone height and position of anatomical structures as part of pre-implant planning.

The *Selection Criteria* booklet specifically states that 'panoramic radiographs should only be taken in the presence of specific clinical signs and symptoms', and goes on to say that 'there is no justification for review panoramic radiography at arbitrary time intervals'.

Equipment

There are several different panoramic units available. Although varying in design and appearance, all consist of four main components, namely:

- An *X-ray tubehead*, producing a narrow fan-shaped X-ray beam, angled upwards at approximately 8° to the horizontal as shown earlier in Fig. 15.9
- *Control panel* (see Fig. 15.11)
- *Patient-positioning apparatus*, including chin and appropriate head immobilizing supports and light beam markers shown later
- *An image receptor* (digital or film), with or without an associated carriage assembly.

Traditional panoramic equipment was designed to use indirect-action radiographic film in an extraoral cassette as the image receptor. With the advent of digital imaging several variations in image receptor now exist, including:

- Cassettes containing indirect-action film and rare earth intensifying screens
- Cassettes containing a digital phosphor plate

- Specially designed solid-state sensors – an integral part of new equipment (see Chapter 6).

Examples of three typical machines are shown in Fig. 15.12 . Ideally:

- Equipment should have a range of tube potential settings, preferably 60–90 kV.
- The beam height at the image receptor should be collimated so that it is no higher than required to expose the area of interest.
- Equipment should be provided with adequate patient-positioning aids incorporating light beam markers.
- Equipment should provide facilities for field-limitation techniques.

Control Panel

The control panel design also varies from one machine to another. Three examples are shown in Fig. 15.11 . The main features usually allow the operator to:

- Select the field size
- Select a limited range of arch shapes and sizes
- Select the mA and kV exposure factors
- Adjust the anteroposterior position of the bite-peg
- Select the size of the patient to be X-rayed
- Adjust the height of the equipment
- Select a range of field-limitation options.

Equipment Movement

Diagrammatic examples of the typical movement of different panoramic machines during an exposure are shown in Figs. 15.13 and 15.4A . As illustrated the movement variation relates to the type of image receptor being used, but all systems enable the narrow X-ray beam to *scan* the patient, gradually exposing different parts of the jaw in the focal trough. In units using solid-state detectors the gradual

build-up of the final tomographic image, during the *scanning* exposure, can be seen in real time on the monitor as shown in Fig. 15.14B .

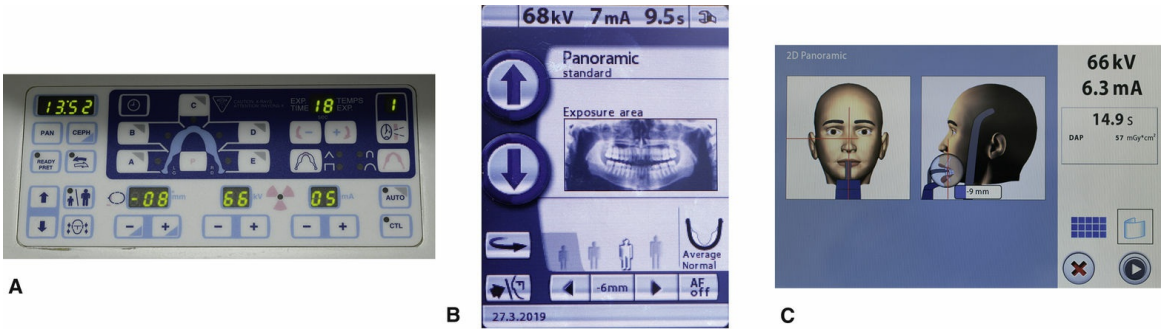


FIG. 15.11 Examples of different designs of Planmeca panoramic control panels from **(A)** the PM2002 Proline; **(B)** the ProOne; **(C)** the ProMax units.

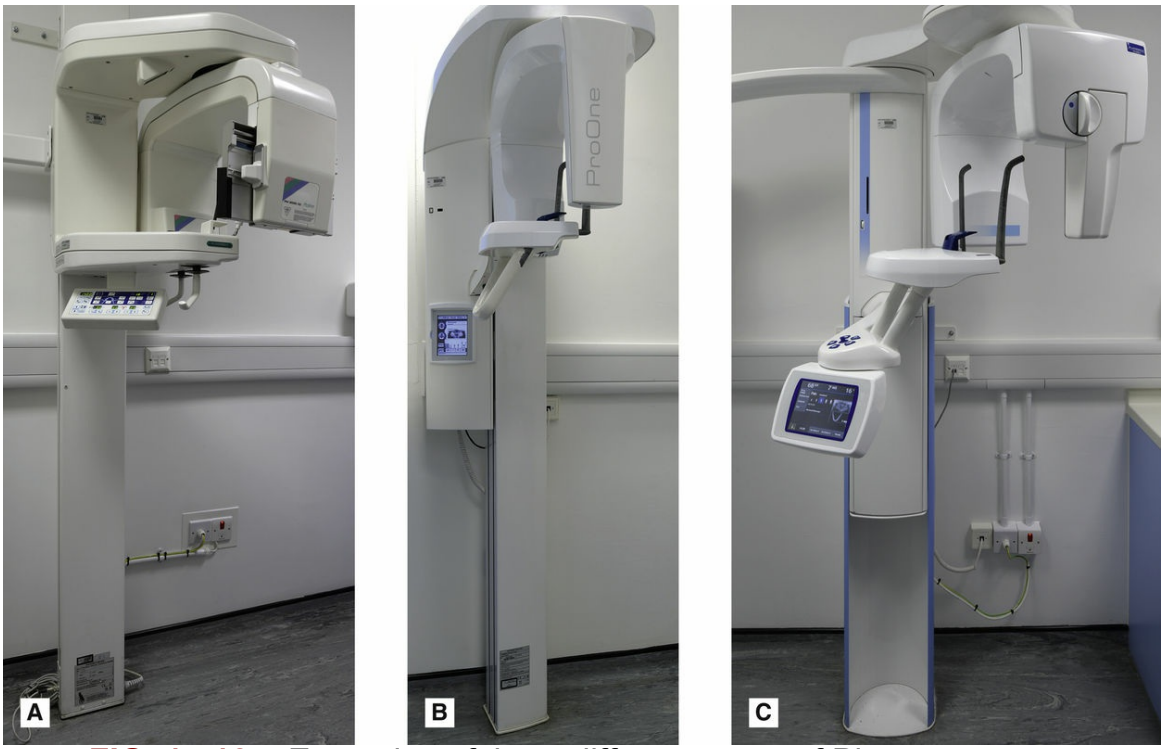


FIG. 15.12 Examples of three different types of Planmeca panoramic radiography machines. (**A**) Traditional PM 2002 Proline unit incorporating a cassette suitable for digital

phosphor plate imaging or film-based. **(B)** The basic ProOne unit incorporating a built-in Dimax 3 solid-state digital sensor. **(C)** The complex multipurpose ProMax also using a solid-state digital sensor.

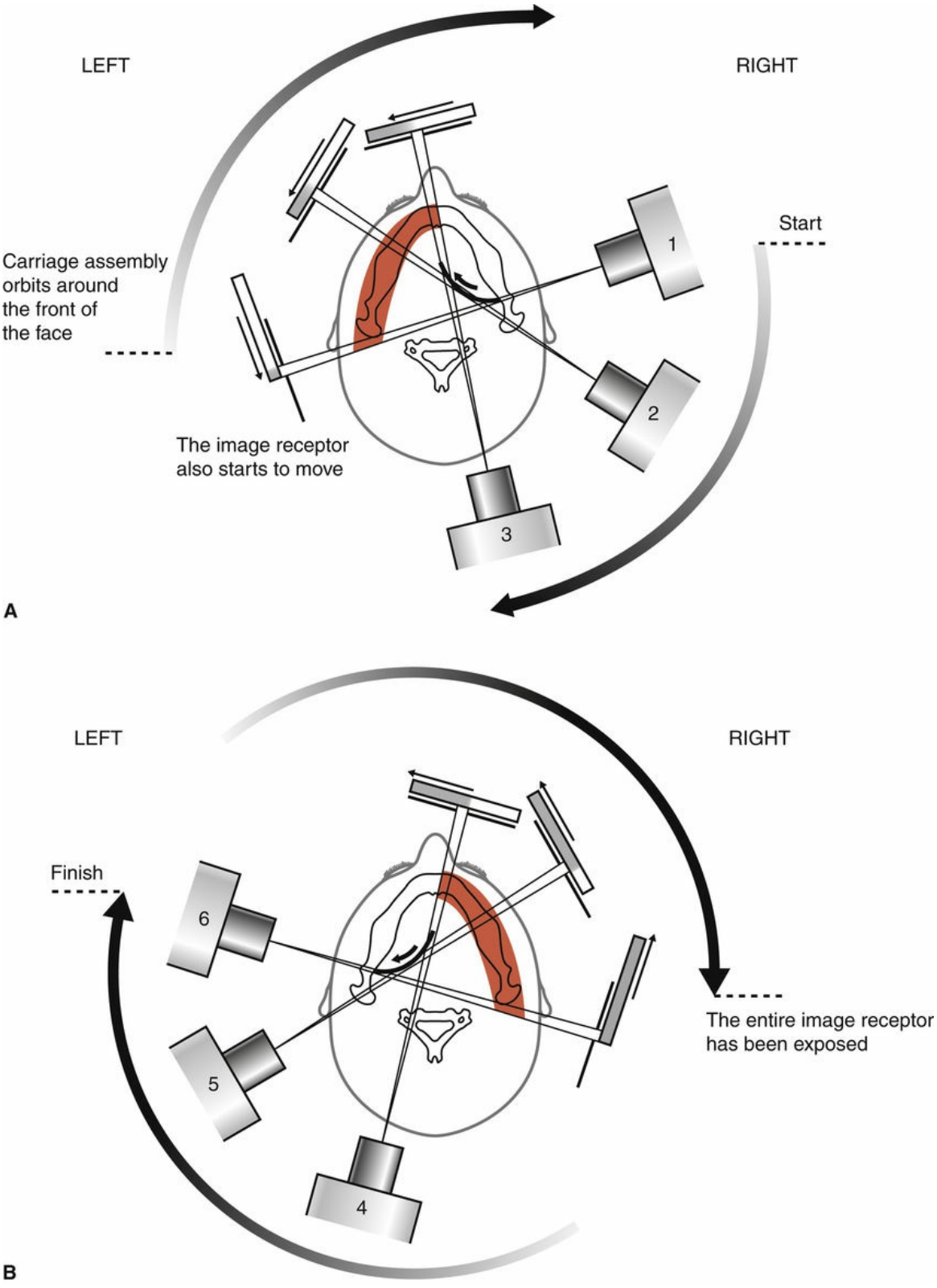


FIG. 15.13 Diagrams from above, showing the complex movements of panoramic equipment using a digital phosphor plate or film as the image receptor. **(A)** Imaging the **left** side

and **(B)** the **right** side of the jaw. The tomographic layer being imaged is highlighted in red. Throughout the cycle the image receptor is also moving so that a different part is exposed at any one time allowing the gradual build-up of the panoramic tomograph shown earlier in Fig. 15.10 .

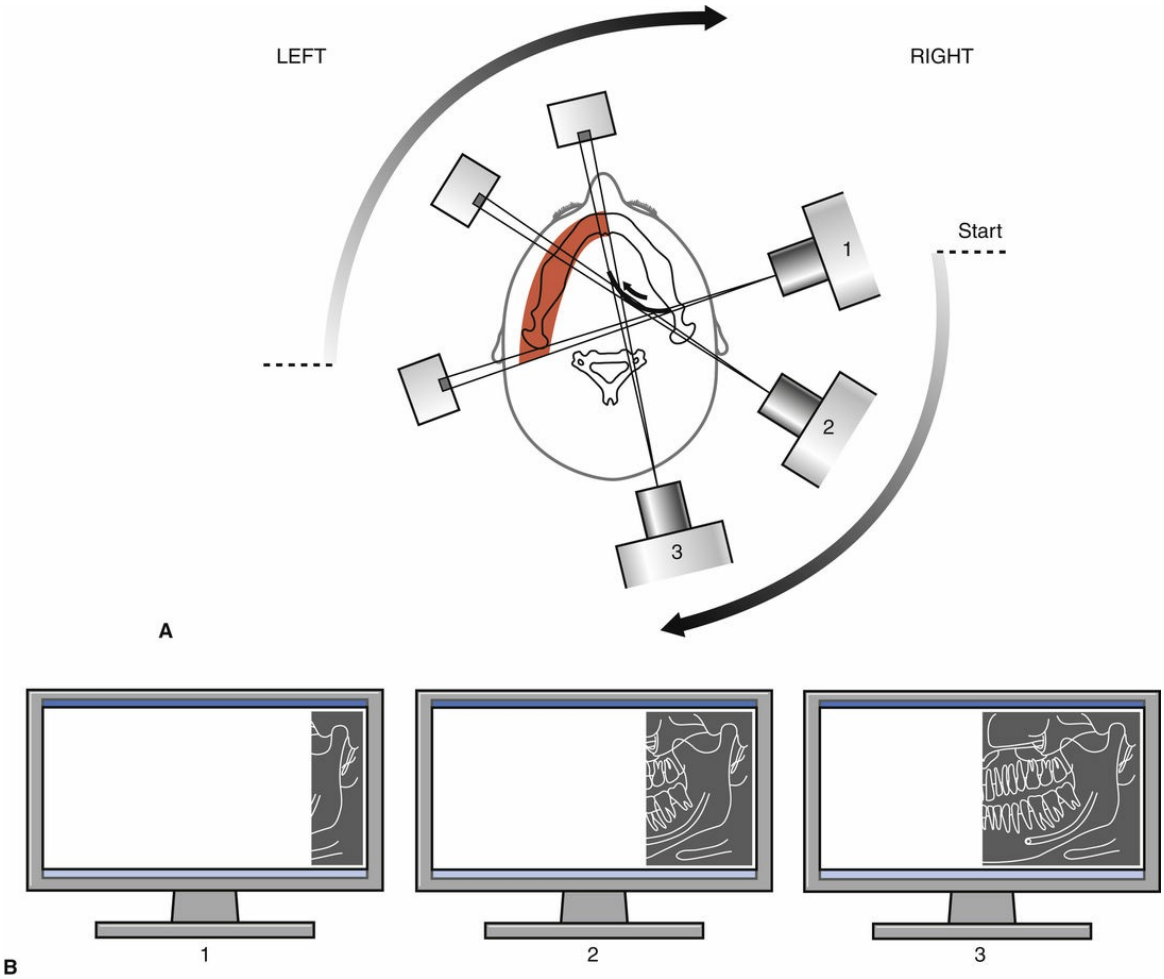


FIG. 15.14 **(A)** Diagram from above, showing the slightly simpler movements of panoramic equipment using a solid-state digital image receptor when imaging the **left** side of the jaw. The tomographic layer being imaged is again highlighted in red. The narrow vertical strip of charge-coupled devices are exposed by the exactly aligned narrow X-ray beam throughout the cycle and continuously send data to the computer. (**B)** Diagram of the computer monitor showing the LEFT side of the panoramic image being built up in real time as the exposure is taking place.

Technique and Positioning

The exact positioning techniques vary from one machine to another. However, there are some general requirements that are common to all machines and these can be summarized as follows.

Patient Preparation

- Patients should be asked to remove any earrings, jewellery, hair pins, spectacles and dentures or orthodontic appliances.
- The procedure and equipment movements should be explained, to reassure patients and if necessary a test exposure should be used to show them the machine's movements.

Equipment Preparation

- The cassette containing the phosphor plate or film should be inserted into carriage assembly (if appropriate).
- The exposure control panel should be covered in cling film (see Chapter 8).
- The operator should put on suitable protective gloves (e.g. latex or nitrile) (see Chapter 8).
- The collimation should be set to the size of field required.
- The appropriate exposure factors should be selected according to the size of the patient – typically in the range of 70–90 kV and 4–12 mA.

Patient Positioning

- The patient should be positioned in the unit so that their spine is straight and instructed to hold any stabilizing supports or handles provided (see Fig. 15.15).
- The patient should be instructed to bite their upper and lower incisors edge-to-edge on the bite-peg with their chin in good contact with the chin support.
- The head should be immobilized using the temple supports.
- The light beam markers should be used so that the mid-sagittal plane is vertical, the Frankfort plane is horizontal and the canine light lies between the upper lateral incisor and canine.

- The patient should be instructed to close their lips and press their tongue on the roof of their mouth so that it is in contact with their hard palate and not to move throughout the exposure cycle (approximately 15–18 seconds).



FIG. 15.15 Patient positioned in the Planmeca ProMax panoramic unit. Note the bite-peg, chin, temple supports and light-beam markers to facilitate positioning.

Important Points to Note

- Panoramic radiography is generally considered to be unsuitable for children under 6 years old, because of the length of the exposure and the need for the patient to keep still.
- A protective lead apron should not be used. In the UK the latest *Guidance Notes* confirm that there is no justification for using a protective lead apron. If used, it can interfere with the final image as shown later.

After Exposure

- The temple supports should release automatically to enable the patient to leave the machine.
- The equipment should be wiped down with a surface disinfectant and the bite-peg sterilized (see Chapter 8).
- Gloves should be discarded as clinical waste.
- The phosphor plate or film should be processed.

The Importance of Accurate Patient Positioning

The positioning of the patient's head within this type of equipment is critical – it must be positioned accurately so that the teeth lie within the *focal trough.* The effects of placing the head too far forward, too far back or asymmetrically in relation to the focal trough are shown in Fig. 15.16 . The parts of the jaws outside the focal trough will be out of focus. The fan-shaped X-ray beam causes patient malposition to be represented mainly as distortion in the horizontal plane, i.e. teeth appear too wide or too narrow rather than foreshortened or elongated. Thus, if the patient is rotated to the left as shown in Fig. 15.16C , the left teeth are nearer the image receptor and will be narrower, while the teeth on the right will be further away from the image receptor and wider. These and other positioning errors are shown later.

However accurately the patient's head is positioned, the inclination of the incisor teeth, or the underlying skeletal base pattern, may make

it impossible to position both the mandibular and maxillary teeth ideally within the focal corridor as shown in Fig. 15.17 .

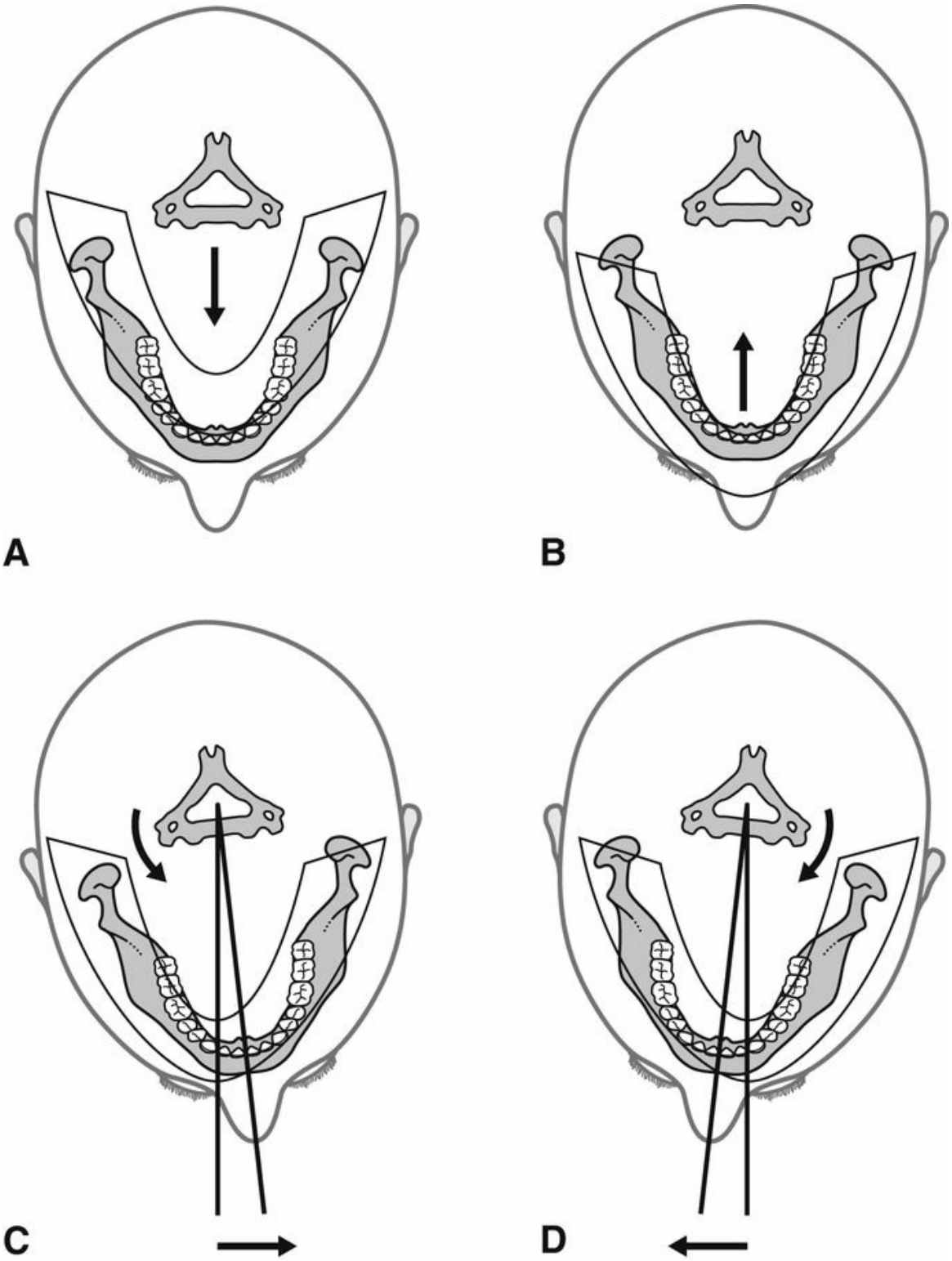


FIG. 15.16 Diagrams showing the position of the mandible in relation to the focal trough when the patient is not positioned correctly. **(A)** The patient is too close to the image receptor and in front of the focal trough. **(B)** The patient is too

far away from the image receptor and behind the focal trough. (**C and D**) The patient is placed asymmetrically within the machine.

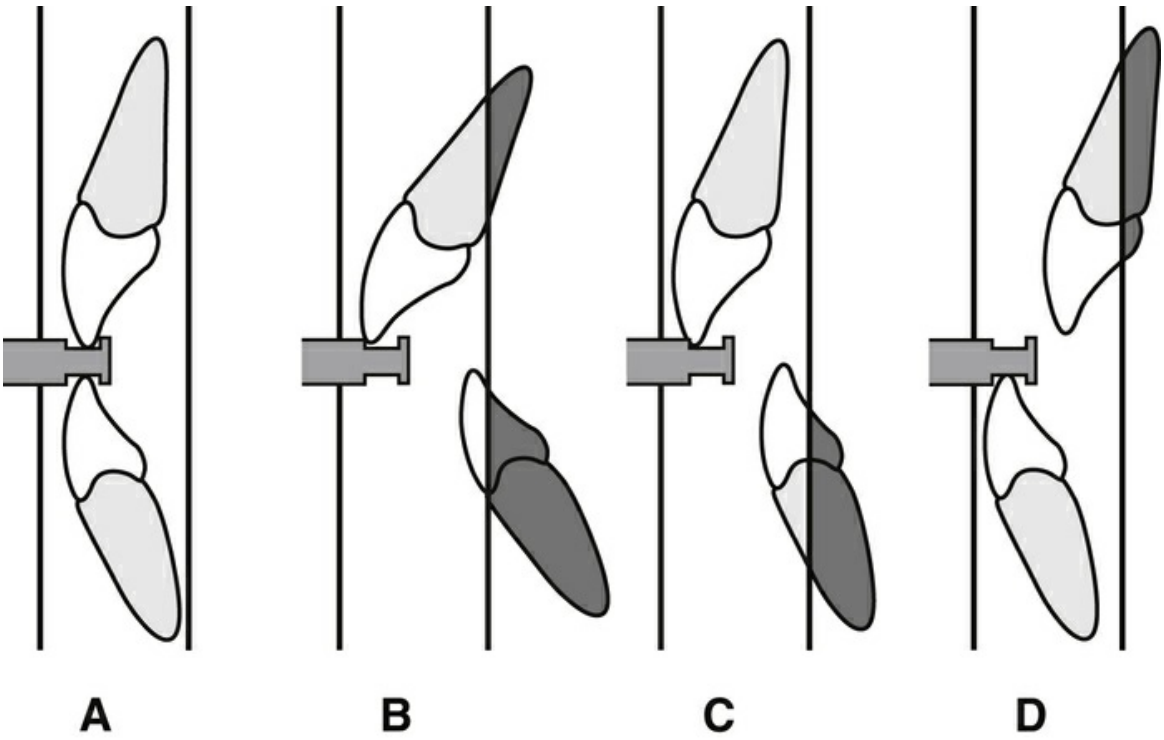


FIG. 15.17 Diagrams showing the vertical walls of the focal trough in the incisor region and the relative positions of the teeth with different underlying dental or skeletal abnormalities. **(A)** Class I. **(B)** Gross class II division 1 malocclusion with large overjet. **(C)** Angle's class II skeletal base. **(D)** Angle's class III skeletal base. The shaded areas outside the focal trough will be blurred and out of focus.

Technique Variations

There are a number of technique variations possible with modern equipment, including:

- *Edentulous patient positioning* – the chin support is used instead of the bite-peg and the canine positioning light beam is

centred on the corner of the mouth.

- *Temporomandibular joint programmes* (see Chapter 30).
- *Cross-sectional imaging* – for implant assessment (see Chapter 23).
- *Collimation* – restricting the size of the beam so restricting the field of view, e.g. the height of the beam is automatically reduced when selecting the settings for children.
- *Field-limitation* techniques – only preselected parts of the patient are exposed and appear on the final image (see Fig. 15.18).
- *Non-standard programmes* – for example:
  - *Improved orthogonality*
  - *Improved interproximality*
  - *Panoramic bitewing mode* .

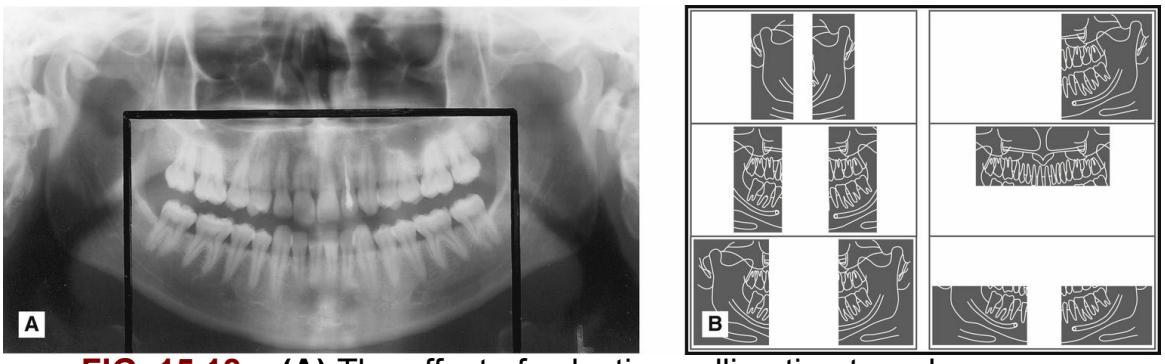


FIG. 15.18 **(A)** The effect of selecting collimation to reduce the height of the beam and field-limitation techniques to exclude the rami and parotid glands producing the so-called *dentition only* image. This has been reported to reduce the effective dose by approximately 50%. **(B)** Diagram showing a selection of images that can be obtained by using collimation and field-limitation techniques.

Normal Anatomy

The normal anatomical shadows that are evident on panoramic radiographs can essentially be subdivided into:

- *Real or actual shadows* of anatomical structures in, or close to, the curved focal trough including:
  - Hard tissue shadows
  - Air shadows
  - Soft tissue shadows
- *Standard ghost or artefactual shadows*
- *Non-standard ghost or artefactual shadows.*

Real or Actual Shadows (see Figs. 15.19 and 15.20)

Important hard tissue shadows include:

- Teeth
- Mandible
- Maxilla, including the floor, medial and posterior walls of the antra
- Hard palate
- Zygomatic arches
- Styloid processes
- Hyoid bone
- Nasal septum and conchae
- Orbital rim.

Important air shadows include:

- Mouth/oral opening
- Oropharynx.

Important soft tissue shadows include:

- Ear lobes
- Nose
- Soft palate
- Dorsum of tongue

- Lips and cheeks
- Nasolabial folds.

Standard Ghost or Artefactual Shadows (see Figs. 15.21 and 15.22)

These shadows are created by the normal rotatory tomographic movement and are caused by structures on the opposite side to the side being imaged, or by structures a long way from the focal trough. Since these structures are not in the focal trough the shadows they cast appear out of focus and blurry. The 8° upward angulation of the X-ray beam means that these ghost shadows appear at a higher level on the image than the structures that have caused them. The more important standard ghost shadows include:

- Cervical vertebrae
- Body, angle and ramus of the contralateral side of the mandible
- Palate.

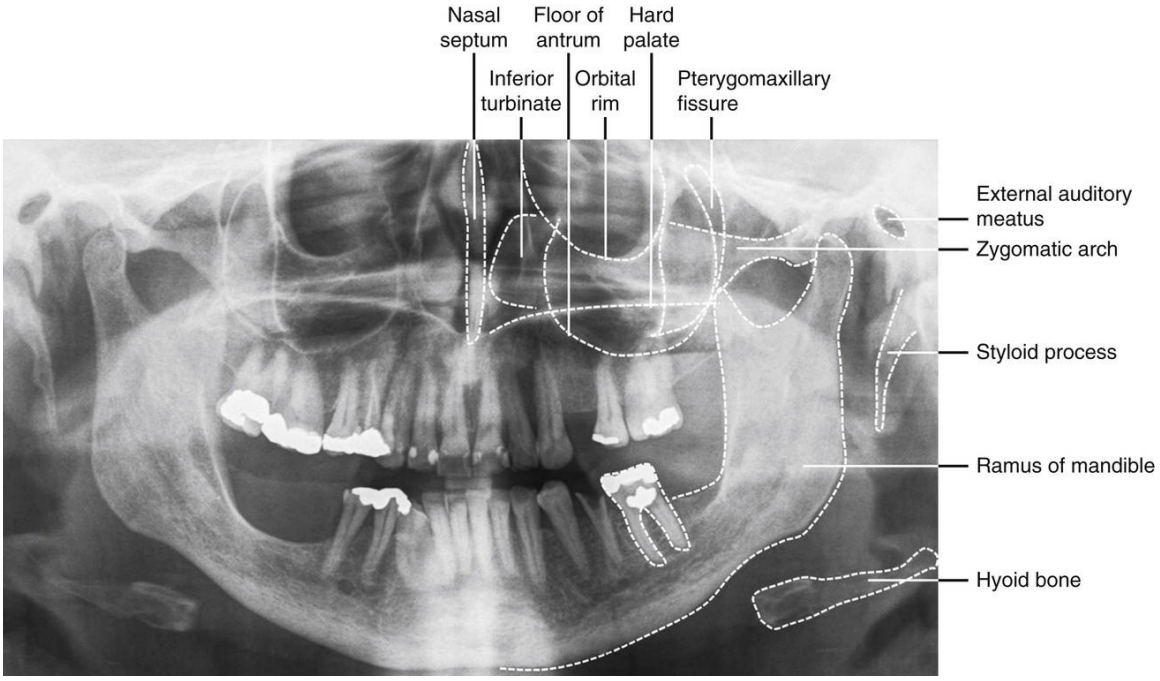


FIG. 15.19 A panoramic radiograph showing the main normal real hard tissue shadows drawn in on one side.

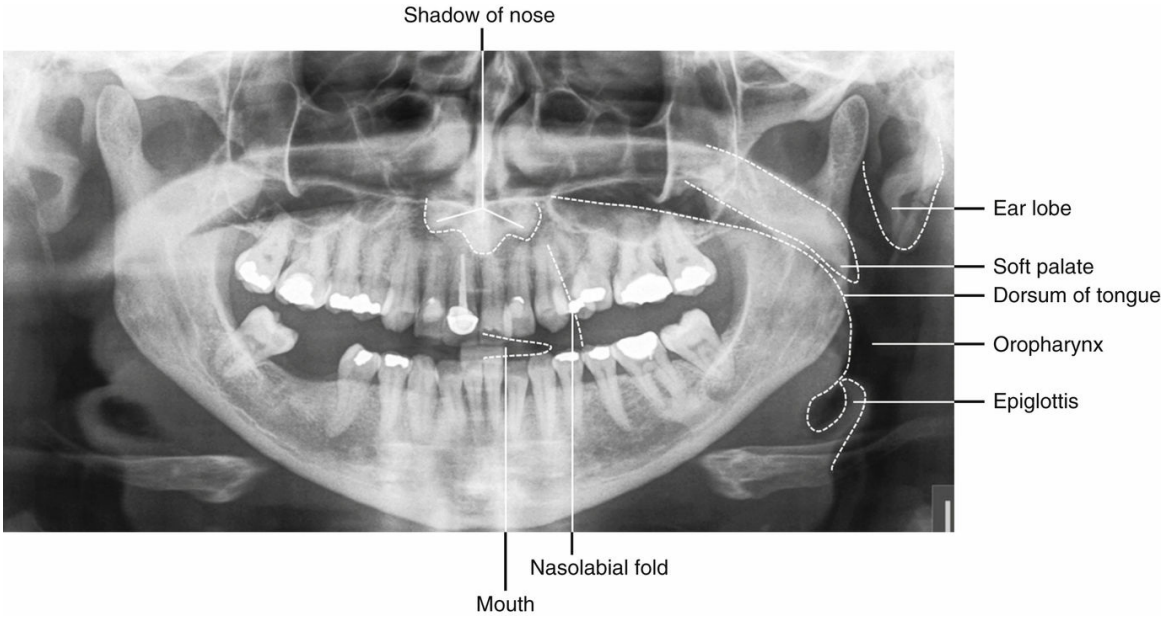


FIG. 15.20 A panoramic radiograph showing the main real soft tissue and air shadows drawn in on one side.

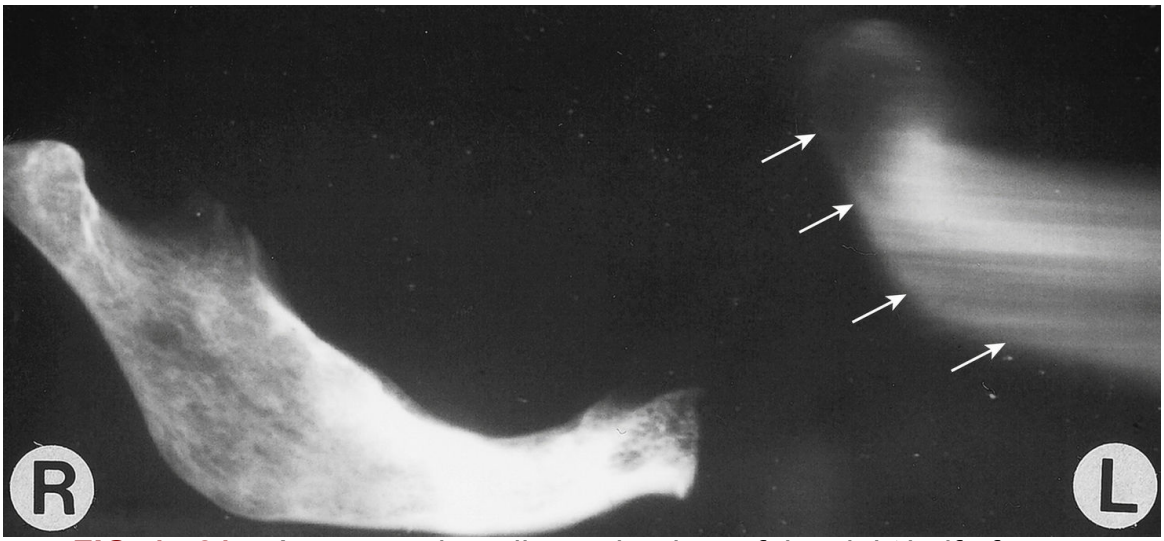


FIG. 15.21 A panoramic radiograph taken of the *right* half of a hemisectioned mandible. The real shadows are clearly

shown on the *right.* The ghost shadow of the mandible is shown on the *left* (arrowed). Note these ghost shadows are at a higher level on the film than the real shadows because of the 8° rising X-ray beam that is used.

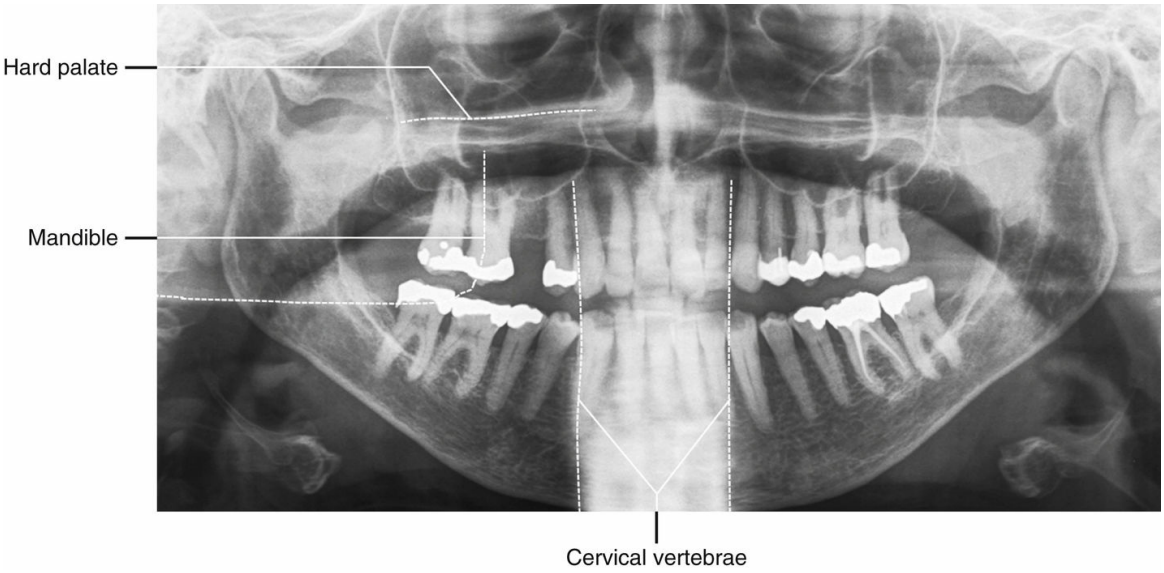


FIG. 15.22 A panoramic radiograph showing the main standard anatomical ghost or artefactual shadows drawn in on one side.

Non-standard Ghost or Artefactual Shadows (see Figs. 15.23 –15.25)

These unusual and confusing shadows are the result of manufacturers developing ever more complex digital panoramic programmes, using non-standard movement of the tubehead and image receptor, in an attempt to improve image quality. As stated earlier examples include:

- *Improved orthogonality* to improve imaging for periodontal assessment and implant planning
- *Improved interproximality* to improve caries detection
- *Panoramic bitewing mode* to produce extraoral bitewings.

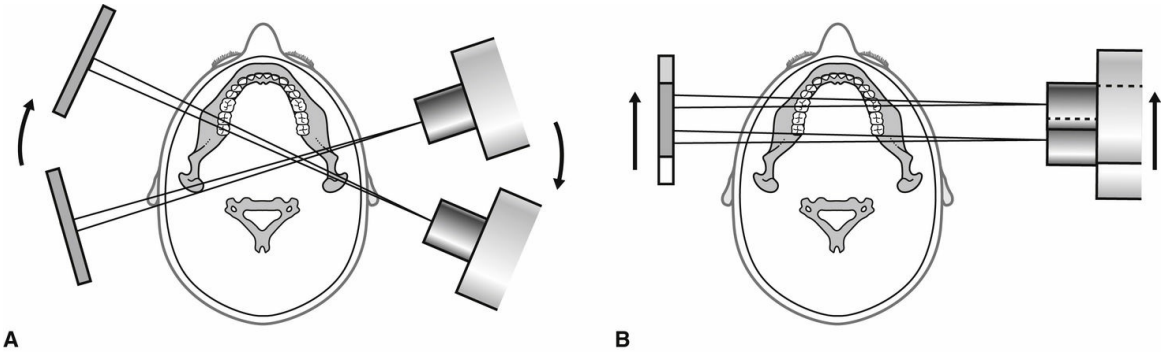


FIG. 15.23 Diagrams showing the **(A)** standard rotatory panoramic equipment movement and **(B)** non-standard movement of the *improved orthogonality* programme.

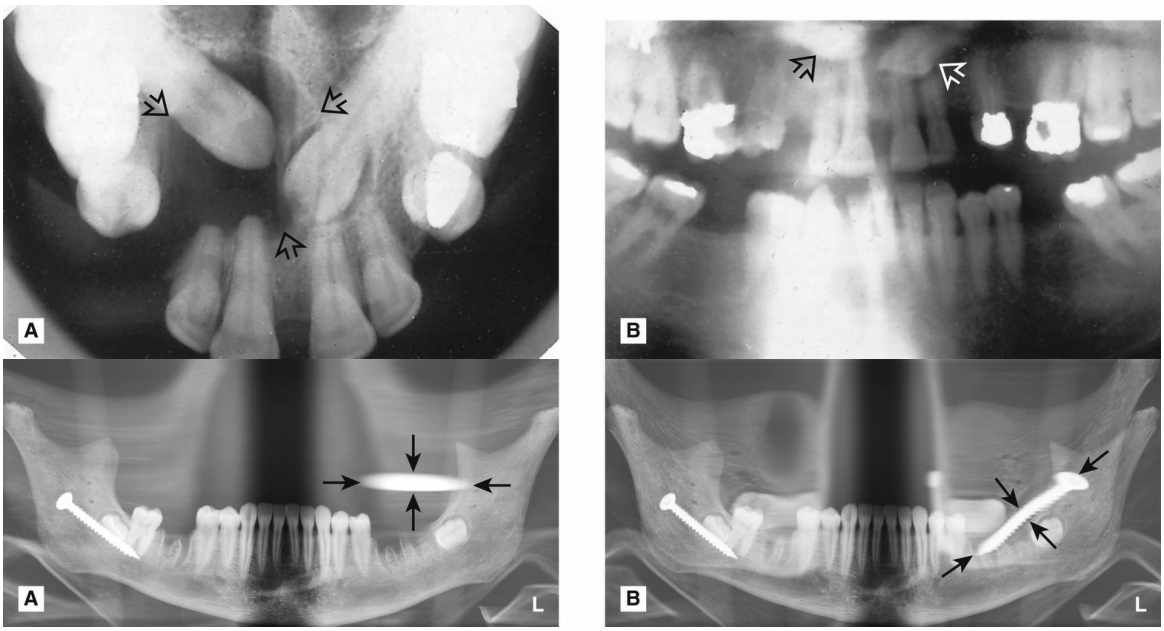


FIG. 15.24 Panoramic radiographs of a dried skull with a small screw attached to the lingual aspect of the right mandible. **(A)** Standard programme showing the screw on the **right** in focus and its standard ghost shadow on the **left** (arrowed). **(B)** Non-standard *improved orthogonality* programme showing the same screw on the **right** but a completely different non-standard ghost shadow on the **left** (arrowed).

Courtesy of Mr S. Harvey.

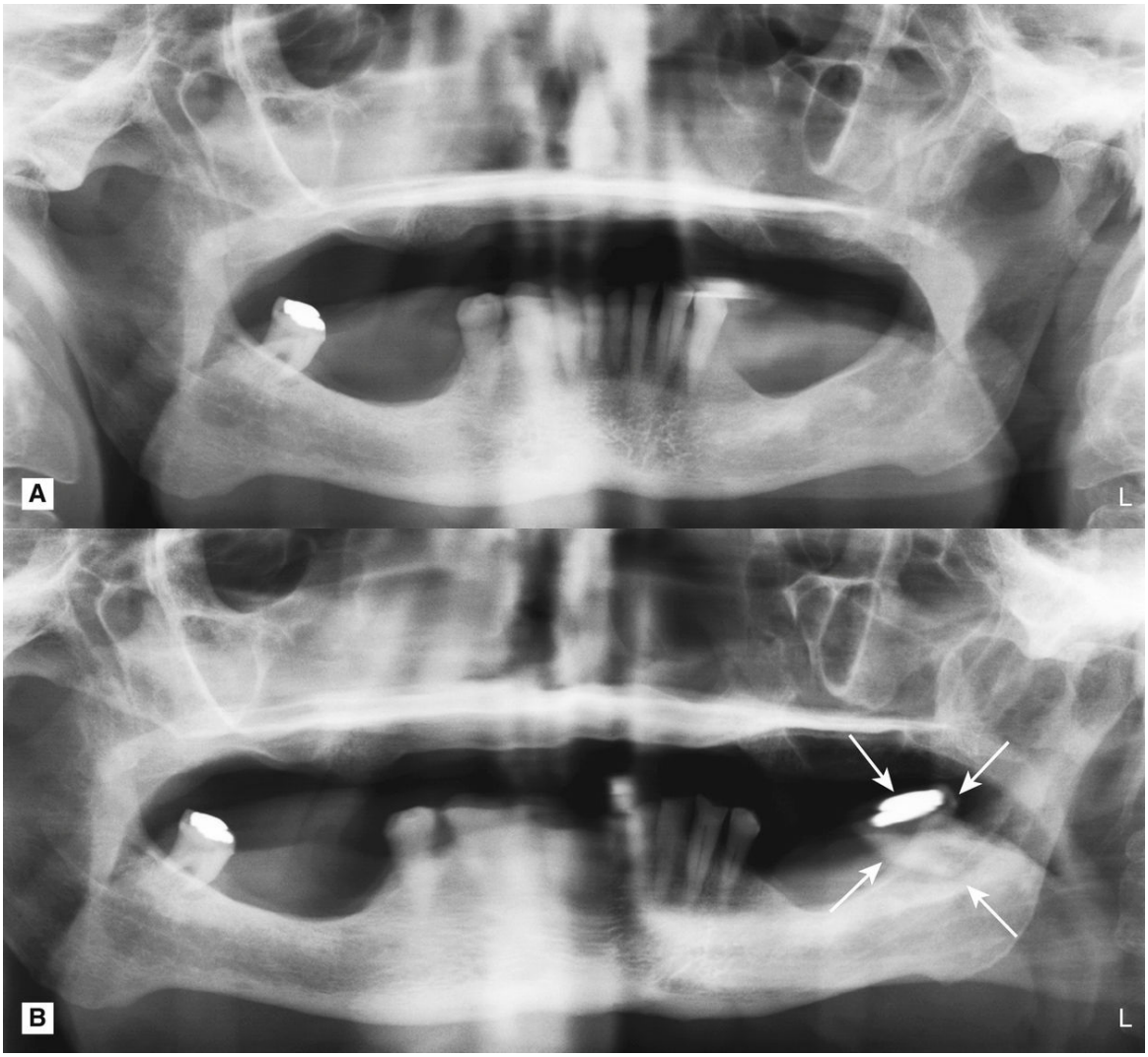


FIG. 15.25 **(A)** Panoramic radiograph of a patient taken using the standard programme. Note the edentulous **left** mandible. (B) Panoramic radiograph of the same patient using the non-standard *improved orthogonality* programme. Note the confusing non-standard ghost shadow of an apparent lower **left** molar tooth (arrowed) cast by the actual lower molar on the **right** .
Courtesy of Mr S. Harvey.

Advantages and Disadvantages

Advantages

- A large area is imaged and all the tissues within the focal trough are displayed, including the anterior teeth, even when the patient is unable to open the mouth.
- The image is easy for patients to understand, and is therefore a useful teaching aid.
- Patient movement in the vertical plane distorts only that part of the image being produced at that instant.
- Positioning is relatively simple and minimal expertise is required.
- The overall view of the jaws allows rapid assessment of any underlying, possibly unsuspected, disease.
- The view of both sides of the mandible on one image is useful when assessing fractures and is comfortable for the injured patient.
- The overall view is useful for evaluation of periodontal status and in orthodontic assessments.
- The antral floor, medial and posterior walls are well shown.
- Both condylar heads are shown on one film, allowing easy comparison (see Chapter 30).
- The radiation dose (*effective dose*) may be lower than a full mouth survey of intraoral images in some cases (see Chapter 6).
- Development of field-limitation techniques which result in further dose reduction.

Disadvantages

- The tomographic image represents only a section of the patient. Structures or abnormalities not in the focal trough may not be evident (see Fig. 15.26).
- Soft tissue and air shadows can overlie the required hard tissue structures (see Fig. 15.27).
- Ghost or artefactual shadows can overlie the structures in the focal trough (see Fig. 15.28).
- The tomographic movement together with the distance

between the focal trough and image receptor produce distortion and magnification of the final image (approximately × 1.3).

- The use of indirect-action film and intensifying screens results in some loss of image quality, but image resolution can be improved by using digital image receptors.
- The technique is not suitable for children under 6 years or on some disabled patients because of the length of the exposure cycle.
- Some patients do not conform to the shape of the focal trough and some structures will be out of focus.
- Movement of the patient during the exposure can create difficulties in image interpretation (see Fig. 15.29).

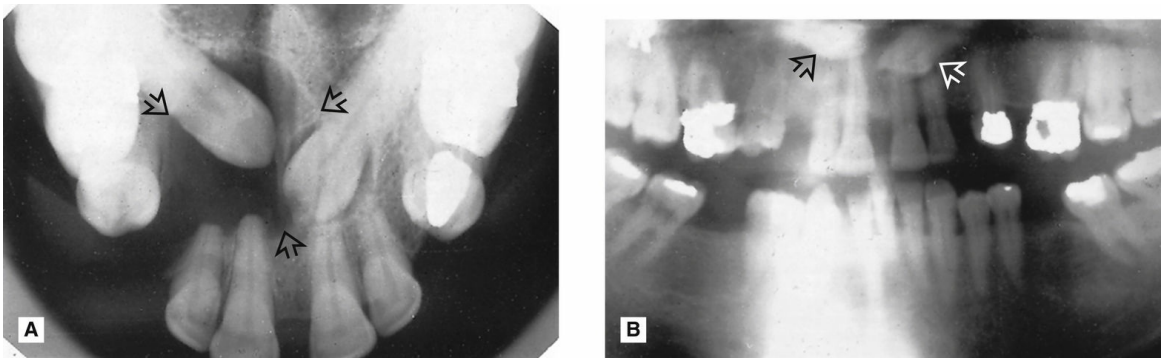


FIG. 15.26 **(A)** Upper standard occlusal showing unerupted 3|3 and a large dentigerous cyst (arrowed) associated with 3| **(B)** Panoramic radiograph showing the two unerupted canines out of focus (arrowed) and only a suggestion of the dentigerous cyst, because they are all palatally positioned and outside the focal trough.

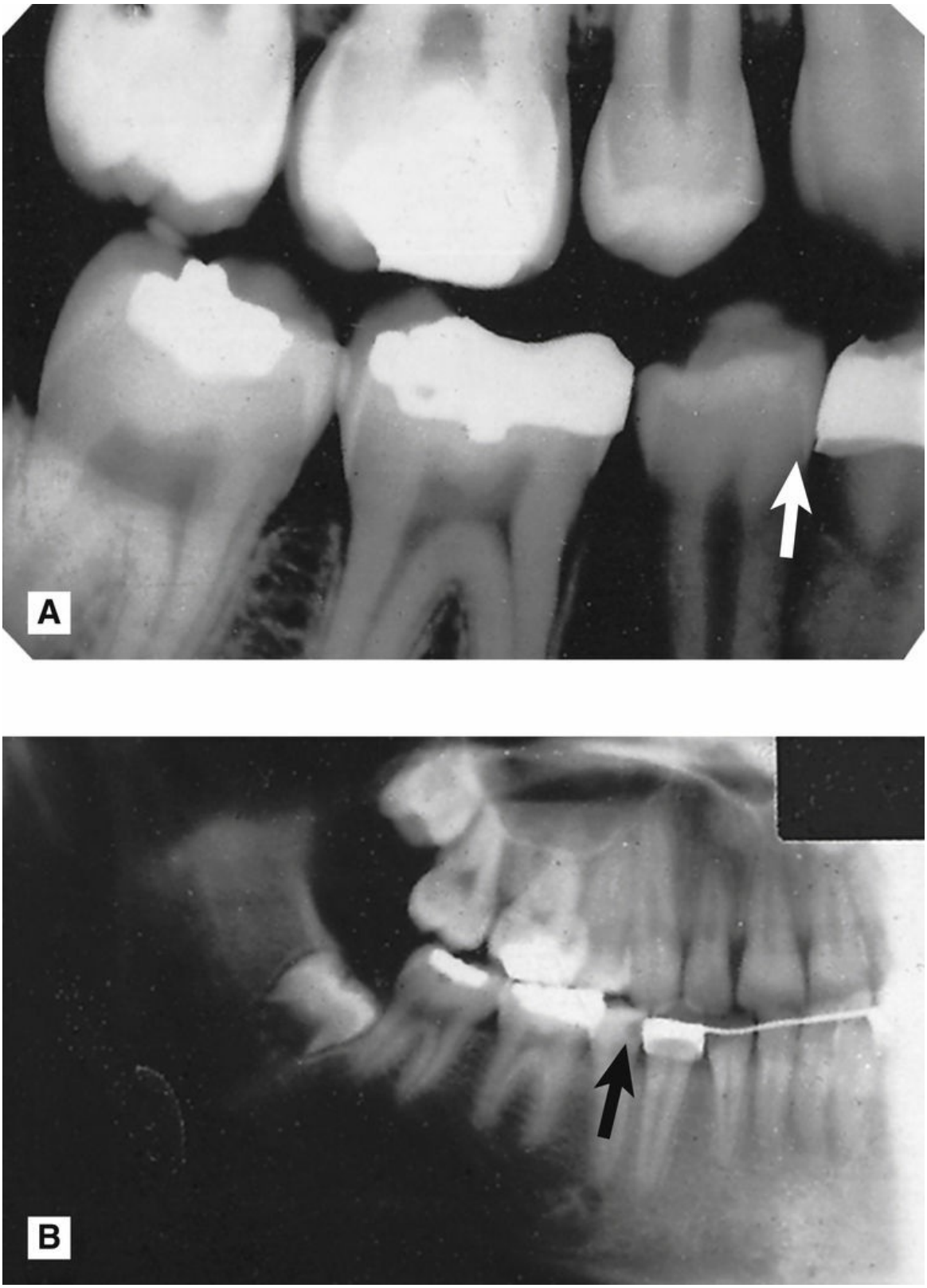


FIG. 15.27 **(A)** Right bitewing showing no evidence of mesial caries in $\overline{5}|$ (arrowed). **(B)** Panoramic radiograph

showing an apparent lesion in this tooth (arrowed). This appearance is created by the overlying air shadow of the corner of the mouth.


A

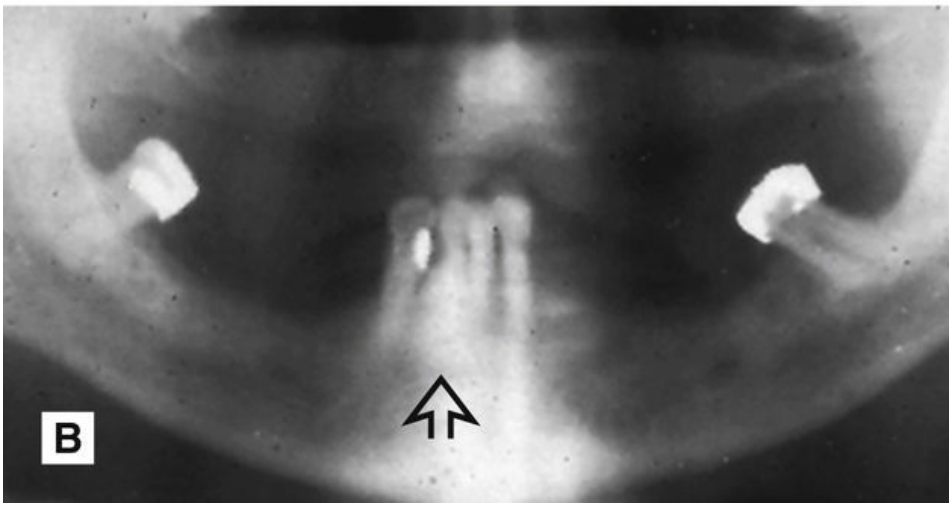

B

FIG. 15.28 **(A)** Periapical of $\overline{21|12}$ region showing an area of radiolucency at the apex of $\overline{1|}$ (arrowed). **(B)** Panoramic radiograph showing no evidence of the lesion (arrowed) owing to superimposition of the shadow of the cervical vertebrae.

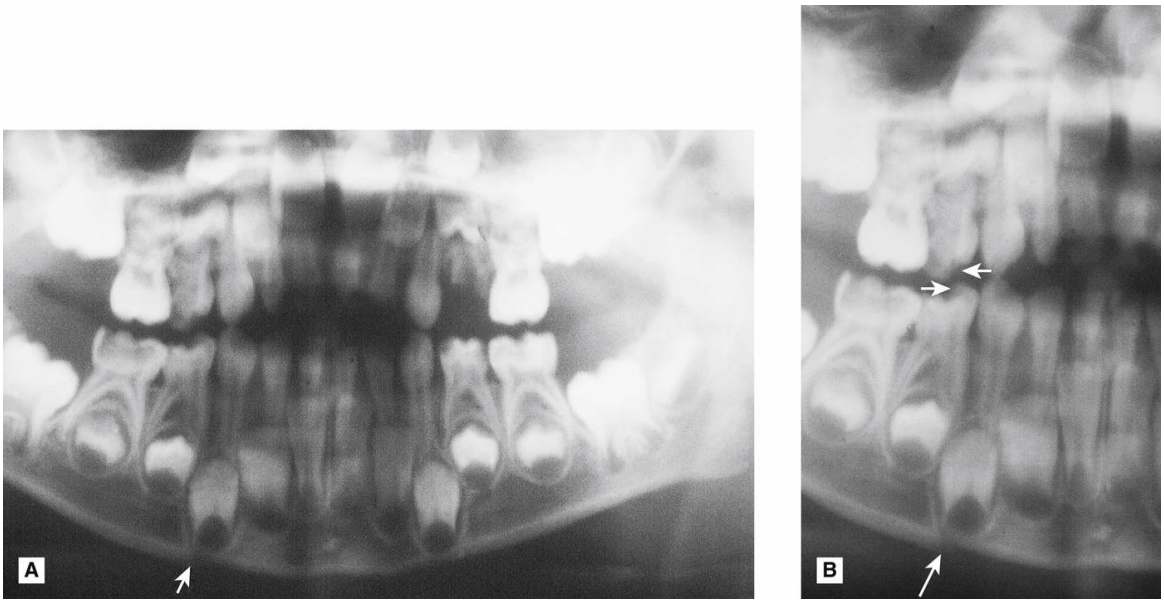


FIG. 15.29 **(A)** Panoramic radiograph of a young child, who had fallen over, showing a step deformity (arrowed) in the lower border of the mandible suggesting a fracture. **(B)** Same radiograph enlarged showing the step deformity (large arrow), but also notice the step deformities in the crowns of the upper and lower first deciduous molars (small arrows). Sudden slight vertical movement of the patient makes interpretation difficult. The mandible was not fractured.

Assessment of Image Quality

As mentioned in previous chapters, in relation to all other radiographs, image quality assessment essentially involves three separate stages, namely:

- Comparison of the image against ideal quality criteria
- Subjective rating of image quality using published standards
- Detailed assessment of rejected images to determine the source of error.

Ideal Quality Criteria

Irrespective of the type of image receptor being used, typical quality criteria for a full field of view panoramic radiograph include the following:

- All the upper and lower teeth and their supporting alveolar bone should be clearly demonstrated.
- The whole of the mandible should be included.
- Magnification in the vertical and horizontal planes should be equal.
- The right and left molar teeth should be equal in their mesiodistal dimension.
- The density across the image should be uniform with no air shadow above the tongue creating a radiolucent (black) band over the roots of the upper teeth.
- The image of the hard palate should appear above the apices of the upper teeth.
- Only the slightest ghost shadows of the contralateral angle of the mandible and the cervical spine should be evident.
- There should be no evidence of artefactual shadows owing to dentures, earrings or other jewellery.
- The patient identification label should not obscure any of the above features.
- The image should be clearly labelled with the patient's name and date of the examination,
- The image should be clearly marked with a **R** ight and/or **L** eft letter.

Subjective Rating of Image Quality

The simple two-point subjective quality rating scale for both digitally-captured and film-captured images published in the UK's latest *Guidance Notes* was introduced in Chapter 9 and is discussed in detail, together with the errors associated with computer software, exposure factors and chemical processing in Chapter 17 . The summary quality rating criteria for both types of imaging are shown again in Table 15.1 . The remainder of this chapter deals with panoramic patient preparation and positioning errors which are the same irrespective of the type of image receptor used.

Assessment of Not Acceptable Images and Determination of Errors

Patient Preparation Errors (see Fig. 15.30)

These can include:

- Failure to remove jewellery
  - Earrings
  - Necklaces
  - Piercings
- Failure to remove dentures
- Failure to remove orthodontic appliances
- Failure to remove spectacles
- Inappropriate use of the lead apron.

Patient Positioning Errors (see Figs. 15.31 –15.32)

These can include:

- Failure to ensure that the spine is straight (ghosting shadow error)
- Failure to ensure the incisors are biting edge-to-edge on the bite-peg (anteroposterior error)
- Failure to use the light beam marker to ensure midsagittal

plane is vertical and the head is not rotated (horizontal error)
- Failure to use the light beam marker to ensure the Frankfort plane is horizontal (vertical error)
- Failure to instruct the patient to press the tongue against the roof of the mouth (air shadow error)
- Failure to instruct the patient to remain still throughout the exposure (movement error).

TABLE 15.1

Subjective quality rating criteria for digital and film captured images based on the latest UK *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment*, (second edition).

Quality	Basis
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction and of sufficient image quality to answer the clinical question
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction which render the image diagnostically unacceptable

Equipment Positioning Errors (see Fig. 15.33)

These can include:

- Failure to set height adjustment correctly
- Failure to select correct exposure settings (see Chapter 17)
- Failure to use the cassette correctly.

Footnote

Panoramic radiographs should not be considered an alternative to high-resolution intraoral radiographs. However, they are commonly considered as an alternative to right and left *oblique lateral* radiographs or the bimolar projection (see Chapter 12), mainly because it is assumed that less operator expertise is required to produce panoramic

images of adequate diagnostic quality. Unfortunately, the multiple and varied causes of error in panoramic radiography make the technique very operator-dependent, no matter how sophisticated the equipment and the image receptors become.

The diagnostic value of all panoramic images is increased considerably if clinicians understand that the image created is a tomograph (whatever the image receptor) and are aware of the limitations that this imposes. A suggested systematic approach to interpretation of panoramic images is outlined in Chapter 19 .

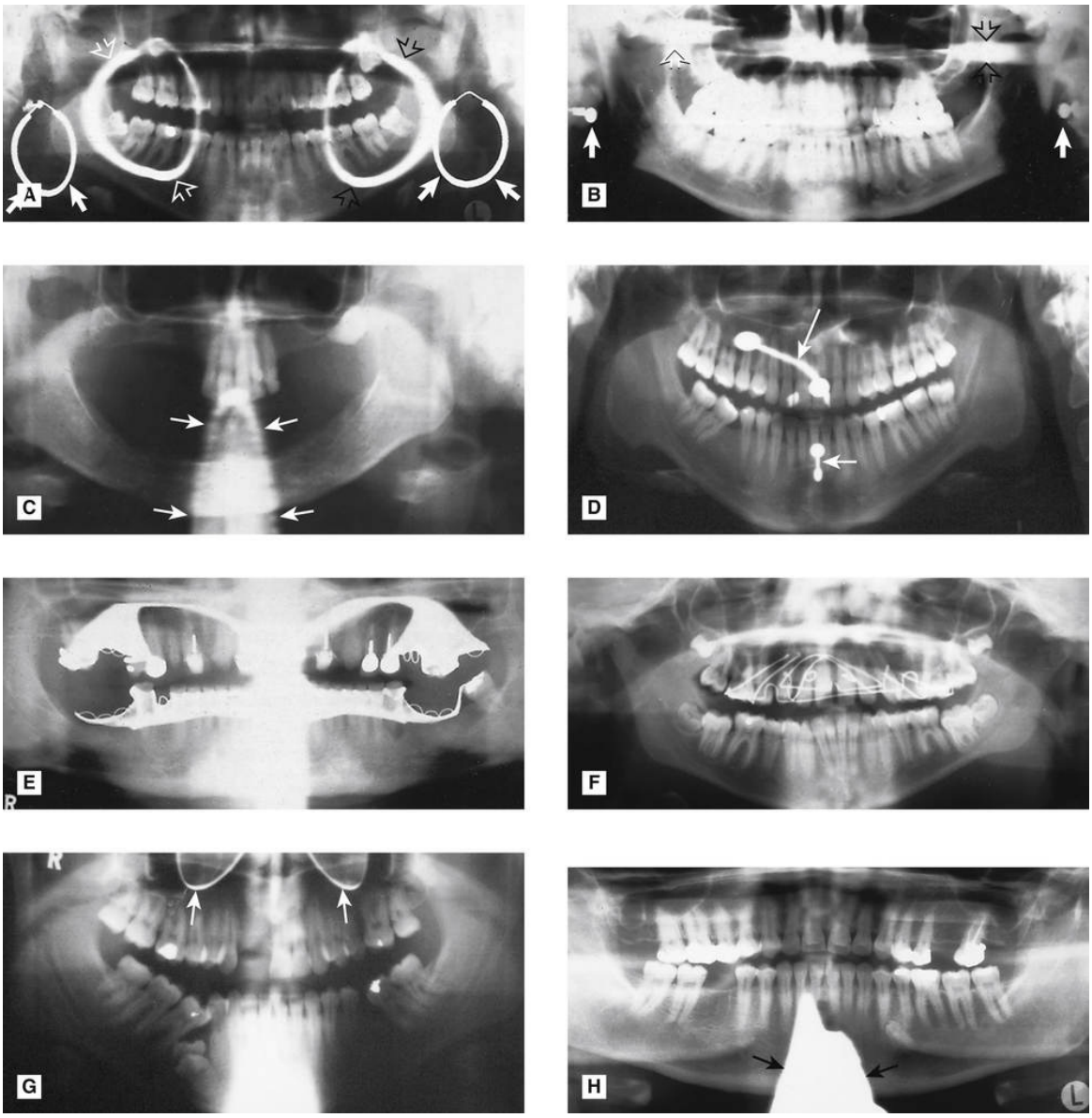


FIG. 15.30 Examples of common patient preparation errors.

(A) Failure to remove large ring-shaped earrings – note each earring casts two shadows, one real (in focus, solid arrows) and one ghost (blurred, open arrows). The ghost shadow of the LEFT earring is marked with white open arrows, that of the RIGHT earring with black open arrows.
(B) Failure to remove stud earrings – real shadows (solid arrows) with ghost shadows (open arrows).
(C) Failure to remove a necklace – blurred ghost shadow (arrowed).
(D) Failure to remove piercing in the tongue (large arrow) and lower lip (small arrow).

(E) Failure to remove upper and lower metallic partial dentures.
(F) Failure to remove an upper orthodontic appliance.
(G) Failure to remove spectacles (arrowed).
(H) Inappropriate use of a protective lead apron – too high on the neck casting a dense radiopaque shadow (arrowed) over the anterior part of the mandible.

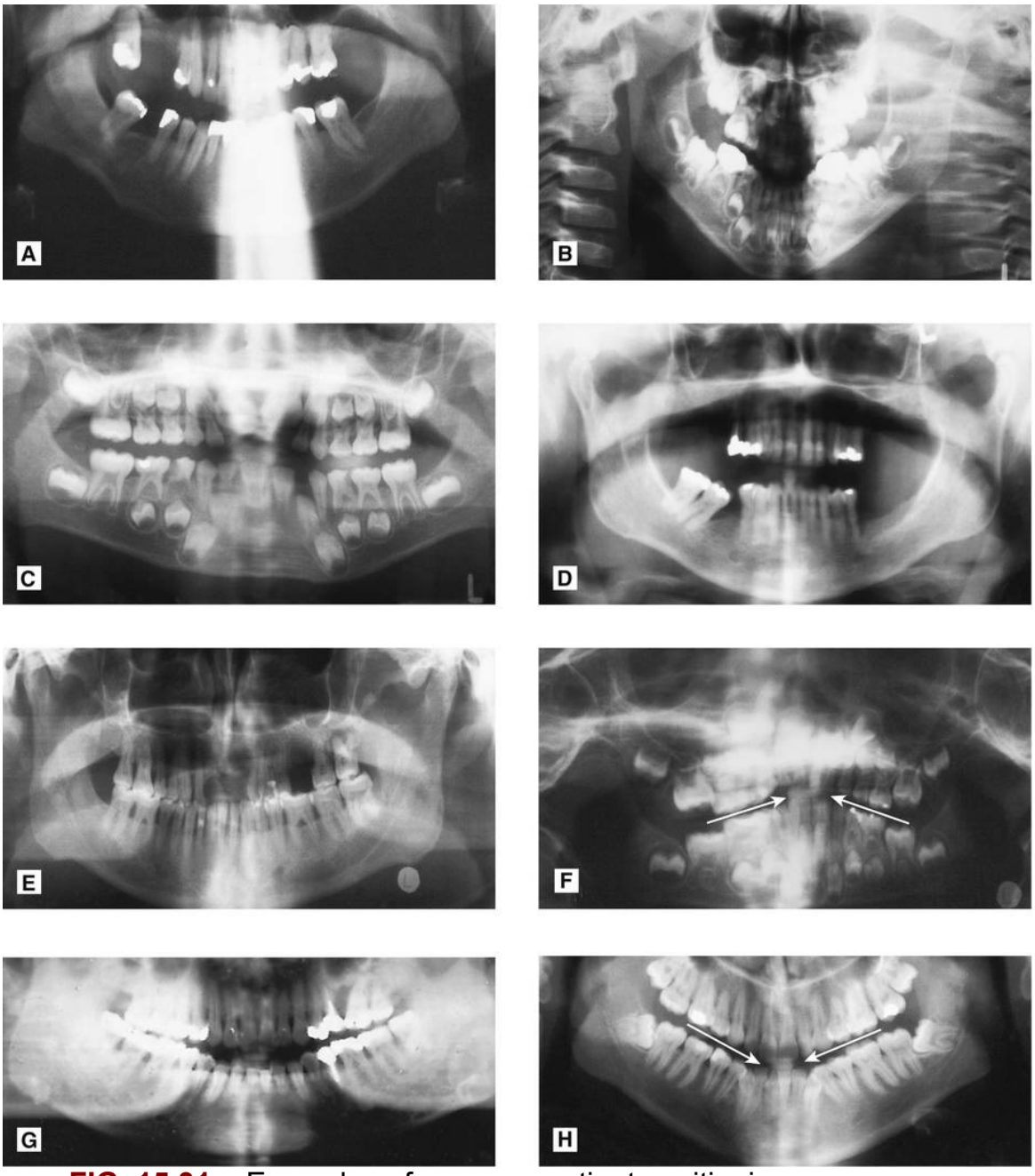


FIG. 15.31 Examples of common patient positioning errors. **(A)** Failure to position the neck correctly – extension of the neck causing excessive spinal ghosting shadows over the anterior teeth. **(B)** Anteroposterior error – patient positioned too far forwards (too close to the image receptor) and vertical error – Frankfort plane not horizontal (chin tipped down) creating narrow, out of focus anterior teeth, distorted occlusal plane (so-called *smiley face*) and excessive peripheral spinal shadowing. **(C)** Anteroposterior error – patient positioned too far back (too far away from the image receptor) creating

widened, magnified and out-of-focus anterior teeth. **(D)** Anteroposterior error – patient positioned too far forwards (too close to the image receptor) creating narrowed incisors and failure to instruct patient to keep their tongue in contact with the palate creating the radiolucent band across the film. **(E)** Horizontal error – patient asymmetrical, rotated to the RIGHT. The RIGHT molars are closer to the image receptor and smaller, the LEFT molars are further away from the image receptor and larger. **(F)** Vertical error – Frankfort plane not horizontal (chin tipped up) creating out–of–focus upper incisors and distorted occlusal plane (arrowed) (so-called *grumpy face*). **(G)** Vertical error – Frankfort plane not horizontal (chin tipped down) creating out of focus lower incisors and excessive ghosting shadows of the contralateral angles of the mandible. ***(H)*** Vertical error – Frankfort plane not horizontal (chin tipped down) creating out of focus lower incisors and distorted occlusal plane (arrowed) (so-called *smiley face*).

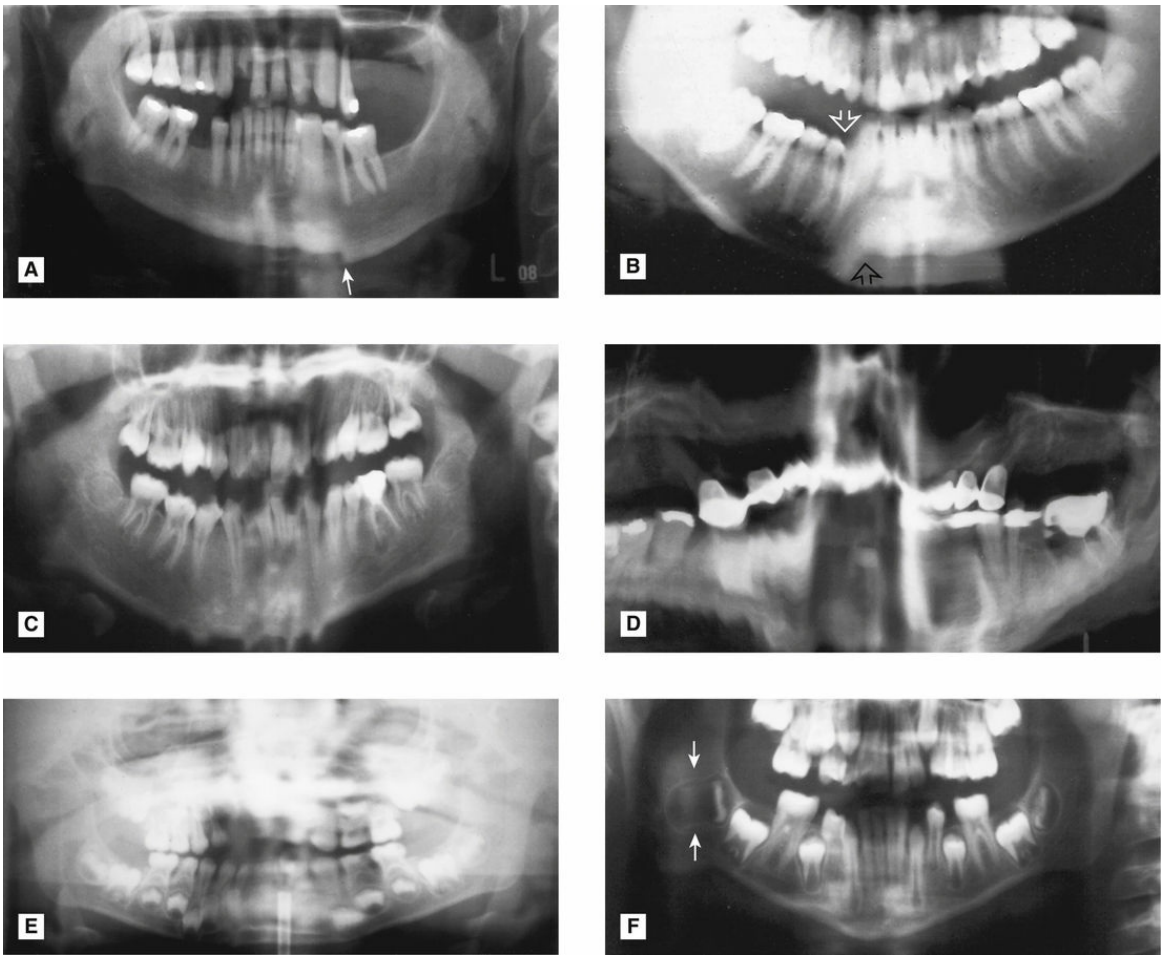


FIG. 15.32 Examples of failure to instruct the patient to keep still during the full panoramic cycle.

(A) Sudden movement in the vertical plane – distortion of the image 45 region creating a step-deformity in the lower border (arrowed) (see also Fig. 15.29).
(B) Movement in the vertical plane caused by the patient opening their mouth causing distortion in the 43 region (arrowed).
(C) Multiple vertical movements while the anterior teeth were being imaged.
(D) Continuous shaking movements throughout the cycle.
(E) Sudden side-to-side horizontal movement while the anterior teeth were being imaged causing them to be blurred.
(F) Horizontal movement towards the end of the cycle causing horizontal elongation and stretching of the shadow of the developing lower right third molar (arrowed).

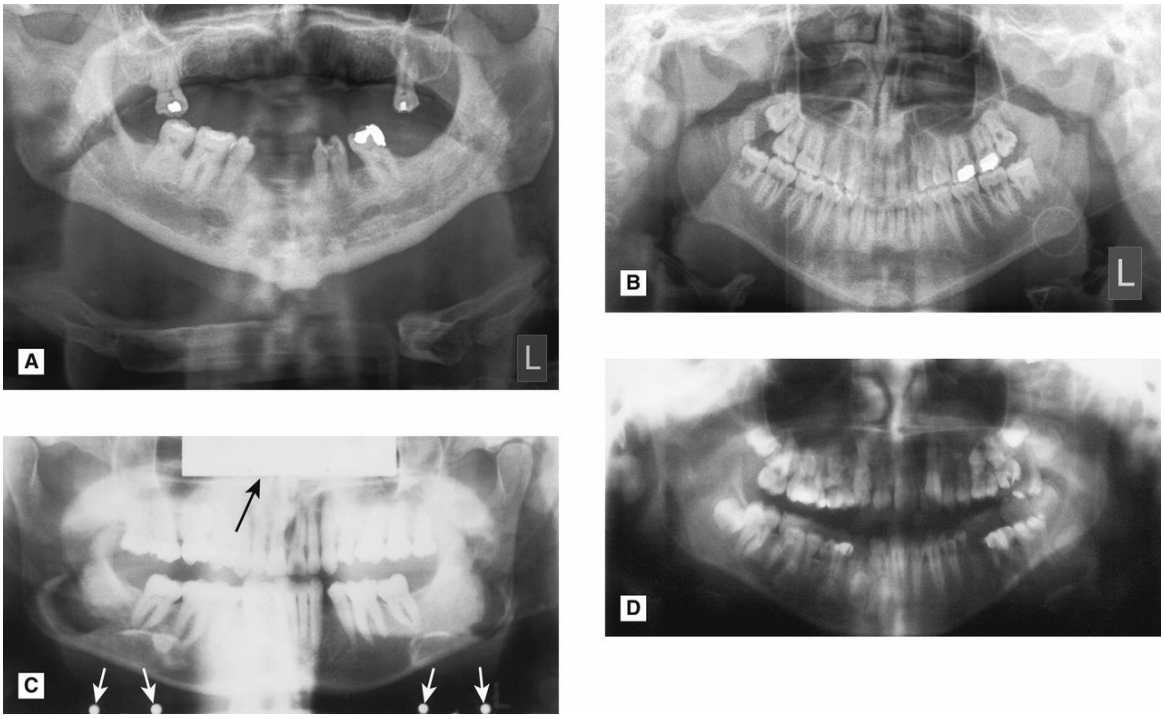


FIG. 15.33 Examples of equipment positioning errors.

(A) The X-ray tubehead and image receptor carriage assembly positioned too low relative to the patient – the antra and condyles are not imaged.
(B) Modern cassette positioned back-to-front.
(C) Traditional cassette positioned back-to-front in the carriage assembly. Name plate and hinge screws are evident (arrowed).
(D) Cassette inadvertently used twice and double-exposed.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

16

Cone Beam Computed Tomography

Cone beam computed tomography (CBCT) has been developed in recent years specifically for use in the dental and maxillofacial regions and is gradually establishing itself as the imaging modality of choice in certain clinical situations. It is also referred to as *digital volume tomography* or *cone beam volumetric imaging.* As described later, the size of the *volume or field of view* (FOV) of the maxillofacial skeleton imaged varies; as a result CBCT scans are often described by their *FOV:*

- *Small, limited or dento-alveolar* (height of ≤5 cm)
- *Medium or maxillofacial* (height of 5.1–10.0 cm)
- *Large or craniofacial* including the cranial base ± the skull vault (height of >10 cm).

Main Indications

Considerable controversy exists as to the main indications for CBCT and robust clinical research justifying its use is still limited. Some authorities argue that CBCT should be regarded as almost routine for all dental and maxillofacial applications, while others argue that CBCT should not be used unless the results of the examination are going to alter patient management as the technique delivers a higher dose than conventional two-dimensional imaging. In 2012, the European Commission published *Radiation Protection No. 172 'Evidence based guidelines on cone beam CT for dental and maxillofacial radiology'* based on what evidence was available at that time. These guidelines, and a more cautious approach to the justified use of CBCT, are

endorsed by the authors. Hence the indications summarised here are based broadly on the European Commission's recommendations.

The Developing Dentition

CBCT may be indicated for:

- Localization of an unerupted tooth (small FOV)
- Assessment of external resorption in relation to unerupted teeth (small FOV)
- Localized assessment of an impacted tooth (small FOV)
- Assessment of cleft palate (small or medium FOV)
- Planning complex orthodontic/surgical management of maxillofacial skeletal abnormalities (medium or large FOV).

CBCT is generally not indicated for:

- Planning the placement of temporary anchorage in orthodontics
- Routine orthodontic diagnosis.

Restoring the Dentition

If conventional imaging proves inadequate, CBCT may be indicated for:

- Assessment of periodontal infra-bony defects and furcation lesions (small FOV)
- Periapical assessment (small FOV)
- Assessment of root canal anatomy in multirooted teeth (small FOV)
- Planning surgical endodontic procedures (small FOV)
- Endodontic treatment complicated by resorption lesions, combined *perio-endo* lesions, perforations and atypical pulp anatomy (small FOV)
- Assessment of dental trauma (suspected root fracture) (small

FOV).

CBCT is generally not indicated for:

- Diagnosis of dental caries
- Routine imaging of periodontal support
- Routine diagnosis of periapical disease
- Routine assessment of root canal anatomy.

Surgical Applications

CBCT may be indicated for:

- Assessment of lower third molars where an intimate relationship with the inferior dental canal is suspected (small FOV)
- Assessment of unerupted teeth (small FOV)
- Cross-sectional imaging before implant placement (small or medium FOV)
- Assessment of pathological lesions affecting the jaws (small or medium FOV) including cysts, tumours, giant cell lesions and osseous dysplasias
- Assessment of facial fractures where soft tissue detail is not required (medium or large FOV)
- Planning orthognathic surgery to obtain three-dimensional datasets of the craniofacial skeleton (medium or large FOV)
- Assessment of the bony elements of the temporomandibular joint (small or medium FOV)
- Assessment of the bony walls of the maxillary antra.

Clinical examples illustrating many of these indications are included in later chapters.

Equipment and Theory

Multiple CBCT machines are currently available with new, upgraded models launched regularly by most manufacturers of X-ray equipment. Almost all modern machines resemble panoramic units as shown in Fig. 16.1 .

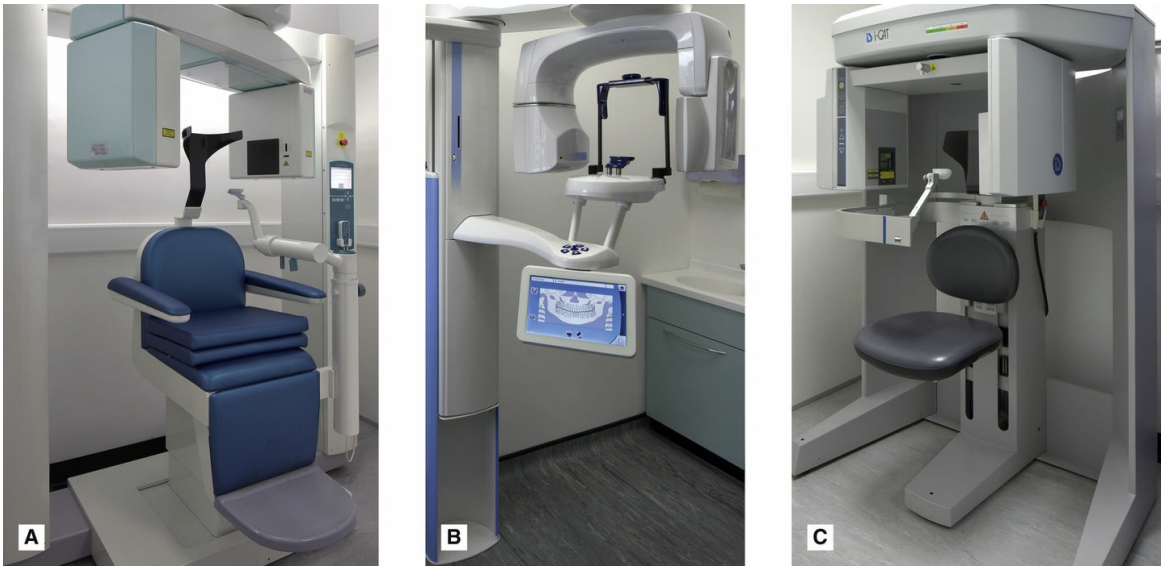


FIG. 16.1 Examples of three cone beam computed tomography machines designed for imaging the maxillofacial skeleton. **(A)** The 3D Accuitomo (J. Morita, Japan), **(B)** the ProMax (Planmeca, Helsinki, Finland) and **(C)** the i-CAT™ (Kavo Kerr, USA).

All equipment uses a cone-shaped X-ray beam (rather than the flat fan-shaped beam used in conventional CT as described in Chapter 18) and a special detector (e.g. an image intensifier linked to a charge-coupled device or, more commonly, an amorphous silicon flat panel). The scanning/image creation process divides into three stages:

- Data acquisition
- Primary reconstruction
- Secondary or multiplanar reconstruction.

Stage 1 – Data Acquisition

The patient is positioned with the unit (as described later). The equipment orbits around the patient in a 180°, 270° or 360° rotation, taking approximately 5–40 seconds, and in one cycle or scan, images the cylindrical or spherical *volume* referred to as the *field of view* (FOV). Since all the information/data is obtained in the single scan, the patient must remain stationary throughout the exposure. As described, the FOV can vary in size enabling small, medium or large volumes of a patient to be imaged. Using a large FOV (e.g. 15 cm^3), most of the maxillofacial skeleton fits within the cylindrical or spherical shape and is imaged in the one scan as shown in Fig. 16.2 . In some cases, large volume scans are obtained by computerized *stitching together* several separate overlapping small volume scans.

Stage 2 – Primary Reconstruction

Having obtained data from the one scan, the computer then divides the volume into tiny cubes or *voxels* (ranging in size between 0.076 and 0.55 mm^3) and calculates the X-ray absorption in each voxel. As with *pixels* in two-dimensional digital imaging, described in Chapter 5 , each voxel is allocated a number and then allocated a colour from the grey scale from black through to white. Typically, one scan contains more than 100 million voxels. The overall image resolution clinically of hard tissues (teeth and bones) is generally very good in CBCT imaging, although measured spatial resolution (1–3 line pairs per millimetre) is not yet as good as two-dimensional film-based or digital imaging (10–25 line pairs per millimetre) (see Chapter 4). Using a smaller voxel size potentially increases the spatial resolution but increases the radiation dose. Even so, CBCT cannot be used to examine the soft tissues in detail because of the size of the kV and types of detectors used and the amount of scatter. Essentially all that can be seen is the outline of the soft tissues where they interface with air.

Stage 3 – Secondary or Multiplanar Reconstruction

After the primary reconstruction, the computer software then allows the operator to select voxels in the three anatomical orthogonal planes to create sagittal, coronal or axial images as shown in Fig. 16.2 . A set of sagittal, coronal and axial images appear simultaneously on the computer monitor. The software then enables these image datasets to be scrolled through in real time. For example, by selecting and moving the horizontal cursor up and down on the coronal image, all the axial images can be scrolled through from top to bottom.

Using a small FOV (e.g. 4 cm^3) just two or three teeth and their supporting structures fit within the cylindrical or spherical shape. The same three stages of data acquisition, primary reconstruction and secondary or multiplanar reconstruction are employed to create images in the sagittal, coronal and axial planes as shown in Fig. 16.3 .

Multiplanar reconstruction also allows voxels in other planes to be selected. For example, it is possible to plot the curvature and shape of the dental arch to enable the computer to construct a panoramic image made up of the voxels that coincide with the plotted arch shape – either mandibular or maxillary (see Fig. 16.4).

In addition, it is also possible to reconstruct cross-sectional (also referred to as *transaxial*) images of any part of the jaw, and with appropriate software to produce so-called *volume rendered* or *surface rendered* images as shown in Fig. 16.5 .

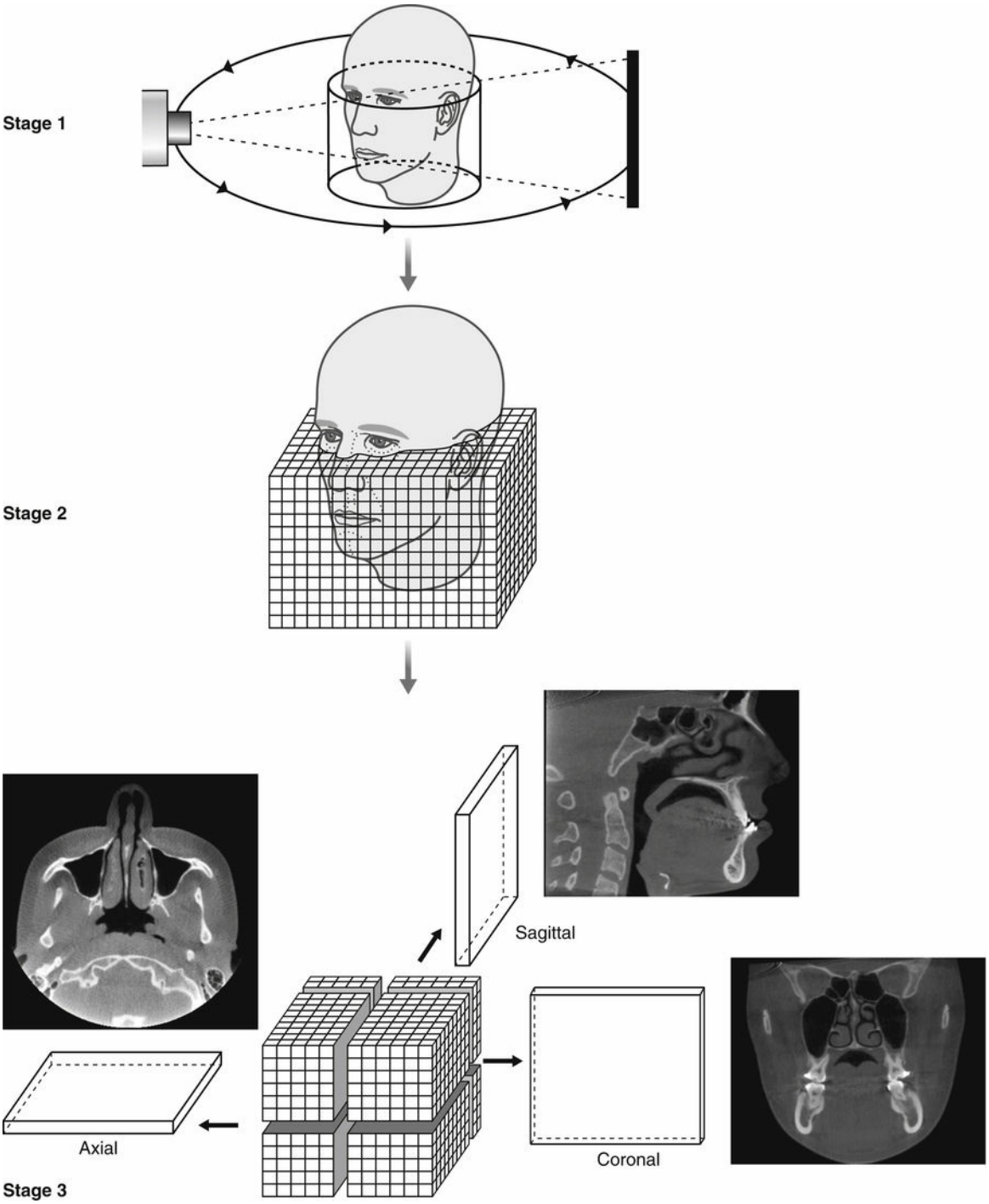


FIG. 16.2 Diagram showing the basic three-stage concept of a large volume CBCT scan. **Stage 1** – *Data acquisition:* a cone-shaped X-ray beam is used, which orbits around the patient obtaining information/data in a cylindrical volume. The patient's maxillofacial skeleton is positioned within the cylinder. **Stage 2** - *Primary reconstruction:* the computer divides the cylinder into tiny cubes or voxels. **Stage 3** - *Secondary or multiplanar reconstruction:* the computer

creates separate images in the sagittal, coronal and axial anatomical planes.

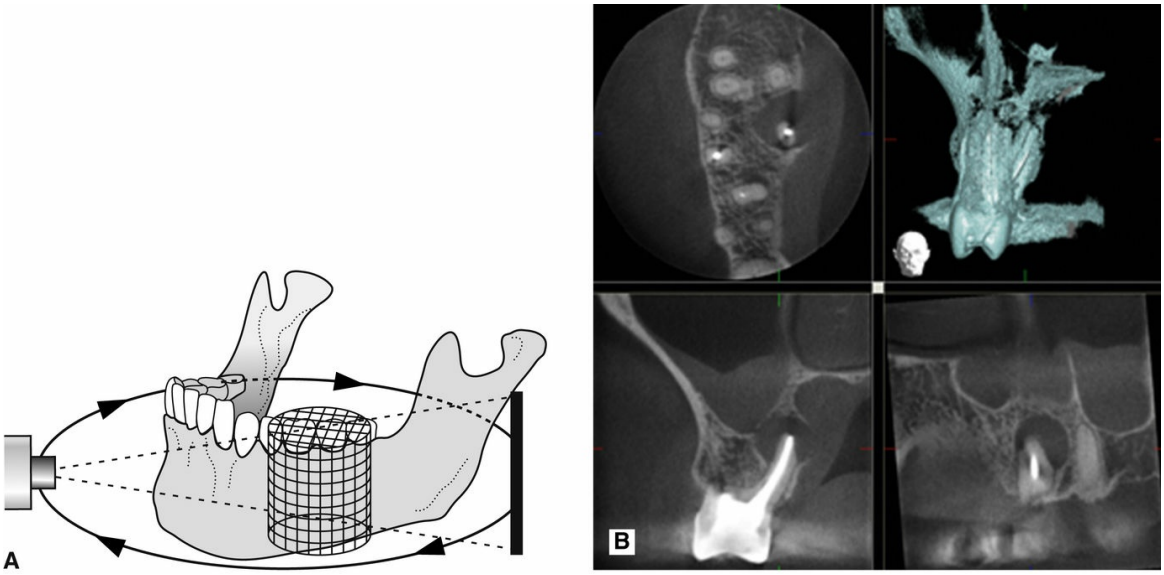


FIG. 16.3 **(A)** Diagram showing the basic concept of *data acquisition* for a small field of view CBCT. A cone-shaped X-ray beam orbits once round the patient acquiring data within a small cylinder containing two or three teeth. **(B)** An example of a small volume CBCT scan showing axial, coronal and sagittal images and a three-dimensional reconstructed image after *secondary or multiplanar reconstruction .*

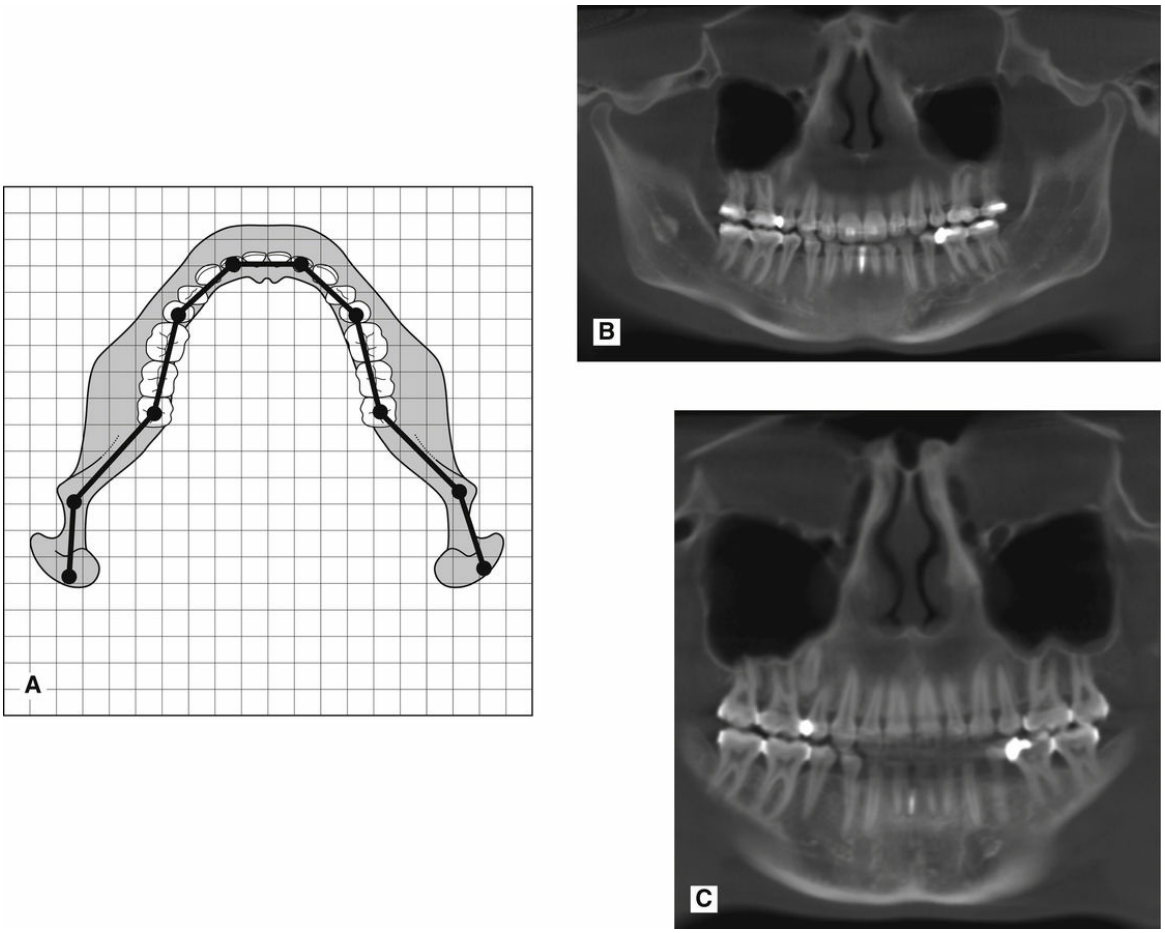


FIG. 16.4 **(A)** Diagram showing how plotting the shape of the arch identifies the voxels that are required for the computer to generate a panoramic image. **(B)** Panoramic image based on the curved shape of the mandibular arch. **(C)** Panoramic image based on the curve of the maxillary arch.

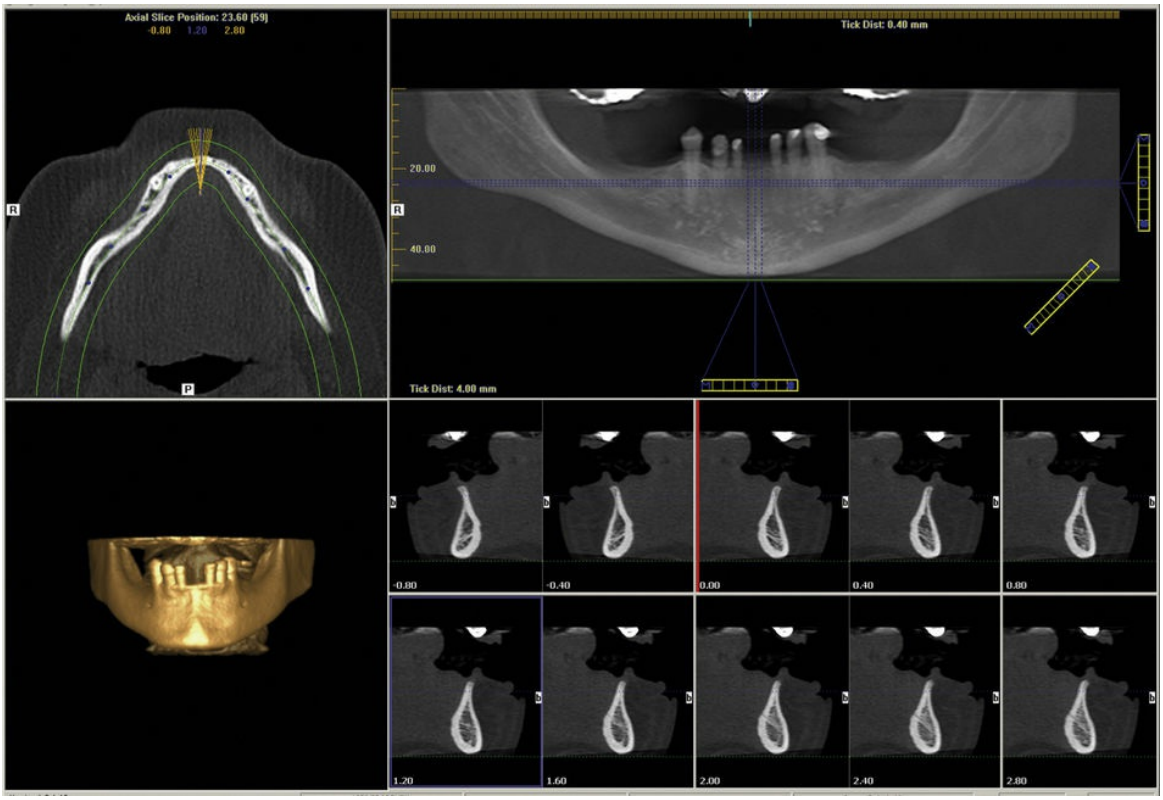


FIG. 16.5 An example of the i-CAT™ *implant planning screen*, showing an axial slice allowing the arch shape to be defined resulting in the panoramic image, together with 10 transaxial/cross-sectional images through the midline of the mandible and a volume-rendered three-dimensional image.

Technique and Positioning

As in panoramic radiography, described in Chapter 15 , the exact patient positioning techniques vary from one machine to another, but whatever the machine, written protocols for each CBCT examination should be provided which include details of patient positioning, exposure parameters and volume size. There are, however, some general requirements that are common to all machines and these can be summarized as follows.

Patient Preparation

- Patients should be asked to remove any earrings, jewellery, hair pins, spectacles and dentures or orthodontic appliances.
- The procedure and equipment movements should be explained to reassure patients and the importance of remaining stationary throughout the scan should be stressed.

Equipment Preparation

- The smallest volume size needed to answer the clinical question should be used to reduce the radiation dose to the patient. Using a smaller volume reduces scatter and potentially improves image quality.
- Optimal exposure factors should be selected to satisfy the diagnostic requirements of the examination. Higher exposure factors may be chosen if a higher spatial resolution is required.
- Optimal reconstructed voxel size should be selected. If choosing a larger voxel size results in a decreased patient dose (owing to lower exposure factors being used), then this dose should be considered as long as the lower resolution is compatible with the aims of the radiographic examination.
- Some machines offer a 'quick scan' where the rotation arc is decreased. This feature decreases the number of projections taken and therefore decreases the dose. If the required diagnostic information can be obtained using this scan protocol, then it should be selected.

Patient Positioning

- The patient should be positioned using the manufacturer's guidelines to ensure that the correct region of interest is captured. A *scout* view may be useful to ensure the right part of the jaw is imaged as shown in Fig. 16.6 .

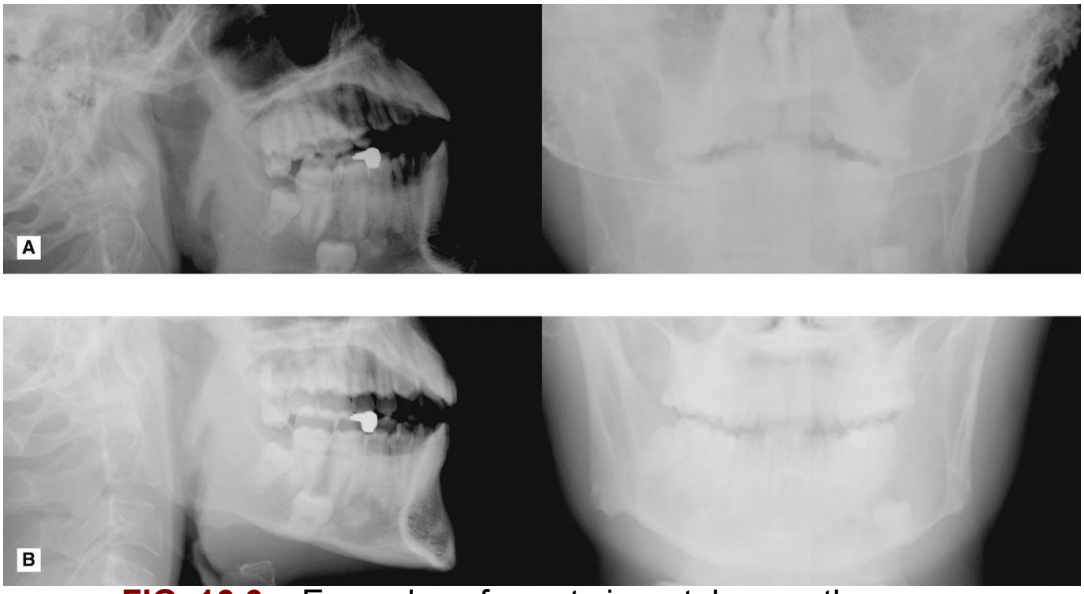


FIG. 16.6 Examples of scout views taken on the Instrumentarium OP200. **(A)** The first scout view of the mandible shows that the lower part of the mandible has been missed. The set-up was altered and the scout view repeated. **(B)** The second scout view after alteration of the set-up. The whole body of the mandible is now included, and the full scan can now be carried out in the knowledge the complete region of interest will be imaged.

- Once positioned correctly, using the light beam markers, immobilization chin cups and head straps must be used to prevent any patient movement (see Fig. 16.7).
- There is no need for the routine use of a protective lead apron.
- There is no need for the routine use of a protective thyroid collar because the thyroid gland does not normally lie in the primary beam; however, its use should be considered on a case-by-case basis, particularly for children. In the UK, Public Health England recommends thyroid collars if the FOV extends well below the mandible. If used, it must be positioned so that it does not interfere with the primary beam, because this could lead to significant artefacts.

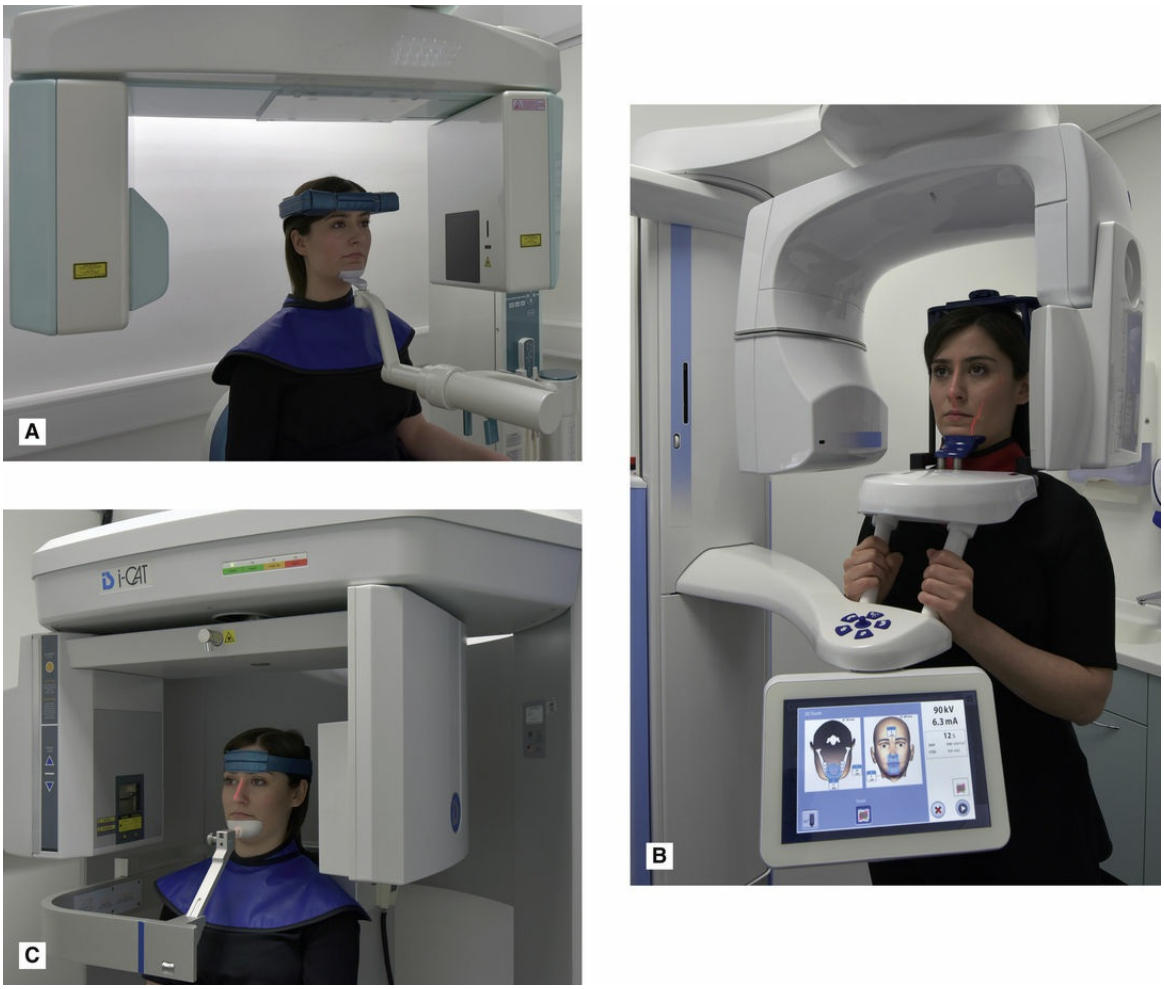


FIG. 16.7 Patient positioned **(A)** seated in the 3D Accuitomo, **(B)** standing in the ProMax and **(C)** seated in the i-CAT Next Generation. Note the use of light beam markers and immobilising chin cups and head restraints to prevent any movement. These photographs show the patient wearing thyroid shielding, but this would only be required if the scan volume (FOV) includes the thyroid.

Normal Anatomy

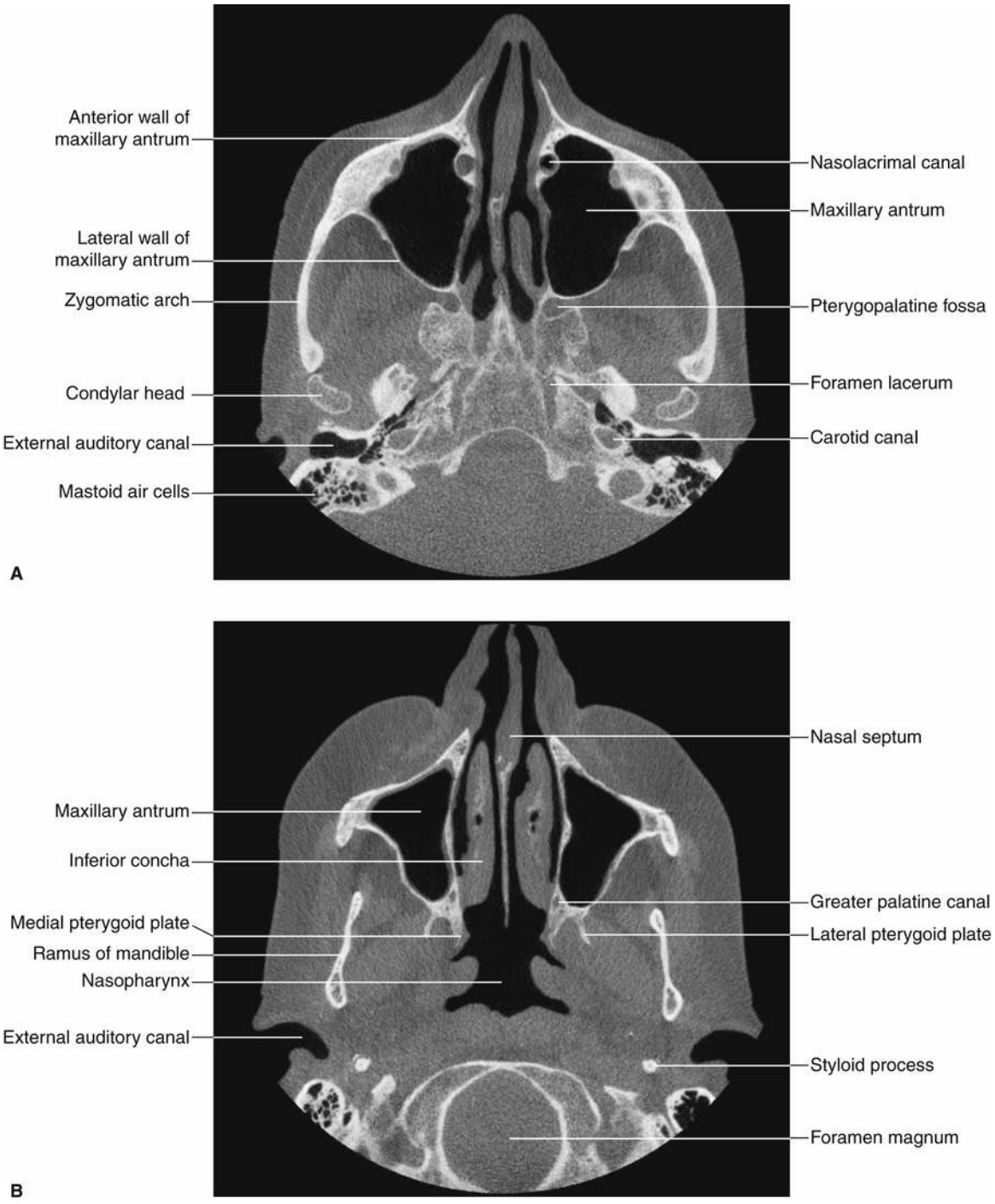


FIG. 16.8 Examples of large volume CBCT images with the main anatomical features indicated. **(A)** An axial image at the level of the condyle. **(B)** An axial image at the level of the ramus of the mandible.

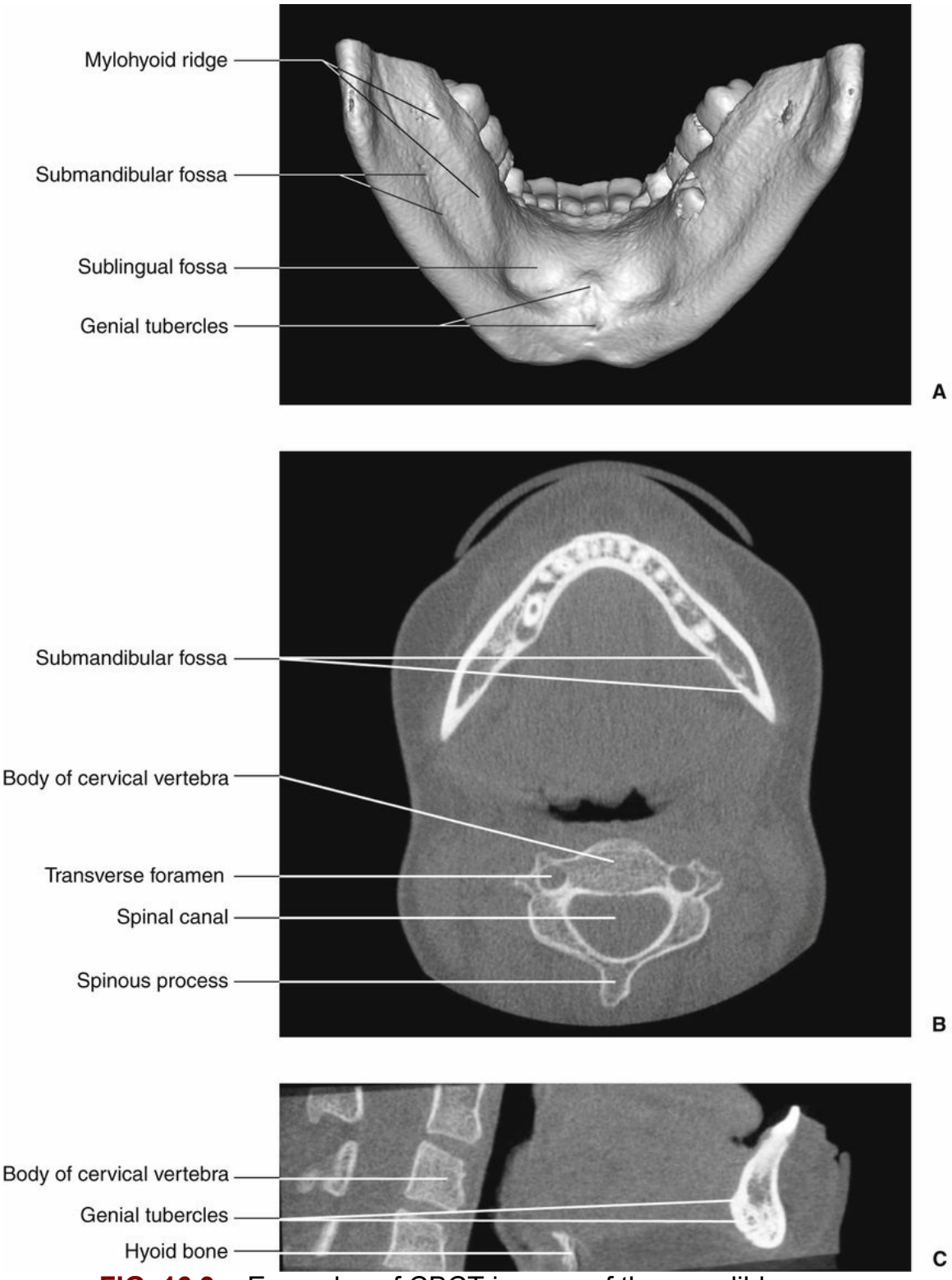


FIG. 16.9 Examples of CBCT images of the mandible showing the main anatomical features. **(A)** A 3-D surface rendered reconstruction of the mandible viewed from the lingual side (DentsplySirona - Simplant®Pro). **(B)** An axial

image through roots of the mandibular teeth. **(C)** A sagittal image through the midline of the mandible.

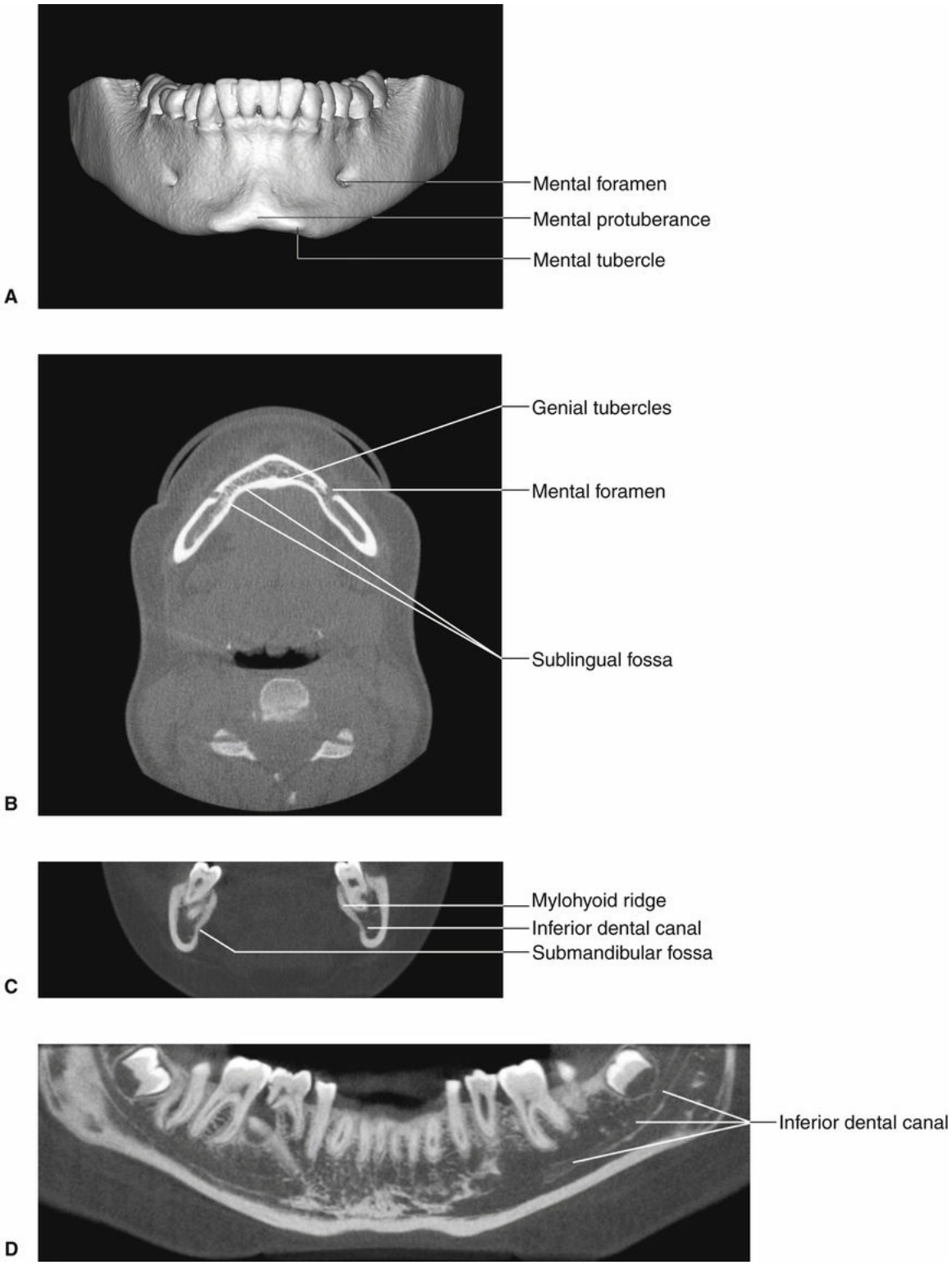


FIG. 16.10 Further examples of CBCT images of the mandible showing the main anatomical features. **(A)** A 3-D surface rendered reconstruction of the mandible viewed from the front (DentsplySirona - Simplant®Pro). **(B)** An axial image

at the level of the mental foramina. **(C)** A coronal image through the molar teeth. **(D)** A panoramic type reconstruction along the course of the inferior dental canal.

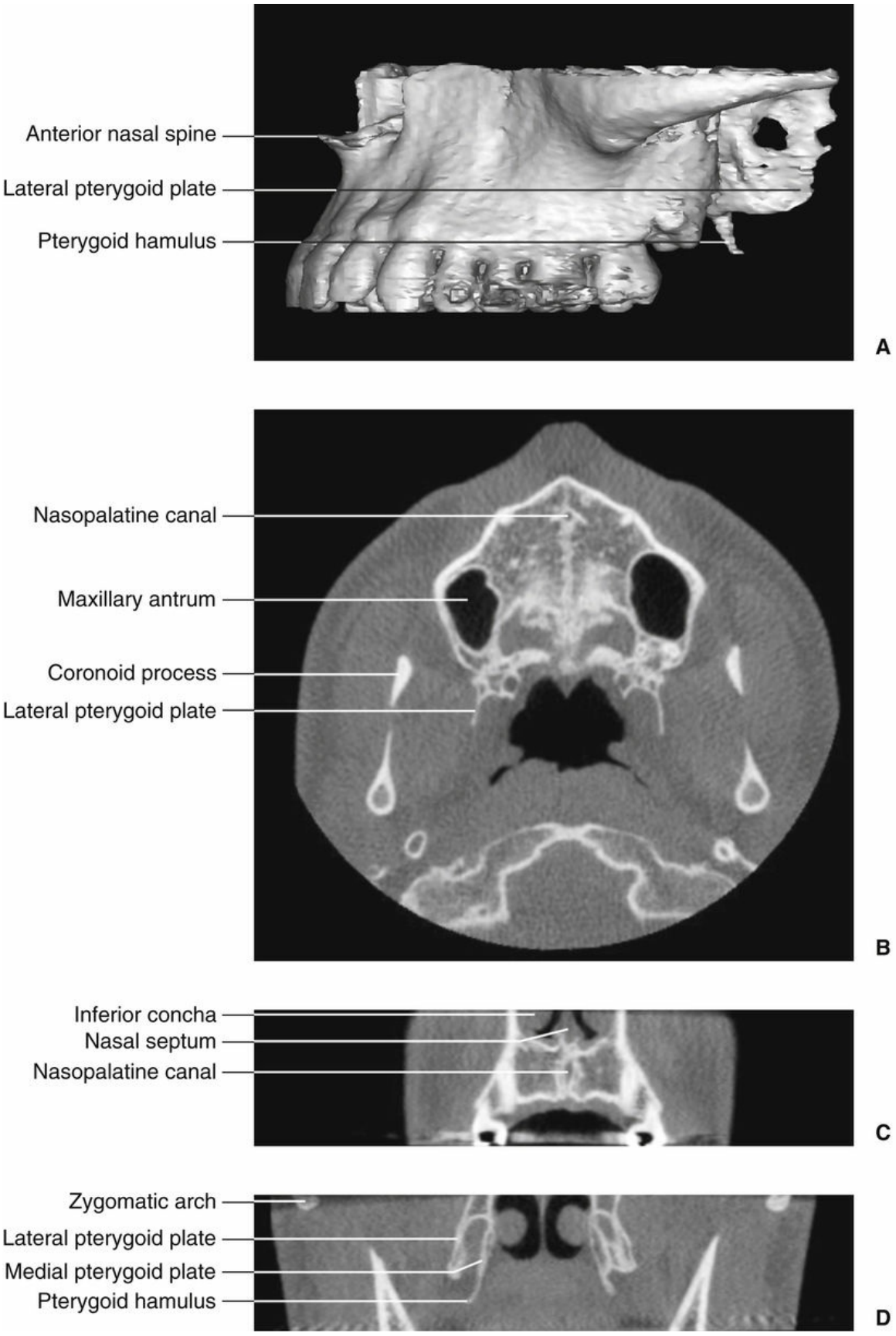

Anterior nasal spine
Lateral pterygoid plate
Pterygoid hamulus
A
Nasopalatine canal
Maxillary antrum
Coronoid process
Lateral pterygoid plate
B
Inferior concha
Nasal septum
Nasopalatine canal
C
Zygomatic arch
Lateral pterygoid plate
Medial pterygoid plate
Pterygoid hamulus
D

FIG. 16.11 Examples of CBCT images of the maxilla showing the main anatomical features. **(A)** A 3-D surface rendered reconstruction of the left side of the maxilla (DentsplySirona - Simplant®Pro). **(B)** An axial image through the base of the maxillary antra. **(C)** A coronal image through the Nasopalatine canal. **(D)** A coronal image through the pterygoid plates.

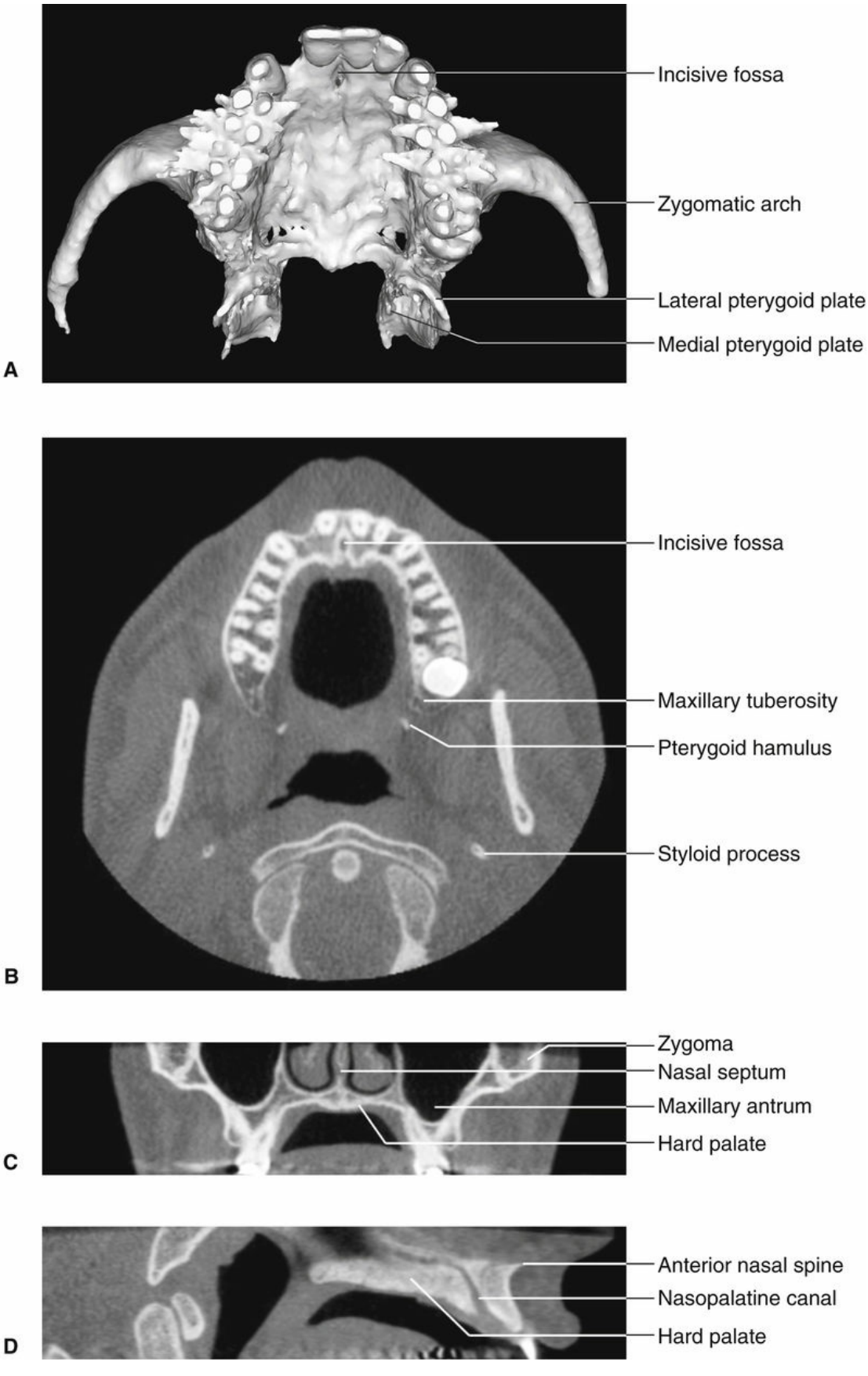

Incisive fossa
Zygomatic arch
Lateral pterygoid plate
Medial pterygoid plate
A
Incisive fossa
Maxillary tuberosity
Pterygoid hamulus
Styloid process
B
Zygoma
Nasal septum
Maxillary antrum
Hard palate
C
Anterior nasal spine
Nasopalatine canal
Hard palate
D

FIG. 16.12 Further examples of CBCT images of the maxilla showing the main anatomical features. **(A)** A 3-D surface-rendered reconstruction of the maxilla viewed from below (DentsplySirona - Simplant®Pro). **(B)** An axial image through the roots of the maxillary teeth. **(C)** A coronal image through the maxillary antra. **(D)** A sagittal image through the midline of the maxilla.

Radiation Dose

The exposure factors on some CBCT machines are fixed by the manufacturer. However, on other units operators are able to adjust the exposure factors – typically in the range of 60–120 kV and in the range of 1–20 mA – allowing for optimization of the dose. As mentioned, the scan time varies between 5 and 40 seconds, but the equipment may use a *pulsed* beam rather than a *continuous* beam. As a result, during a scan lasting 20 seconds the patient may be exposed to ionizing radiation for about 3.5 seconds only.

The effective dose from different CBCT machines varies considerably. It depends on a number of factors, including:

- The exposure factors (kV, mA and time of exposure)
- The volume size – *field of view* (FOV)
- The type of equipment used
- The part of the jaw/maxillofacial skeleton being imaged.

Typically, doses are lower than with medical CT, but higher than conventional dental radiography. However, some new CBCT units are producing very small FOV, high resolution images with doses equivalent to that of a few periapical radiographs. The effective doses from CBCT imaging, initially shown in Chapter 6 , are shown again in Table 16.1 .

Advantages and Disadvantages

Advantages

- Multiplanar reformatting and data manipulation allowing anatomy/pathological conditions to be viewed in different planes.
- Lower radiation dose than medical CT.
- Geometrically accurate images.
- Very good spatial resolution.
- Fast scanning time.
- Compatible with implant and cephalometric planning software.

Disadvantages

- The patient has to remain absolutely stationary throughout the scan to avoid movement artefacts (see Fig. 16.13).

Table 16.1

The effective dose from a range of different radiographic examinations including cbct

X-ray examination	Effective dose (E) mSv
Bitewing/periapical radiograph	0.0003–0.022
Panoramic radiograph	0.0027–0.075
Upper standard occlusal	0.008
Lateral cephalometric radiograph	0.0022-0.0056
Skull radiograph (PA)	0.02
Skull radiograph (lateral)	0.016
Chest (PA)	0.014
Chest (lateral)	0.038
CT head	1.4
CT chest	6.6
CT abdomen	5.6
	0.25–1.4

CT mandible and maxilla	
Barium swallow	1.5
Barium enema	2.2
Small volume CBCT (height of ≤5 cm)	0.0097-0.197
Medium volume CBCT (height of 5.1-10.0 cm)	0.0039-0.674
Large volume CBCT (height of >10 cm)	0.0088-1.073

- Soft tissues not imaged in detail.
- Computer-constructed panoramic-type images are not directly comparable with conventional panoramic radiographs – particular care is needed in their interpretation.
- Radiodense objects such as restorations and root filling materials can produce so-called beam hardening artefacts as well as the streak or star artefacts shown in Fig. 16.14 .

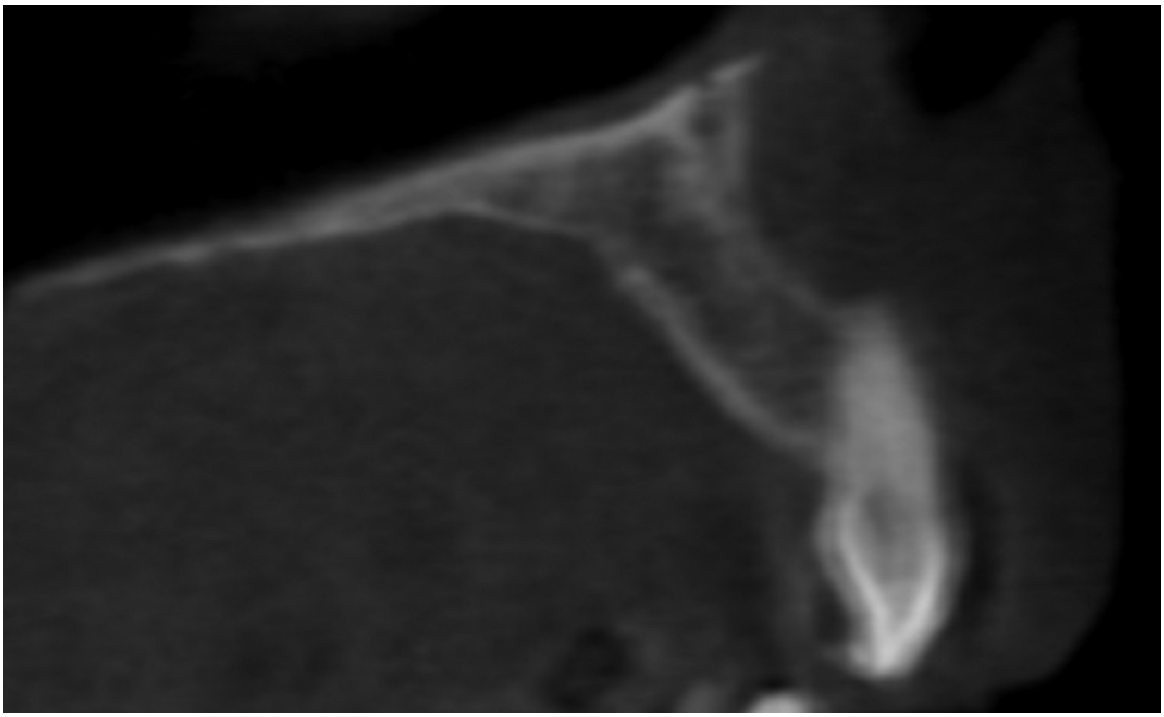


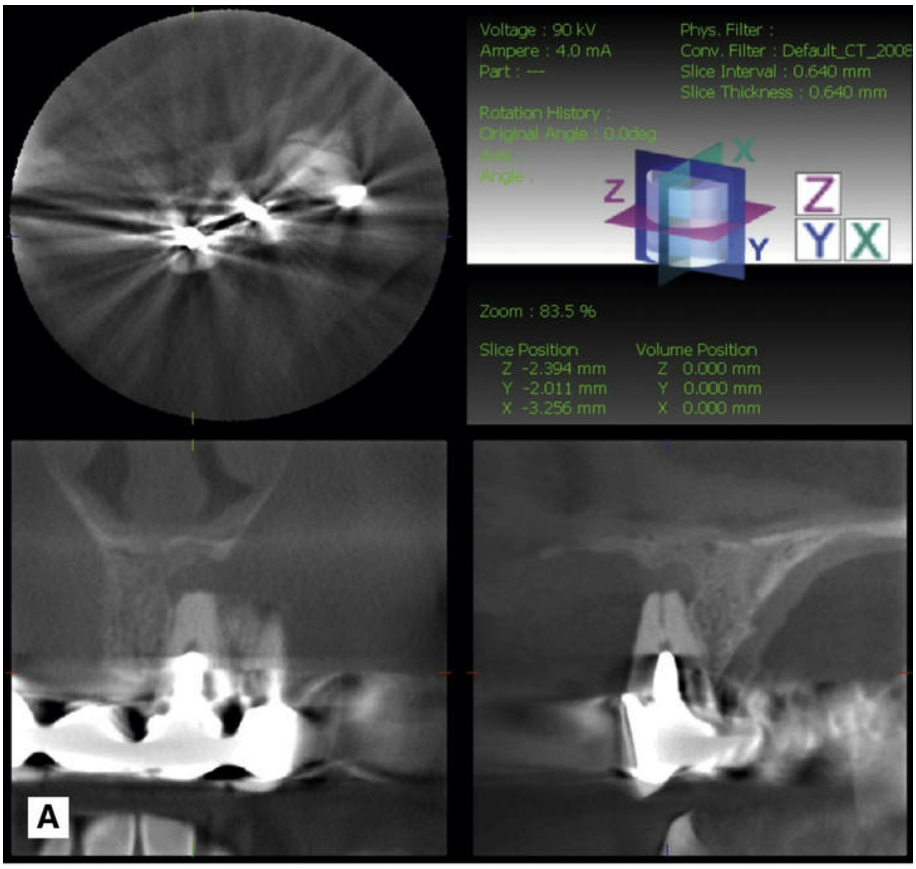
FIG. 16.13 Sagittal section through the upper incisor region resulting from severe patient movement. The scan is not diagnostically acceptable and needs to be retaken.

Assessment of Image Quality

In the UK the latest *Guidance Notes* published by Public Health England (PHE) recommend the same two-level rating scale for CBCT images as they do for conventional two-dimensional imaging – diagnostically acceptable or diagnostically not acceptable. The recommended image quality ratings and minimum targets for CBCT are shown in Table 16.2 .

Quality Assurance

Just as intraoral and panoramic equipment is subject to quality assurance testing, as described in detail in Chapter 17 , so is CBCT equipment. Manufacturers now tend to produce their own machine-specific quality assurance test objects/phantoms as shown in Figs. 16.15 –16.16 . These enable testing for factors such as image noise, image density, spatial resolution and image uniformity. The tests required and the frequency of testing are described in the UK's latest *Guidance Notes.*


Voltage : 90 kV
Ampere : 4.0 mA
Part : ---
Phys. Filter :
Conv. Filter : Default_CT_2006
Slice Interval : 0.640 mm
Slice Thickness : 0.640 mm
Rotation History :
Original Angle : 0.0deg
Axis :
Angle :
Z
X
Y
Z
Y
X
Zoom : 83.5 %
Slice Position
Z -2.394 mm
Y -2.011 mm
X -3.256 mm
Volume Position
Z 0.000 mm
Y 0.000 mm
X 0.000 mm
A

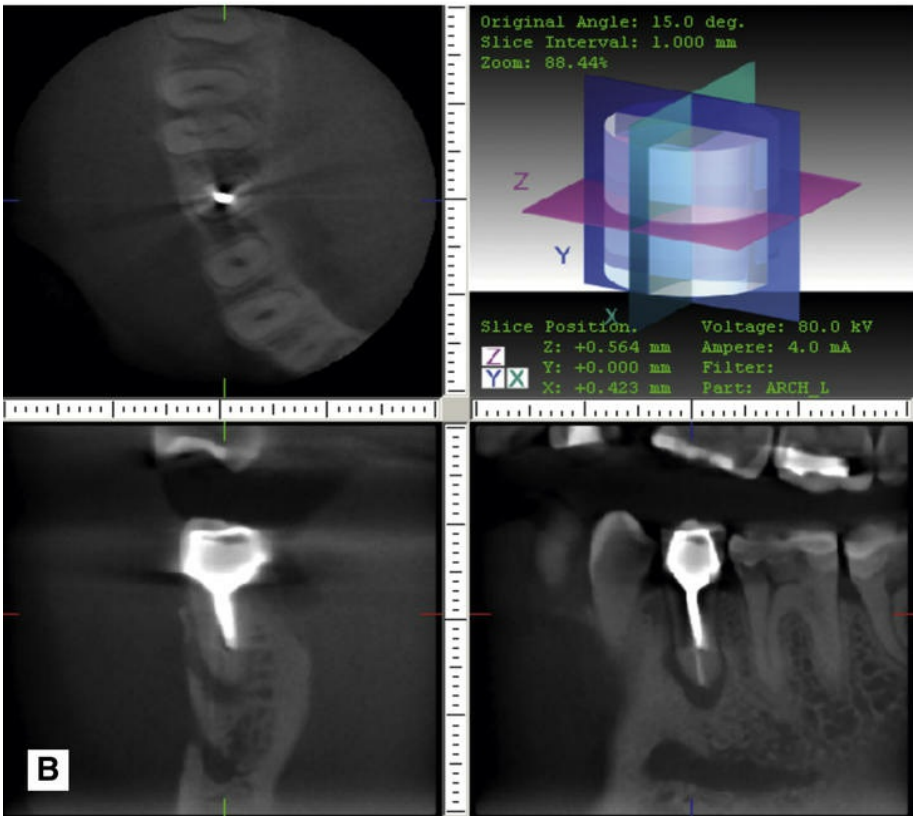

Original Angle: 15.0 deg.
Slice Interval: 1.000 mm
Zoom: 88.44%
Z
Y
X
Slice Position.
Z: +0.564 mm
Y: +0.000 mm
X: +0.423 mm
Voltage: 80.0 kV
Ampere: 4.0 mA
Filter:
Part: ARCH_L
Z
Y
X
B

FIG. 16.14 **(A, B)** Examples showing beam hardening and streak or star artefacts caused by radiodense (metallic) objects.

Table 16.2

Subjective quality rating criteria for cone beam computed tomography based on the latest UK *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment,* (second edition).

Quality	Basis	Target
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction and of sufficient image quality to answer the clinical question	Not less than 95%
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction which render the image diagnostically unacceptable	Not greater than 5%

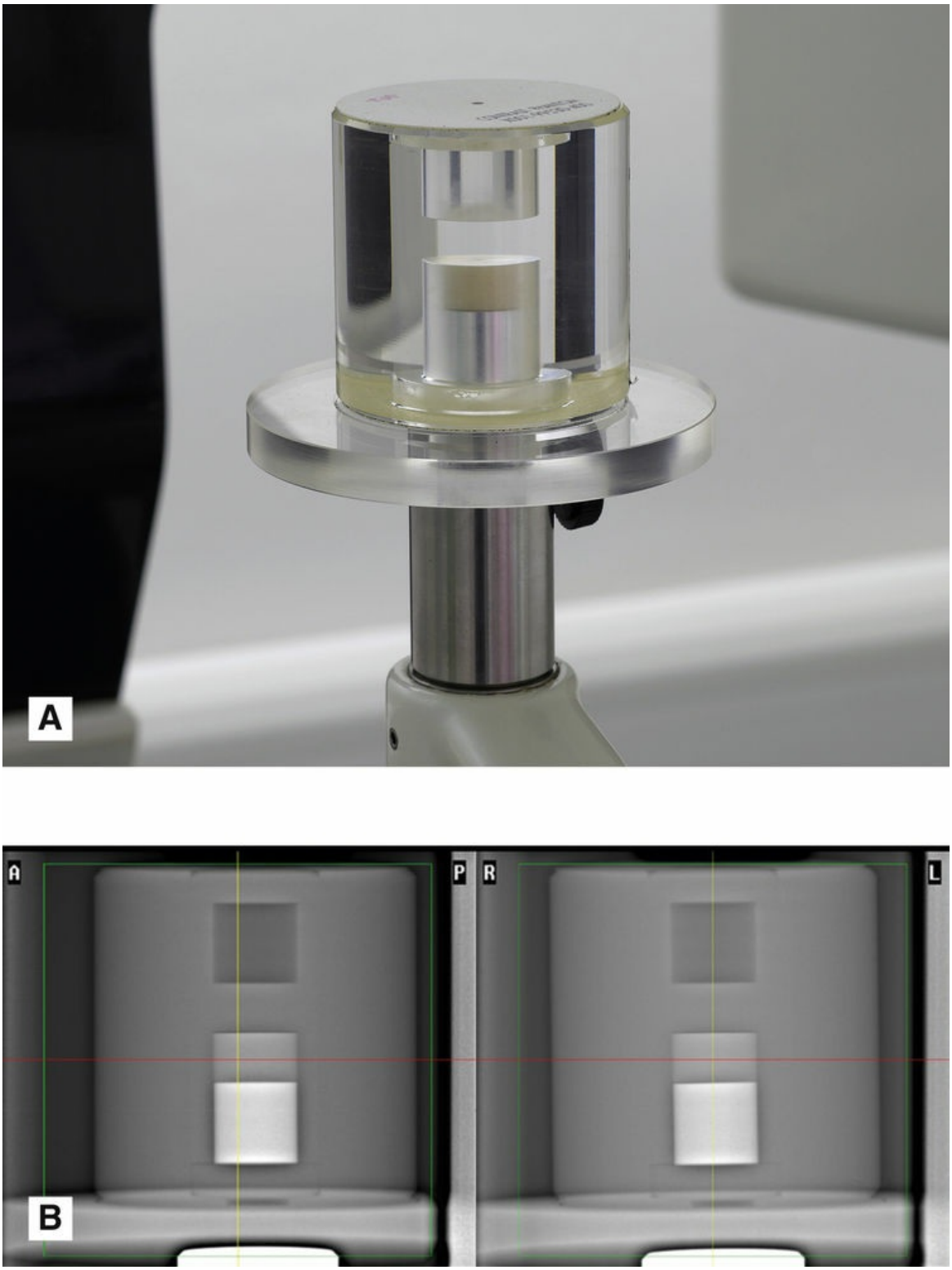


FIG. 16.15 **(A)** The Morita Accuitomo *contrast phantom* used to test noise, uniformity and grayscale positioned in the CBCT unit. **(B)** The resultant AP (lateral) and RL (coronal) test images.

Footnote

The regulations and guidelines on the use of cone beam CT vary in different countries. In the UK the latest recommendations can be found in the *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition). These guidelines address, amongst other things, specific CBCT radiation protection issues, compliance with current UK legislation relating to the use of ionizing radiation and detailed quality assurance standards for CBCT testing. A link to the PHE guidance can be found online at:

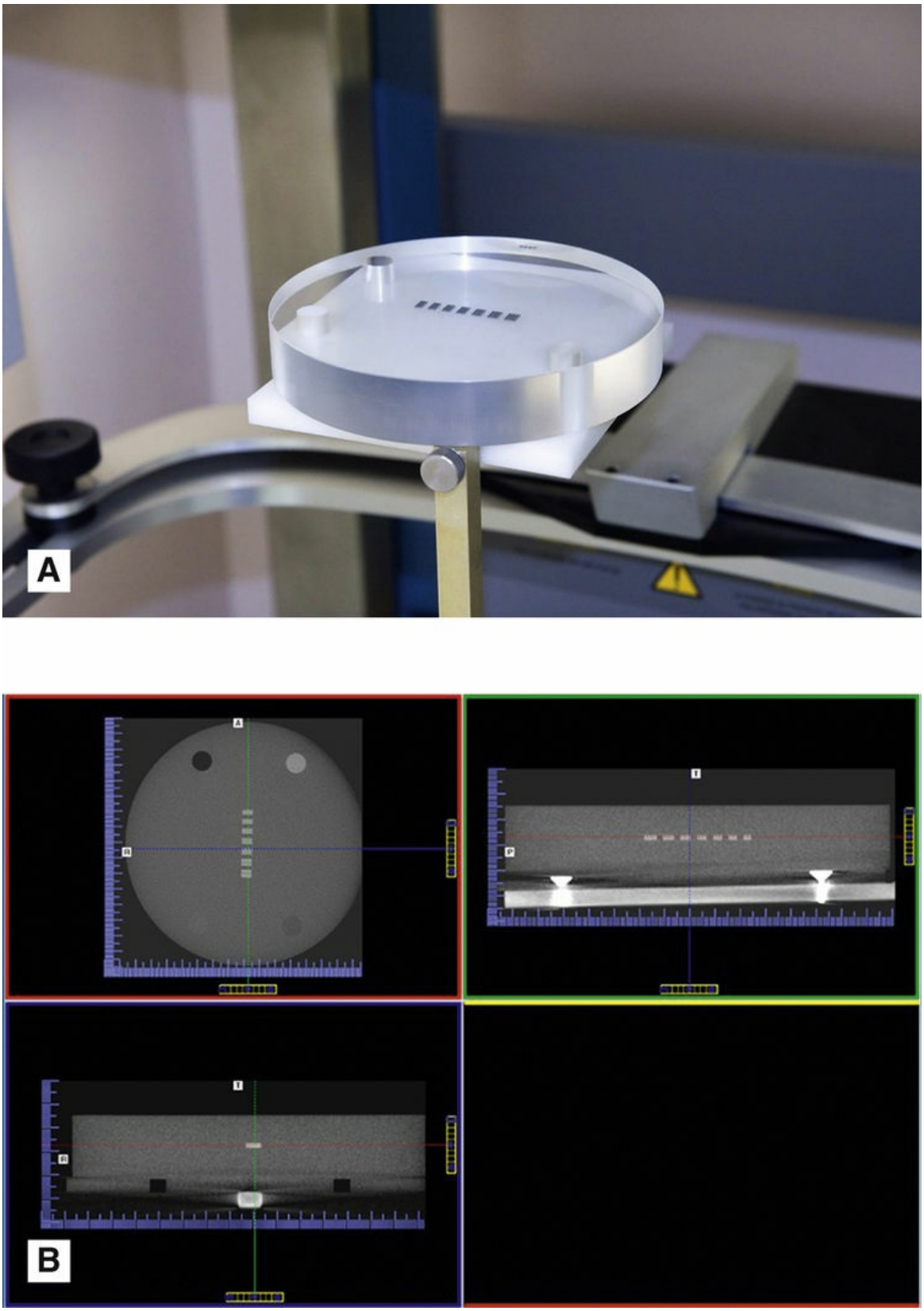


FIG. 16.16 **(A)** The i-CAT™ *resolution phantom* positioned in the CBCT unit. **(B)** The resultant axial, coronal and sagittal

test images.

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To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

17

The Quality of Radiographic Images and Quality Assurance

Introduction

The factors that can affect the quality of radiographic images depend on:

- How the image was taken (radiographic technique)
- What image receptor was used (digital or film)
- How the visual image was created
  - Computer processing (digital)
  - Chemical processing (film).

The effects of poor radiographic technique are the same whatever type of image receptor is used. These technique errors have already been covered in detail in relation to the three main projections used in dentistry, namely, periapicals (see Chapter 4), bitewings (see Chapter 10) and panoramic radiographs (see Chapter 15).

The creation of the visual *digital* image was described in Chapter 7 , together with how computer software can be used to alter and manipulate the image with regards to contrast, brightness (degree of blackening), magnification, inversion, enhancement and pseudocolourization. Creation of the black/white/grey image *on film* using chemical processing was also described in Chapter 7 . These various images can, however, be affected by many other factors. This chapter provides an overarching summary of a Quality Assurance (QA) programme and quality control procedures that apply to dental radiography and is designed for revision, bringing together the

various factors affecting image quality described in earlier chapters. Various image faults are illustrated together with their possible causes.

Quality Assurance (QA)

The World Health Organization (WHO) has defined radiographic QA programmes as an organized effort by the staff operating a facility to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation.

Quality control measures are therefore as essential in a general dental practice *facility* as they are in a specialized radiography department. This importance of quality is acknowledged in the UK in The Ionising Radiation (Medical Exposure) Regulations 2017, which make QA in dental radiography a mandatory requirement. This chapter is based broadly on the recommendations in the latest UK *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition).

Terminology

The main terms in quality procedures include:

- *Quality control* – the specific measures for ensuring and verifying the quality of the radiographs produced.
- *Quality assurance* – the arrangements to ensure that the quality control procedures are effective and that they lead to relevant change and improvement.
- *Quality audit* – the process of external reassurance and assessment that quality control and QA mechanisms are satisfactory and that they work effectively.

Quality Assurance Programmes

A basic principle of QA is that, within the overall QA programme, all necessary procedures should be laid down in writing and in particular:

- Implementation should be the responsibility of a named person and the tasks should be carried out by suitably trained staff
- The frequency of operations should be defined
- The content of the essential supporting records should be defined, as well as the frequency for the formal checking of such records.

As stated in the latest *Guidance Notes* and implied by the WHO definition, a well-designed QA programme should be comprehensive but convenient to operate and maintain. The standards should be evidence based, but once laid down would be expected to require only infrequent verification or modification. The procedures should amount to little more than 'written down common sense'. The aims of these programmes, whether using digital or film-based radiography, can be summarized as follows:

- To produce diagnostic radiographs of consistently high standard
- To decrease the number of repeat radiographs
- To determine all sources of error to allow their correction
- To increase efficiency
- To decrease costs
- To ensure that radiation doses to patients and staff are kept **as low as reasonably practicable** (ALARP).

Quality Control Procedures

The overall quality control procedures for dental radiography relate to:

- Image quality
- Imaging receptors, processing and display equipment
- Patient dose and X-ray generating equipment
- Working procedures
- Staff training and updating
- Audits.

The quality control procedures relating to image quality, imaging receptors, processing and display equipment are obviously different for digital and film-based radiography and will be described first, but separately. The remaining procedures apply equally to both types of imaging and will be jointly discussed later in this chapter.

Digital Image Quality

Digital image quality and the amount of detail shown on a digital radiographic image depends on several factors, including:

- Subject contrast – the black/white and grey difference in the visual caused by different degrees of attenuation as the X-ray beam is transmitted through different parts of the patient's tissues, which depends on:
  - Differences in tissue thickness
  - Differences in tissue density
  - Difference in tissue atomic number
  - Quality of the X-ray beam
- Image geometry – the geometric accuracy of any image depends upon the positions of the X-ray beam, object and image receptor satisfying certain basic geometrical requirements:
  - The object and the digital image receptor should be in contact or as close together as possible
  - The object and the digital image receptor should be parallel to one another
  - The X-ray tubehead should be positioned so that the

X-ray beam meets both the object and the digital image receptor at right angles

- Characteristics of the X-ray beam – the beam used should be:
  - Sufficiently penetrating to pass through the patient, to a varying degree, to interreact differentially with the digital image receptor (solid-state or phosphor plate) to produce a good contrasted black/white/grey image
  - Parallel, i.e. non-diverging, to prevent magnification of the image (see Chapter 3)
  - Produced from a point source to reduce blurring of the image margins and the penumbra effect (see Chapter 3).
- Type of digital image receptor – solid-state or phosphor plate and their resolution and ability to define image sharpness (see Chapter 4)
- Quality of viewing monitor (see Chapter 19)
- Image enhancement software (see Chapter 5).

Practical Factors Influencing Digital Image Quality

In practical terms, the various factors that can influence overall digital image quality can be divided into factors related to:

- The X-ray equipment
- The image receptor – solid-state or phosphor plate
- Image processing and manipulation using computer software (see Chapter 5)
- The patient
- The operator and radiographic technique
- The quality of the viewing monitor.

As a result of all these variables, digital image faults and alterations in digital image quality are inevitable and not all these can be corrected by manipulating the image using image enhancement software, as described in Chapter 5 . QA programmes are still required.

Clinicians using digital imaging need to be able to recognize the cause of the various image faults so that appropriate corrective action can be taken.

Typical Digital Image Faults

Examples of some typical digital image faults, other than those as a result of poor radiographic technique described in Chapters 9 , 10 and 15, are shown below.

Solid-state Detectors

Faults include:

- *Blooming* – caused by overexposure and overloading/ flooding the charge-coupled devices (CCDs)
- Cracked sensor
- Sensor used back to front
- Loss of uniformity.

(See Figs. 17.1 –17.3 .)

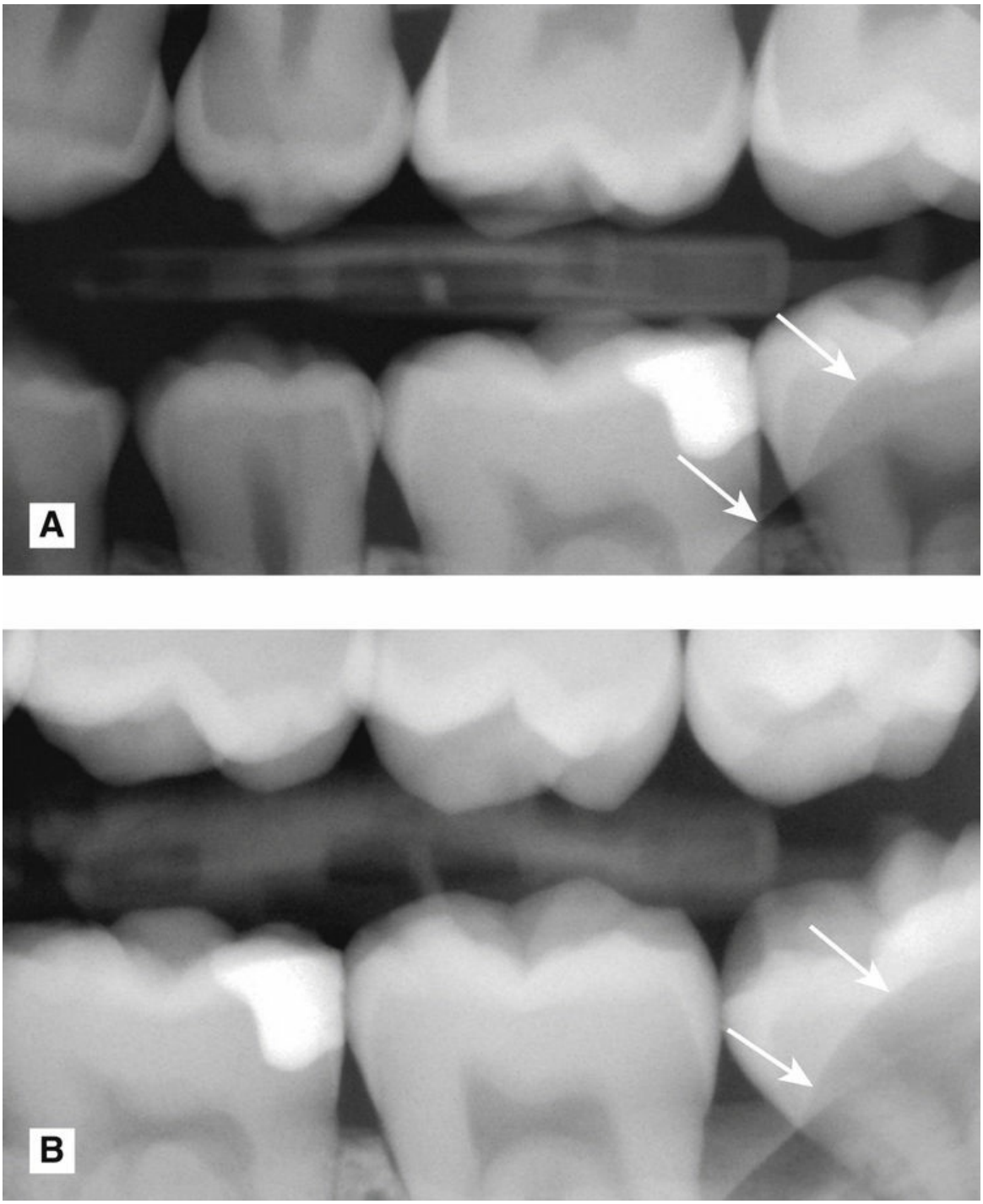


FIG. 17.1 Examples of bitewing radiographs taken using the same solid-state detector that has been dropped and cracked (arrowed).
Courtesy Mr J. Davies.

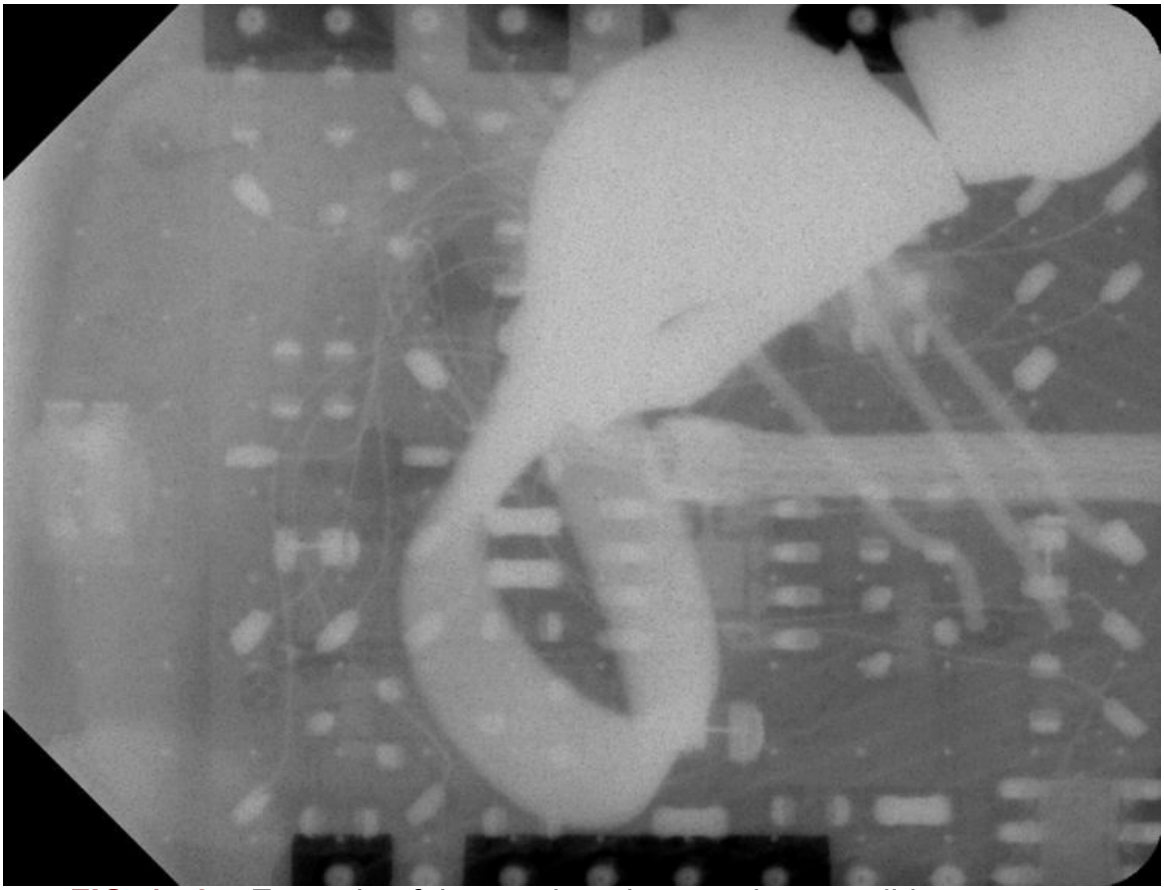


FIG. 17.2 Example of the resultant image when a solid-state sensor is used clinically back to front rendering the internal electronics visible.

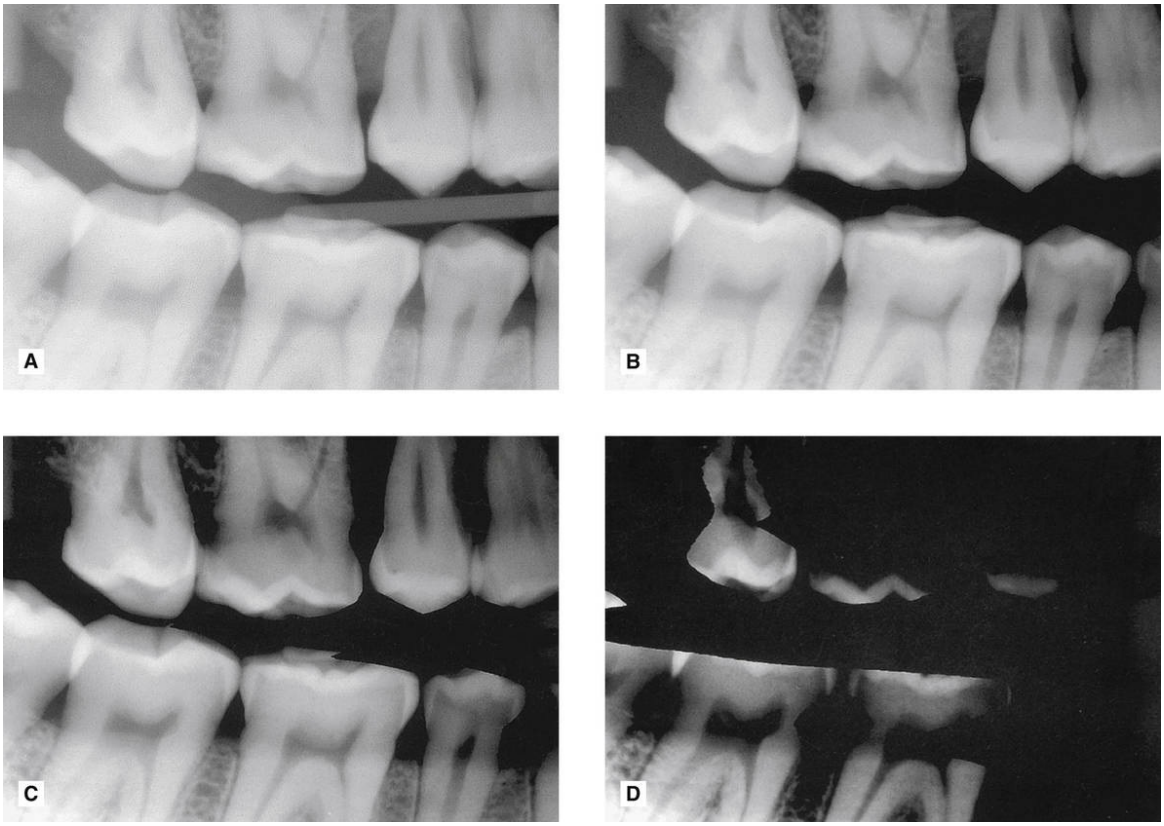


FIG. 17.3 The effect of *blooming.* Four bitewing images taken using a charge-couple device (CCD) solid-state sensor. **(A)** Underexposed. **(B)** Ideally exposed. **(C)** Overexposed. **(D)** Considerably overexposed. In **(C)** and **(D)** , some of the charge-coupled devices have become overloaded or flooded and parts of the image have become completely black. Blooming cannot be reversed by using image manipulation software.

Courtesy Mr J. Davies.

Photostimulable Phosphor Plates

Faults include:

- Phosphor plate used back to front
- Light leakage/fogging
- Debris on the plate
- Scratched plate
- Loss of uniformity.

(See Figs. 17.4 and 17.5 .)

Computer Software Malfunction

As with any computer software, occasional glitches and malfunctions happen. When they do, the digital image can be completely distorted as shown in Fig. 17.6 .



FIG. 17.4 Example of a bitewing radiograph taken with a dirty phosphor plate (see also Fig. 17.8C). The debris on the plate results in an opaque artefact (arrowed).

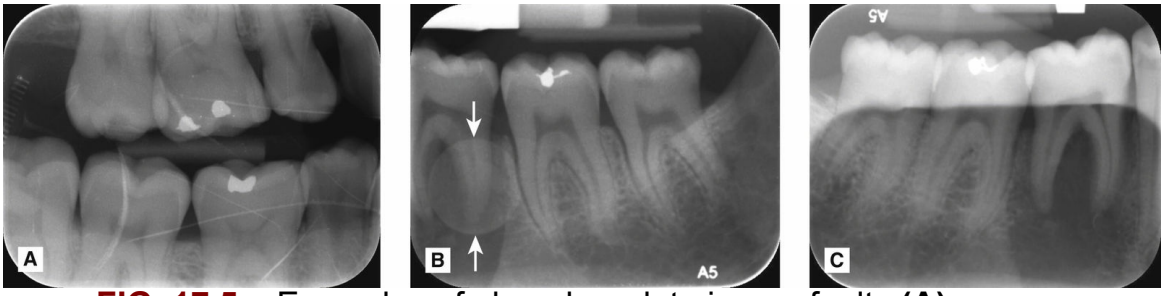


FIG. 17.5 Examples of phosphor plate image faults **(A)** a bitewing taken with a scratched plate, **(B)** a periapical taken with the plate back to front. The circular shadow cast by the magnet is visible (arrowed) and **(C)** a light-fogged image. The top part of the image was exposed to light which has partially cleared the image before the plate was placed in the reader

Courtesy Mr J. Davies.

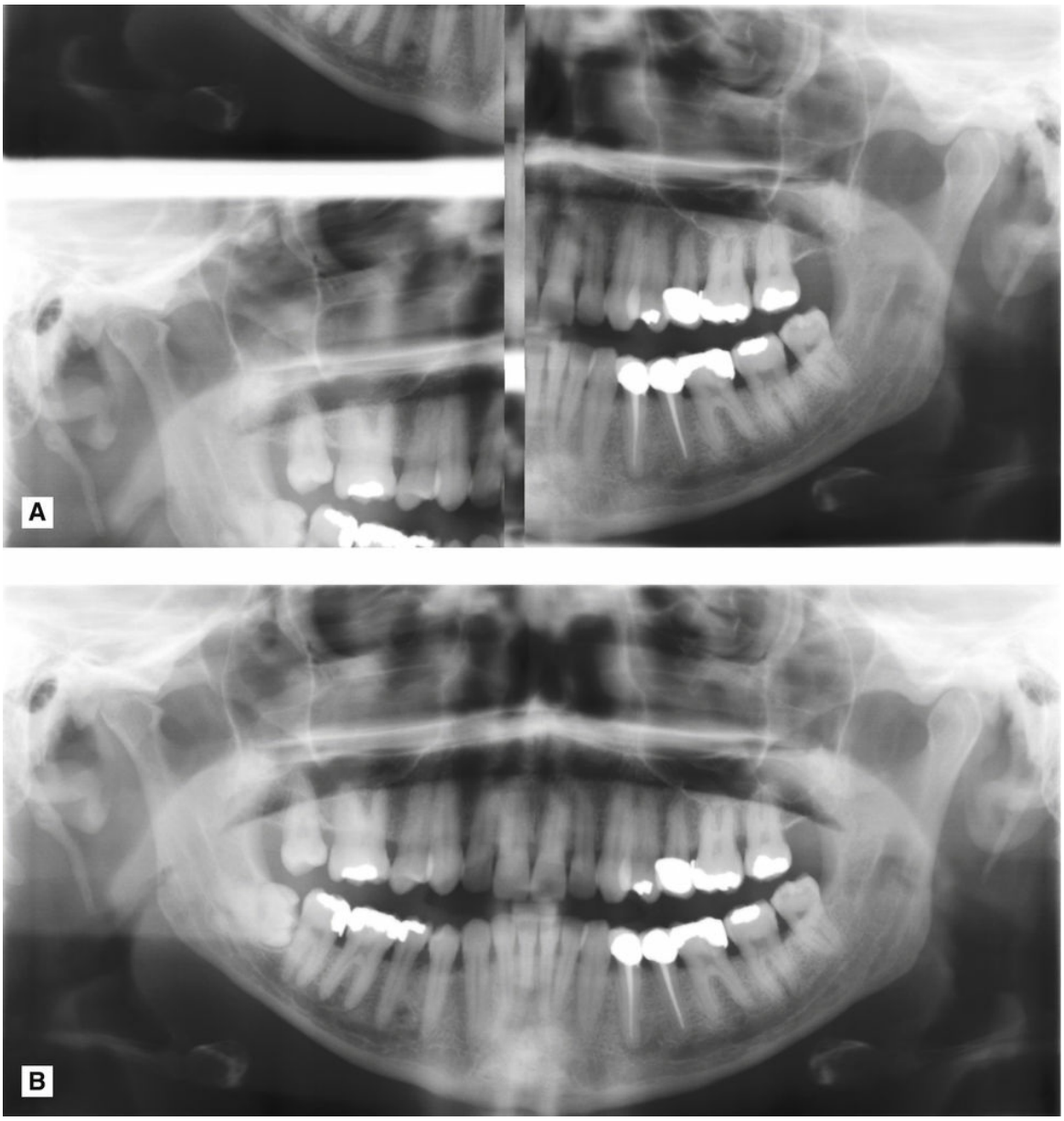


FIG. 17.6 **(A)** Example of a grossly distorted panoramic image resulting from a computer software malfunction. **(B)** What the panoramic should have looked like!
Courtesy Mr J. Llewellyn.

Digital Image Quality Assessment

This assessment should include:

- Investigation of any significant deterioration in quality and

instigation of appropriate corrective action
- Recording all investigations together with the identified cause of deterioration and the action taken
- Regular annotation (approximately every 3 months) of the image quality record to indicate that the day- to-day checks have been carried out and, where appropriate, that no significant deterioration in image quality has been observed
- Subjective assessment of the quality of each radiograph. As mentioned in earlier chapters, in the UK the latest *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* recommend a simple two-point scale for digital imaging (see Table 17.1).

All images should be assessed in this way and the results recorded so that the overall quality of digital radiography can be evaluated against the published targets (see Table 17.2).

Table 17.1

Subjective quality rating criteria for digital and film-captured images based on the UK's *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition)

Quality	Basis
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction and of sufficient image quality to answer the clinical question
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image receptor processing or image reconstruction which render the image diagnostically unacceptable

Table 17.2

Recommended minimum targets for digital image quality based on the UK's *Guidance Notes*

Quality	Target (percentage of radiographs taken)
A = Diagnostically acceptable	Not less than 95%

N = Diagnostically not acceptable	Not greater than *5%*

Digital Image Reject Analysis

Assess all *diagnostically not acceptable* images and record:

- Date
- Nature of the digital image fault/error, as shown earlier, e.g.:
  - – Image too dark, e.g. 'blooming'
  - – Image too pale – sensor underexposed
  - – Image marked – sensor damaged
  - – Unsharp or blurred image – patient movement
  - – Poor positioning
- Known or suspected cause of the error or fault and corrective action taken
- Number of repeat images (if taken).

Quality Control Procedures for Digital Receptors, Computer Processing and Monitors

Solid-state Sensors

These require:

- Regular assessment for non-uniformity of receptors. For this test the receptor is simply exposed to a dose of radiation. The resultant image should be examined for areas of non-uniformity. This test should be carried out every 3 months, or whenever damage is suspected.
- Regular checks to ensure no evidence of cracks or damage to the cable and sensor casing (see Fig. 17.7).
- Subjective check of image quality using a step-wedge phantom.

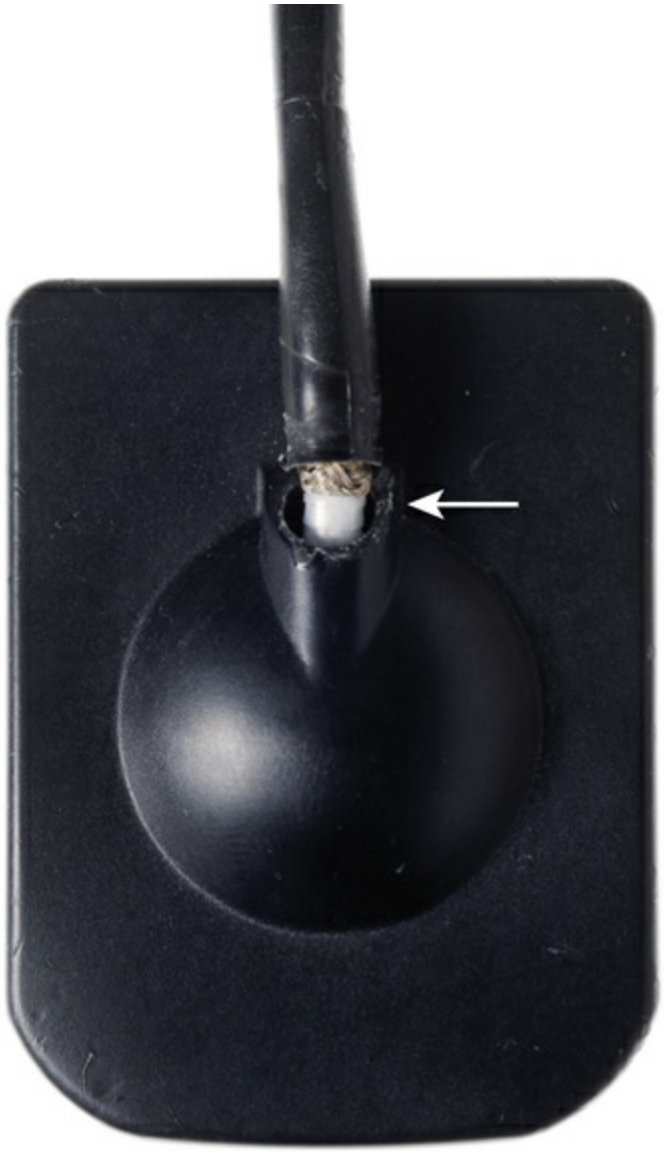


FIG. 17.7 A solid-state detector showing damage to the cable (arrowed).
Courtesy of Mr P. Ash.

Phosphor Plates

These require:

- Regular checks for visible scratches and dirt or debris – if there are visible scratches, the phosphor plate should be exposed to radiation and read to see if the scratches are significant (see

Fig. 17.8).

- Regular cleaning following the manufacturer's instructions.
- Regular assessment for non-uniformity of receptors. For this test the receptor is simply exposed to a dose of radiation. The resultant image should be examined for areas of non-uniformity. This test should be carried out every 3 months or when damage is suspected. Any phosphor plates demonstrating gross non-uniformity (see Fig. 17.8D) should be taken out of clinical use.
- Subjective check of image quality using a step-wedge phantom.

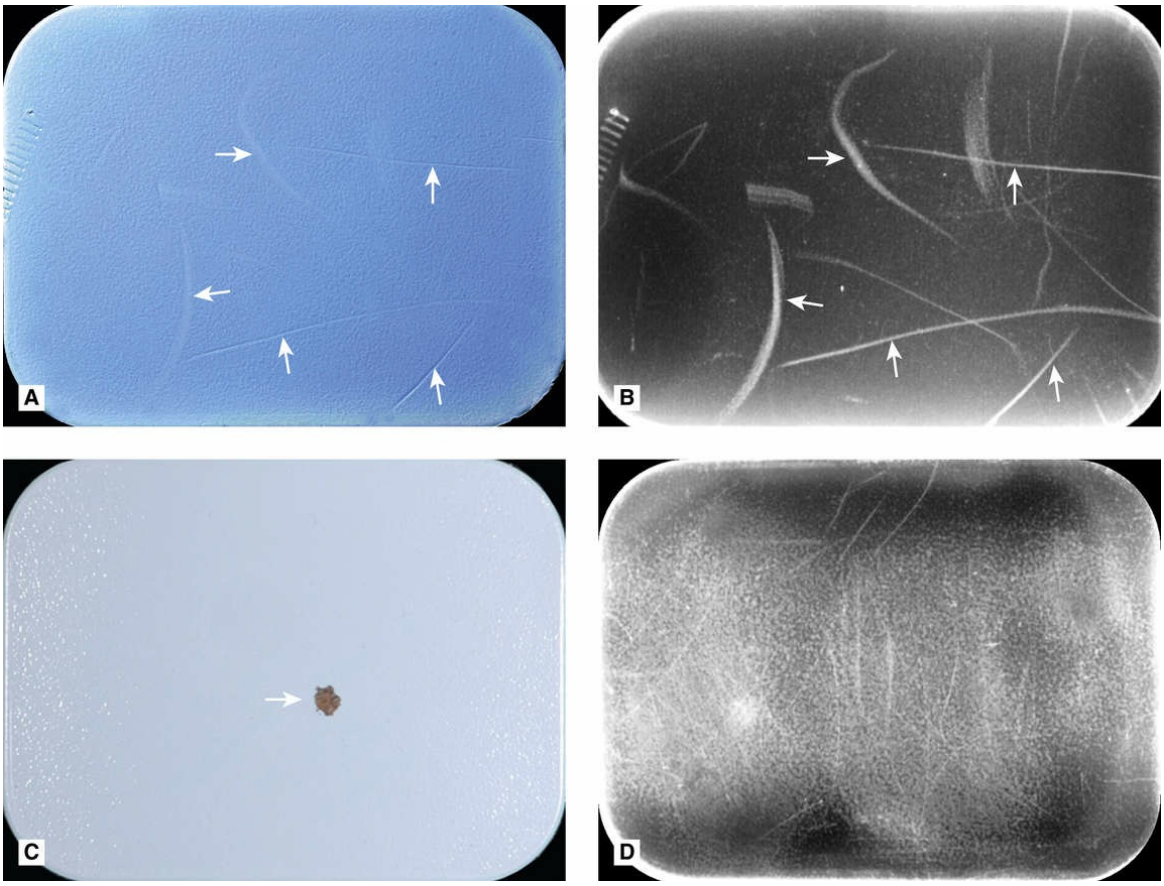


FIG. 17.8 **(A)** A scratched phosphor plate (arrowed). **(B)** Image of the phosphor plate shown in A showing the artefacts (arrowed) created by the scratches. **(C)** Debris on a phosphor plate (arrowed) (see also Fig. 17.4). **(D)** Image showing the result of a uniformity test on a photostimulable phosphor plate. There are several regions of non-uniformity as well as several scratches. This image receptor has failed the test and should not be put back into clinical use.

Tests for Spatial and Contrast Resolution

Some manufacturers supply QA *test objects* that allow the spatial resolution and contrast resolution of digital receptors to be assessed. An example of such a *test object* and its *test pattern* are shown in Fig. 17.9 .

For intraoral radiography the digital image receptor is simply placed in the slot in the test object, underneath the test pattern and the test object is then attached to the end of the spacer cone (see Fig. 17.10

) and exposed. For panoramic radiography the test object is modified and then placed in a special holder so that it lies in the focal plane during the exposure (see Fig. 17.11). The resultant images for both intraoral and extraoral image receptor tests are shown in Fig. 17.12 .

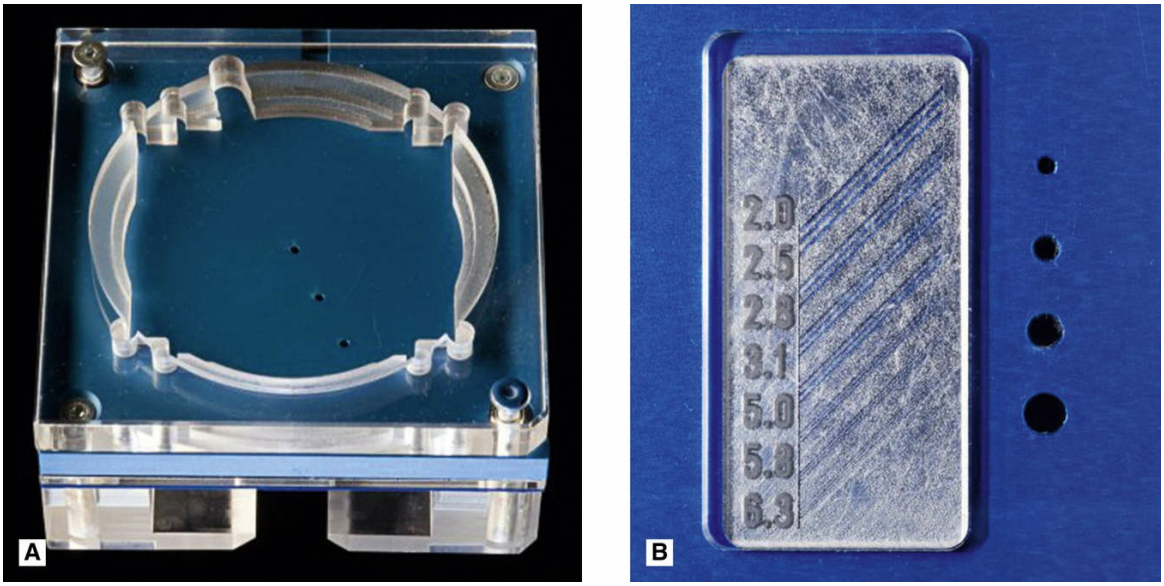


FIG. 17.9 **(A)** The Tor Den digital QA *test object* and **(B)** the *test pattern* that is placed within the test object. The test pattern contains a series of thin lead strips different distances apart (to measure the spatial resolution) and 4 holes - 1.0, 1.5, 2.0 and 2.5 mm in diameter (to measure the low contrast resolution).



FIG. 17.10 The Tor Den QA test object being used to test an intraoral phosphor plate digital receptor.



FIG. 17.11 The Tor Den QA test object being used to test a panoramic phosphor plate digital receptor.

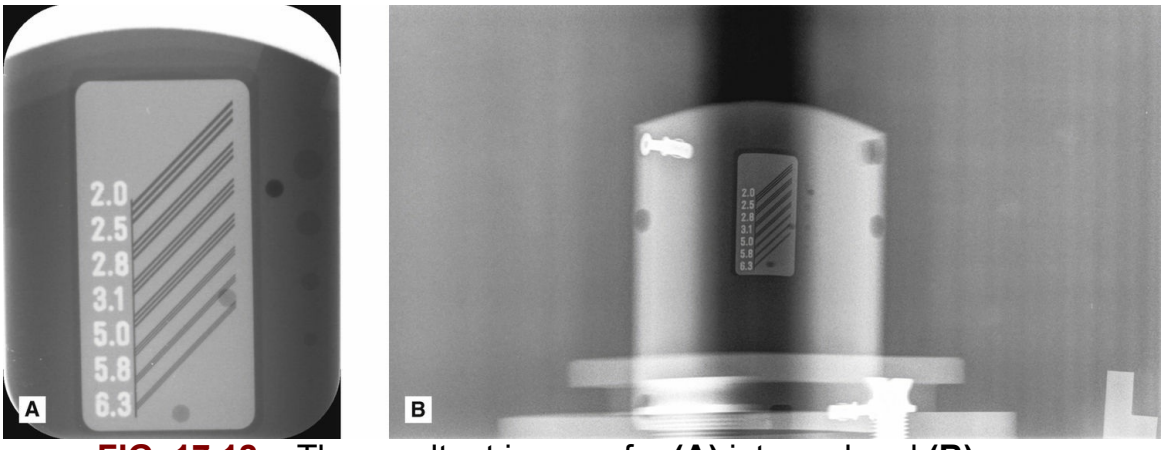


FIG. 17.12 The resultant images for **(A)** intraoral and **(B)** panoramic image receptor tests. The manufacturer

recommends that for intraoral systems the minimum acceptable spatial resolution is 5 line pairs per millimetre and that all four low contrast details be visible. For panoramic image receptors the minimum recommended spatial resolution is 2.5 line pairs per millimetre and that the 2.0 mm and 2.5 mm low contrast details should be visible.

Monitors

These require:

- Regular cleaning
- Regular QA calibration/checks for distortion, grey scale reproduction, luminescence, limiting resolution (at both high and low contrast) and uniformity. This can be done using specific test patterns designed for this purpose such as the SMPTE test pattern designed by the Society of Motion Pictures and Television Engineers and a photometer as shown in Figs. 17.13 –17.16 .

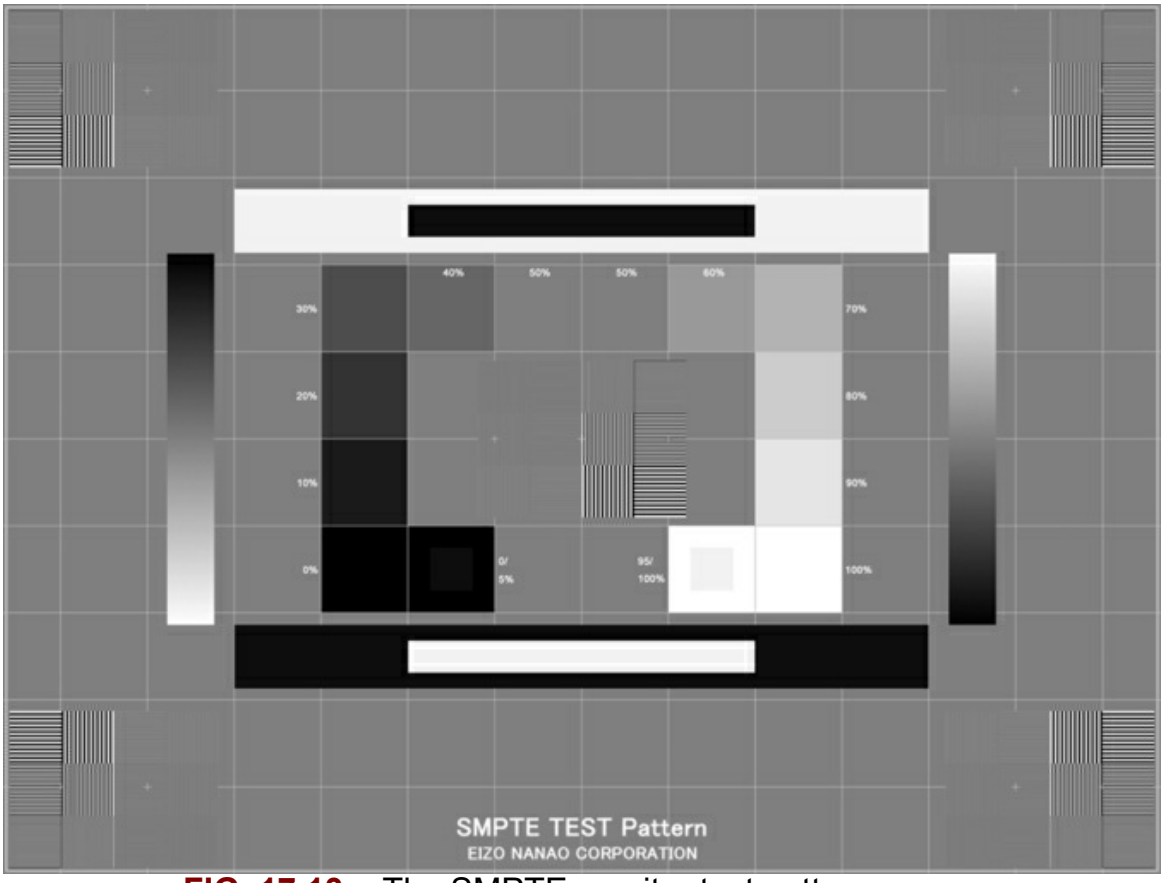


FIG. 17.13 The SMPTE monitor test pattern.
Courtesy SMPTE, www.smpte.org

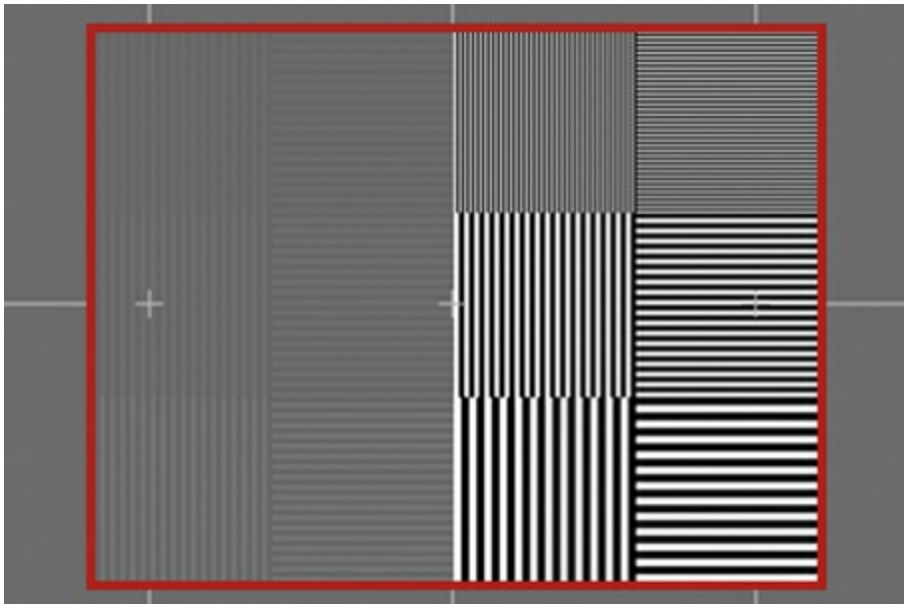


FIG. 17.14 Part of the SMPTE test pattern showing the central low (left side) and high (right side) contrast resolution patterns.

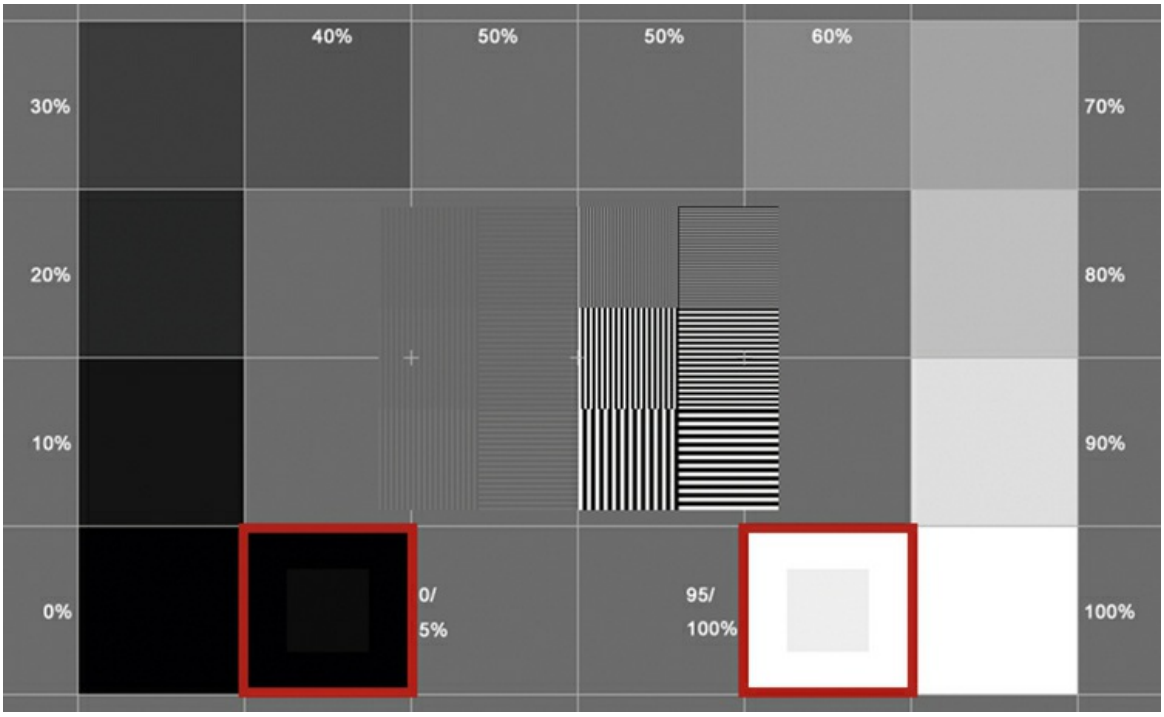


FIG. 17.15 Part of the SMPTE test pattern highlighting the 5%/95% detail and the 95%/100% test patterns. If either inner detail is not visible the monitor settings need to be adjusted.

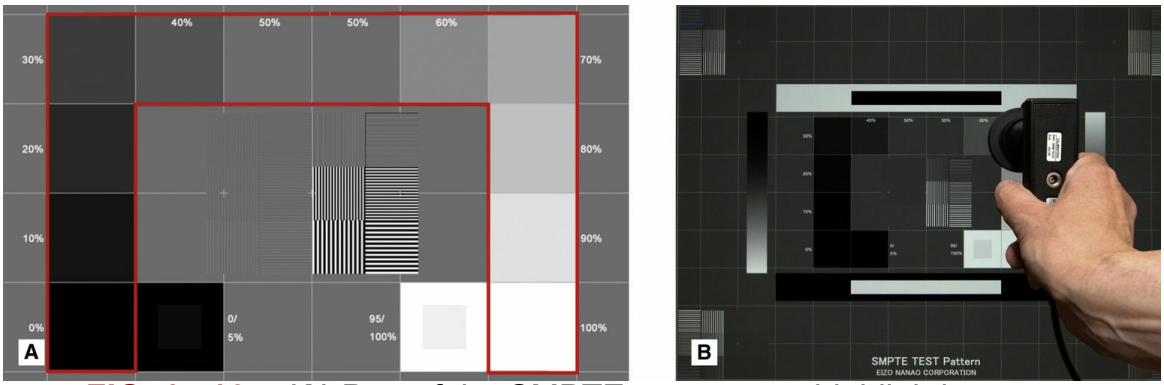


FIG. 17.16 **(A)** Part of the SMPTE test pattern highlighting the outer squares from 100% (white), through the grey scale

to the 0% square (black). **(B)** A photometer being used to measure the luminance of the outer squares to check the grey scale.

Film-Based Image Quality

As mentioned in Chapter 1 , image quality and the amount of detail shown on a radiographic film depends on several factors including:

- Contrast
- Image geometry
- Characteristics of the X-ray beam
- Image sharpness and resolution.

Contrast

Radiographic contrast, i.e. the final visual difference between the various black, white and grey shadows, depends on:

- Subject contrast
- Film contrast
- Fog and scatter.

Subject Contrast

Subject contrast is the difference caused by different degrees of attenuation as the X-ray beam is transmitted through different parts of the patient's tissues. It depends on:

- Differences in tissue thickness
- Differences in tissue density
- Differences in tissue atomic number (photoelectric absorption $\propto Z^3$; see Chapter 2)
- Quality (voltage [kV] or penetrating power of the radiation beam [kV↑, contrast↓ – *kV kills contrast*]).

Film Contrast

Film contrast is an inherent property of the film itself (see Chapter 4). It determines how the film will respond to the different exposures it receives after the X-ray beam has passed through the patient. Film contrast depends on four factors:

- The characteristic curve of the film
- Optical density or degree of blackening
- Type of film – direct or indirect action
- Processing.

Fog and Scatter

Stray radiation reaching the film either as a result of background fog, or owing to scatter from within the patient, produces unwanted film density (blackening), and thus reduces radiographic contrast.

Image Geometry

As mentioned and illustrated in Chapter 1 , the geometric accuracy of any image depends upon the position of the X-ray beam, object and image receptor (digital or film) satisfying certain basic geometrical requirements:

- The object and the film should be in contact or as close together as possible
- The object and the film should be parallel to one another
- The X-ray tubehead should be positioned so that the beam meets the object and the film at right angles.

Characteristics of the X-ray Beam

The ideal X-ray beam used for imaging should be:

- Sufficiently penetrating to pass through the patient, to a varying degree, and react with the film emulsion to produce

good contrast between the various black, white and grey shadows (see earlier)
- Parallel, i.e. non-diverging, to prevent magnification of the image (see Chapter 3)
- Produced from a point source to reduce blurring of the image margins and the *penumbra effect* (see Chapter 3).

Image Sharpness and Resolution

Sharpness is defined as the ability of the X-ray film to define an edge. The main causes of loss of edge definition include:

- Geometric unsharpness, including the penumbra effect (see Chapter 3)
- Motion unsharpness, caused by the patient moving during the exposure
- Absorption unsharpness, caused by variation in object shape, e.g. cervical *burn-out* at the neck of a tooth (see Chapter 20)
- Screen unsharpness, caused by the diffusion and spread of the light emitted from intensifying screens (see Chapter 4)
- Poor resolution. Resolution, or resolving power of the film, is a measure of the film's ability to differentiate between different structures and record separate images of small objects placed very close together, and is determined mainly by characteristics of the film including:
  - Type – direct or indirect action
  - Speed
  - Silver halide emulsion crystal size.

Resolution is measured in line pairs per millimetre.

Practical Factors Influencing Film-based Image Quality

In practical terms, the various factors that can influence overall image quality can be divided into factors related to:

- The X-ray equipment
- The image receptor – film or film/screen combination
- Processing
- The patient
- The operator and radiographic technique.

As a result of all these variables, film faults and alterations in image quality are inevitable. However, because the diagnostic yield from radiography is related directly to the quality of the image, regular checks and monitoring of these variables are essential to achieve and maintain good quality radiographs. It is these checks which form the basis of *Quality Assurance programmes.*

Typical Film Faults

Film Too Dark (see Figs. 17.17 and 17.18)

Possible causes include:

- Overexposure owing to:
  - – Faulty X-ray equipment, e.g. timer
  - – Incorrect exposure time selected
- Overdevelopment owing to:
  - – Excessive time in the developer solution
  - – Developer solution too hot
  - – Developer solution too concentrated
- Fogging owing to:
  - – Poor storage conditions:
  - – Allowing exposure to stray radiation
  - – Too warm
  - – Old film stock used after expiry date
  - – Faulty cassettes allowing ingress of light
  - – Faulty darkroom/processing unit:
  - – Allowing leakage of stray light
  - – Faulty safe-light
- Thin patient tissues.

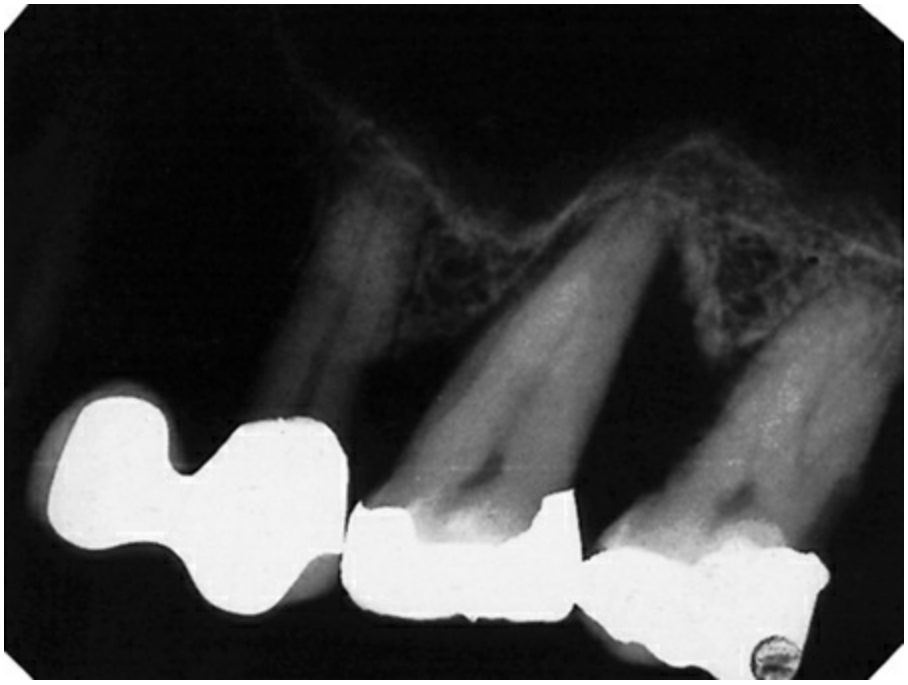


FIG. 17.17 Example of a periapical that is too dark with poor contrast.

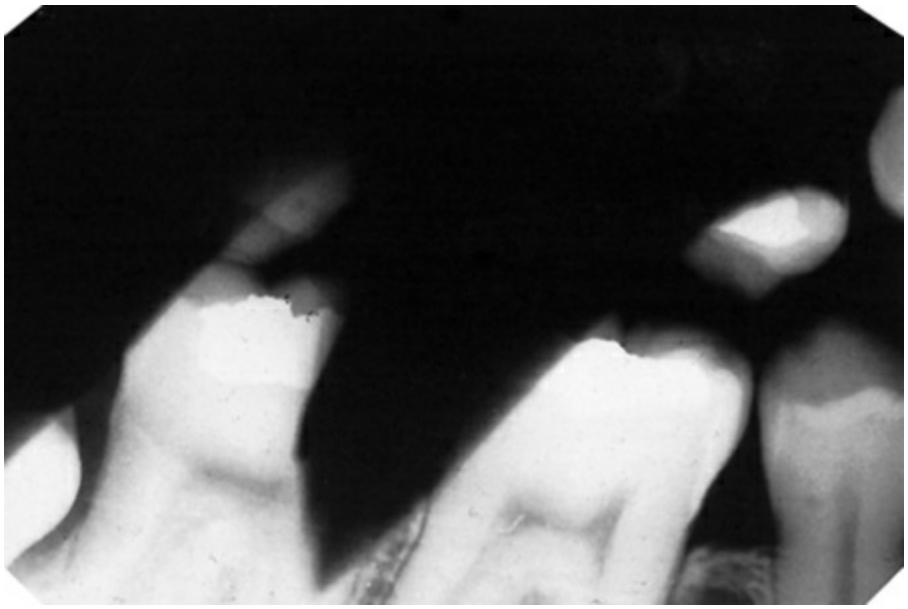


FIG. 17.18 Example of a fogged (blackened) film that has been inadvertently exposed to light.

Film Too Pale (see Fig. 17.19)

Possible causes include:

- Underexposure owing to:
  - – Faulty X-ray equipment, e.g. timer
  - – Incorrect exposure time setting by the operator
  - – Failure to keep timer switch depressed throughout the exposure
- Underdevelopment owing to:
  - – Inadequate time in the developer solution
  - – Developer solution too cold
  - – Developer solution too dilute
  - – Developer solution exhausted
  - – Developer contaminated by fixer
- Excessive thickness of patient's tissues
- Film packet back to front (film also marked).

Film With Inadequate or Low Contrast (see Fig. 17.17 and 17.19)

Possible causes include:

- Processing error owing to:
  - – Underdevelopment (film also pale)
  - – Overdevelopment (film also dark)
  - – Developer contaminated by fixer
  - – Inadequate fixation time
  - – Fixer solution exhausted
- Fogging owing to:
  - – Poor storage conditions:
  - – Allowing exposure to stray radiation
  - – Too warm
  - – Poor stock control and film used after expiry date
  - – Faulty cassettes allowing the ingress of stray light
  - – Faulty darkroom/processing unit.



FIG. 17.19 Example of a periapical that is too pale with poor contrast.

Image Unsharp and Blurred (see Fig. 17.20)

Possible causes include:

- Movement of the patient during the exposure (see also Chapters 9 , 10 and 15)
- Excessive bending of the film packet during the exposure (see also Chapter 9)
- Poor film/screen contact within a cassette
- Film type – image definition is poorer with indirect-action film than with direct-action
- Speed of intensifying screens – fast screens result in loss of detail
- Overexposure – causing burn-out of the edges of a thin object

Film Marked (see Fig. 17.21)

Possible causes include:

- Film packet bent by the operator
- Careless handling of the film in the darkroom resulting in marks caused by:
  - Finger prints
  - Fingernails
  - Bending
  - Static discharge
- Processing errors owing to:
  - Chemical spots
  - Under-fixation – residual silver halide emulsion remaining
  - Roller marks
  - Protective black paper becoming stuck to the film
  - Insufficient chemicals to immerse films fully
- Patient biting too hard on the film packet
- Dirty intensifying screens in cassettes.

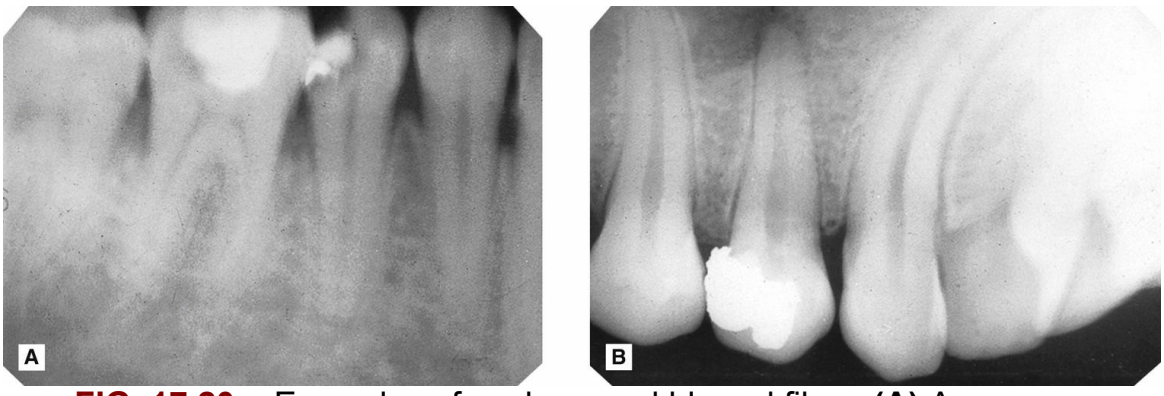


FIG. 17.20 Examples of unsharp and blurred films. **(A)** As a result of patient movement. **(B)** As a result of excessive bending of the film packet during the exposure.

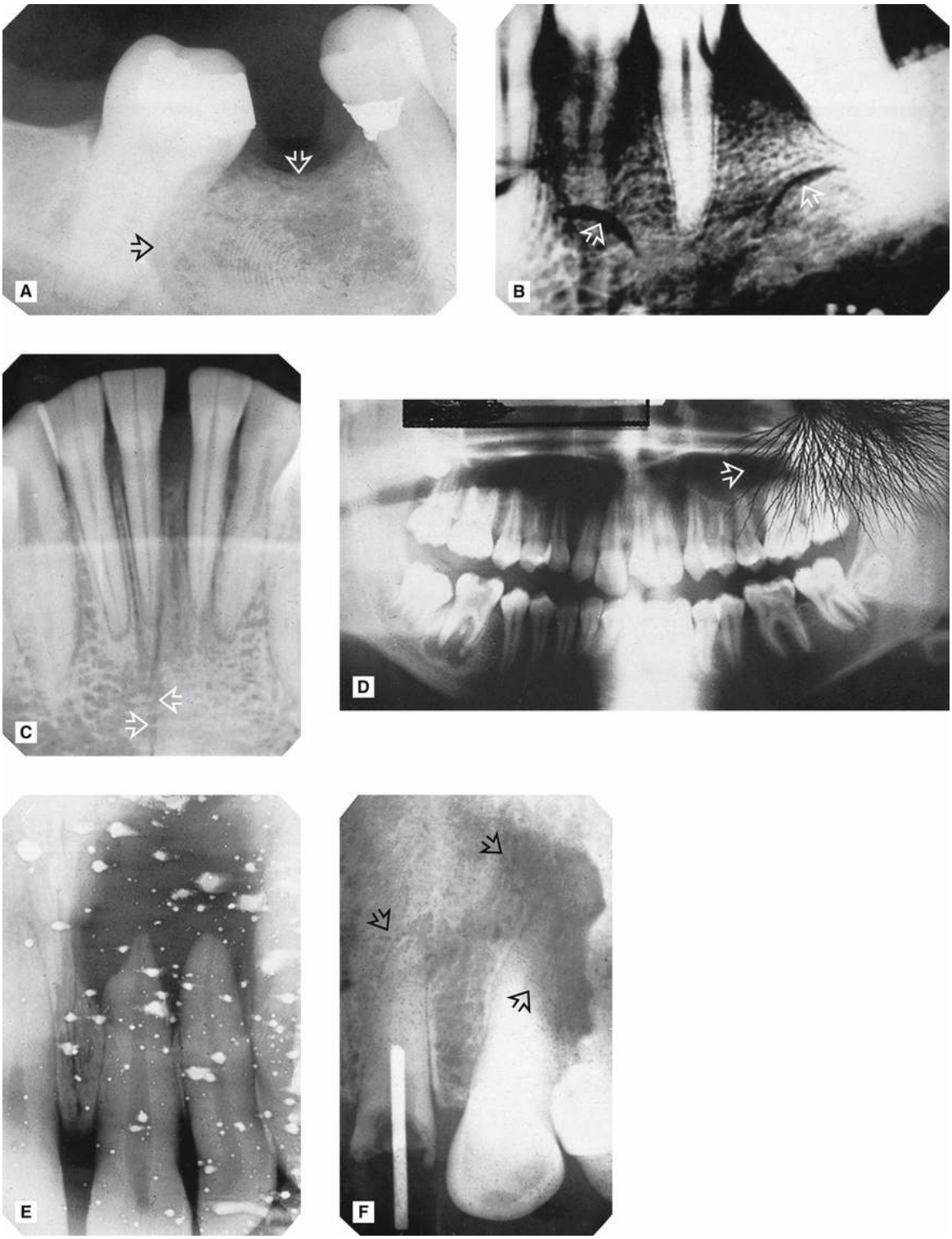


FIG. 17.21 Examples of marked films.

(A) Fingerprint impression in the emulsion (arrowed).
(B) Fingernail marks (arrowed).
(C) Sharply bent film (arrowed) damaging the emulsion.

(D) Discharge of static electricity (arrowed).
(E) Fixer splashes on the emulsion before the film was placed in the developer.
(F) Marks (arrowed) caused by residual emulsion remaining following inadequate fixation (these are usually brown).

Film-based Image Quality Assessment

Image quality assessment is an important test of the entire QA programme. Hence the need for clinicians to be aware of all the various factors, outlined earlier, that affect image quality and to monitor it on a regular basis. This assessment should include:

- A day-to-day comparison of the quality of every radiograph to a high standard reference film positioned permanently on the viewing screen and an investigation of any significant deterioration in quality.

Table 17.3

Subjective quality rating criteria for digital and film-captured images based on the UK's *Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment* (second edition)

Quality	Basis
A = Diagnostically acceptable	No errors or minimal errors in either patient preparation, exposure, positioning, image processing or image reconstruction and of sufficient image quality to answer the clinical question
N = Diagnostically not acceptable	Errors in either patient preparation, exposure, positioning, image processing or image reconstruction which render the image diagnostically unacceptable

Table 17.4

Recommended minimum targets for film-based image quality based on the UK's *Guidance Notes*

Quality	Target (percentage of radiographs taken)

A = Diagnostically acceptable	Not less than 90%
N = Diagnostically not acceptable	Not greater than 10%

- A formal analysis of film quality, either retrospective or prospective, approximately every 6 months. The latest UK *Guidance Notes* recommended the simple two-point subjective rating scale shown in Table 17.3 , and shown previously in Chapters 9 , 10 and 15, be used for film-based intraoral and extraoral radiography.
- Based on these quality ratings, performance targets can be set. Suitable targets recommended in the latest *Guidance Notes* are shown in Table 17.4
- Analysis of all diagnostically not acceptable films (quality rating N), sometimes referred to *as film reject analysis* (see below).

Film Reject Analysis

This is a simple method of identifying all film faults and sources of error and amounts to a *register of reject radiographs.* To do this, it is necessary to collect all rejected (quality rating N) radiographs and record:

- Date
- Nature of the film fault/error, as shown earlier, e.g.:
  - Film too dark
  - Film too pale
  - Low or poor contrast
  - Unsharp image
  - Poor positioning
- Known or suspected cause of the error or fault and corrective action taken (see Table 17.5)
- Number of repeat radiographs (if taken)
- Total number of radiographs taken during the same time period. This allows the percentage of faulty films to be calculated.

A regular review of film reject analysis records is an invaluable aid for identifying a range of problems, including a need for equipment maintenance, additional staff training as well as processing faults that could otherwise cause unnecessary radiation exposure of patients and staff.

TABLE 17.5

Summary of common film quality problems and their possible causes. Reproduced, with modifications, from *Dental Update* with kind permission of Professor K. Horner and George Warman Publications.

Reason for Rejection	General	Particular	Remedy to each particular fault
Film too dark	Processing fault	Developer concentration too high	Dilute or change chemicals
	(overdevelopment)		
		Development time too long	Adjust as necessary
		Developer temperature too high	Adjust as necessary
	Excessive X-ray exposure	Incorrect exposure setting	Adjust and repeat examination
		Faulty timer on X-ray set	Arrange service and repair of X-ray set
		Thin patient tissues	Decrease exposure and repeat
	Fogged film	Light leak in darkroom	Check and correct
		Faulty safelighting	Inspect safelights visually, coin test, and correct any fault detected
		Old film stock	Discard film
		Poor film storage	Discard film and re-assess storage facilities
		Light leak in cassette	Check hinges and catches and repair or replace if required
Film too pale	Processing fault	Overdiluted developer	Change chemicals
	(underdevelopment)	Inadequate development time	Adjust as necessary
		Developer temperature too low	Adjust as necessary
		Exhausted developer	Change chemicals
		Developer contaminated by fixer	Change chemicals
	Inadequate development time	Incorrect exposure setting	Adjust and repeat
		Faulty timer on X-ray set	Arrange service and repair of X-ray set
		Excessive thickness of patient's tissues	Increase exposure and repeat
Inadequate or low contrast	Technique error	Film back to front	Adjust and repeat
	Processing fault	Overdevelopment (plus dark films)	Check development and time/ temperature relationship
		Underdevelopment (plus pale films)	As above
		Developer contaminated by fixer	Change chemicals
		Inadequate fixation time (films opaque; milky sheen)	Adjust as necessary
		Fixer exhausted (films opaque; milky sheen)	Change fixer solution
	Fogged film	See above	See above

Table Continued

Reason for Rejection	General	Particular	Remedy to each particular fault
Unsharp image	Technique error	Patient movement	Assess and instruct patient carefully
		Excessive bending of the film packet during exposure	Adjust and repeat
		Poor patient positioning (in panoramic radiography)	Greater care in positioning and full use of positioning aids
	Cassette error	Poor film/screen contact	Check cassette and repair or replace if necessary
		Incorrect intensifying screen speed	Change screens
	Excessive X-ray exposure	Incorrect exposure setting for thin object causing *burn-out*	Decrease exposure setting and repeat
Film marked	Handling fault	Film packet bent	Careful handling
		Careless handling in darkroom	As above
	Processing fault	Chemical spots	Careful chemical handling
		Insufficient chemicals to allow full immersion of film	Check chemical tanks and adjust
		Automatic roller marks	Clean processor
		Patient biting too hard on the film	Instruct patient correctly and repeat
		Dirt on intensifying screens	Clean screens regularly
Poor positioning (see Chapters 9, 10 and 15)	Film packet incorrectly positioned	Film back to front (plus pale film)	Use film holders for intraoral radiography when possible
	X-ray tubehead incorrectly positioned	Not covering area of interest	As above
	Patient incorrectly positioned	Film used twice (plus dark film)	Greater care in film handling
		Too steep an angle producing foreshortening	Use beam-aiming devices when possible
		Too shallow an angle producing elongation	As above
		Patient incorrectly placed (in panoramic unit)	Greater care in positioning and full use of positioning aids

Quality Control Procedures for Film, Chemical Processing and Light Boxes

Darkroom

The QA programme should include instructions on all the regular checks that should be made, and how frequently, with all results recorded in a log. Important areas include:

- General cleanliness (daily), but particularly of work surfaces and film hangers (if used)
- Light-tightness (yearly), by standing in the darkroom in total darkness with the door closed and safelights switched off and visually inspecting for light leakage

- Safelights (yearly), to ensure that these do not cause fogging of films. Checks are required on:
  - – Type of filter – this should be compatible with the colour sensitivity of film used, i.e. blue, green or ultraviolet (see Chapter 6)
  - – Condition of filters – scratched filters should be replaced
  - – Wattage of the bulb – ideally it should be no more than 25 W
  - – Their distance from the work surface – ideally they should be at least 1.2 m (4 ft) away
  - – Overall safety (i.e. their fogging effect on film) – the simple quality control measure for doing this is known as the *coin test:*
    1. Expose a piece of screen film in a cassette to a very small even exposure of X-rays (so-called *flash* exposure) to make the emulsion ultrasensitive to subsequent light exposure
    2. In the darkroom, remove the film from the cassette and place on the worksurface underneath the turned-off safelight
    3. Place a series of coins (e.g. nine) in a row on the film and cover them all with a piece of card
    4. Turn on the safelight and then slide the card to reveal the first coin and leave for approximately 30 seconds
    5. Slide the card along to reveal the second coin and leave again for approximately 30 seconds
    6. Repeat until all the coins have been revealed
    7. Process the film in the normal way.

An example of the coin test is shown in Fig. 17.22 . Fogging (blackening) of the film owing to the safelight will then be obvious when compared to the clear area protected by the coin. The part of the film adjacent to the first coin will have been exposed to the safelight for the longest time and will be the darkest. In practice, the normal film-handling time under the safelight can be measured and the effect of safelight fogging established.

NOTE. The *coin test* can also be used to assess the amount of light transmission through the safety glass of automatic processors by performing the test within the processor under the safety glass under normal daylight loading conditions.

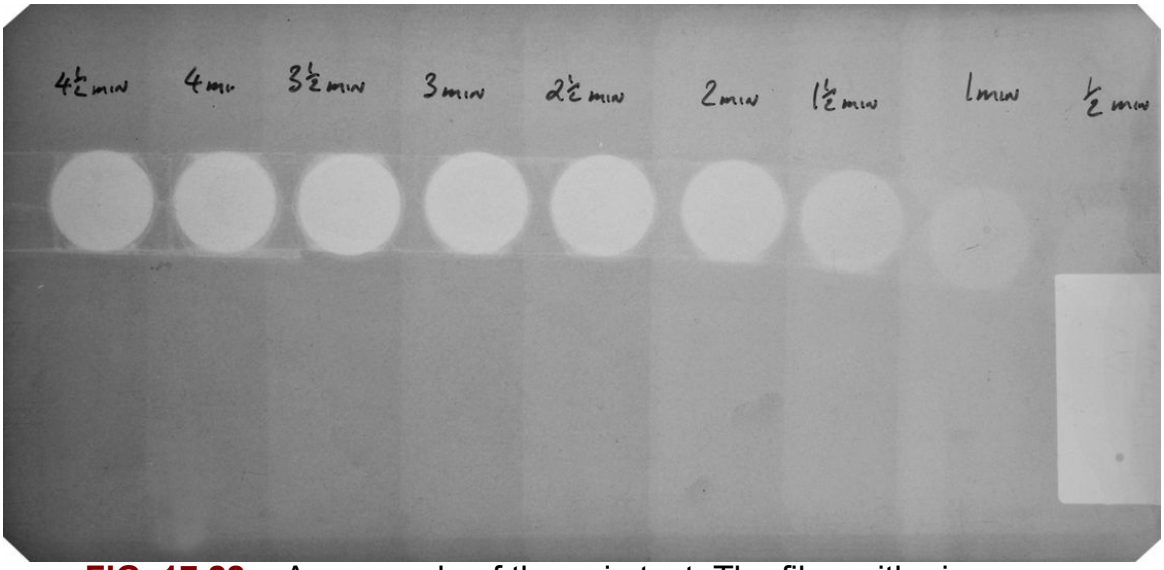


FIG. 17.22 An example of the coin test. The film, with nine coins on it, has been gradually uncovered every 30 seconds. The coin-covered part of the film remains white while the surrounding film is blackened or fogged. The longer the film is exposed to the safelight the darker it becomes.

Image Receptors

The QA programme requires written information, usually obtained from the suppliers, on film speed, expiry date and storage conditions as well as details regarding the maintenance and cleaning instructions

of cassettes and intensifying screens. Typical requirements could include X-ray film and cassettes.

X-ray Film

This requires:

- Ideal storage conditions – cool, dry and away from all sources of ionizing radiation – as recommended by the manufacturers
- Strict stock control with records to ensure use before the expiry date
- Careful handling.

Cassettes

These require:

- Regular cleaning of intensifying screens with a proprietary cleaner
- Regular checks for light-tightness, as follows:
    1. Load a cassette with an unexposed film and place the cassette on a window sill in the daylight for a few minutes
    2. Process the film – any ingress of light will have fogged (darkened) the film (see Fig. 17.23A)
- Regular checks for film/screen contact, as follows:
    1. Load a cassette with an unexposed film and a similar-sized piece of graph paper
    2. Expose the cassette to X-rays using a very short exposure time
    3. Process the film – airy areas of poor film/screen contact will be demonstrated by a loss of definition of the image of the graph paper (see Fig. 17.23B)
- A simple method of identification of films taken in similar-looking cassettes, e.g. a Letraset letter on one screen.

Processing

The QA programme should contain written instructions about each of the following: chemical solutions, processing equipment and working procedures.

Chemical Solutions

These should be:

- Always made up to the manufacturers' instructions, taking special precautions to avoid even trace amounts of contamination of the developer by the fixer, e.g. always fill the fixer tank first so that any splashes into the developer tank can be washed away before pouring in the developer
- Always at the correct temperature
- Changed or replenished regularly – ideally every 2 weeks – and records should be kept to control and validate these changes
- Monitored for deterioration. This can be done easily using radiographs of a *step-wedge phantom:*
    1. Make a simple step-wedge phantom using the lead foil from inside intraoral film packets (see Fig. 17.24)
    2. Radiograph the step-wedge using known exposure factors
    3. Process the film in fresh solutions to produce a standard reference film
    4. Repeat, using the same exposure factors, every day as the solutions become exhausted
    5. Compare each day's film with the standard reference film to determine objectively any decrease in blackening of the processed film, which would indicate deterioration of the developer (see Fig. 17.25)
    6. Record the results.

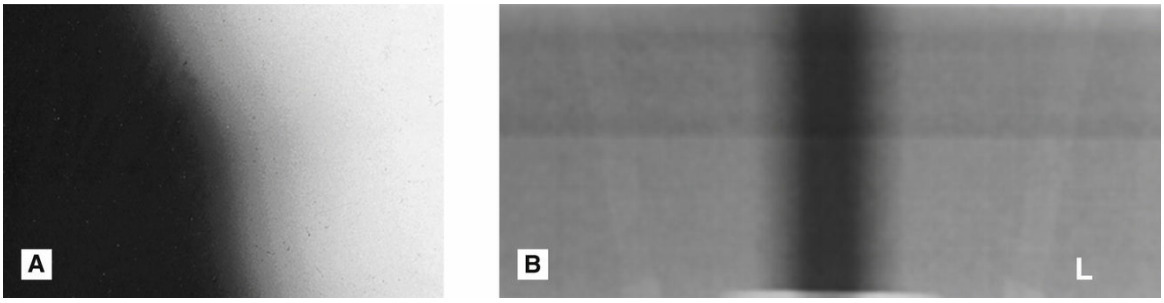


FIG. 17.23 **(A)** Radiograph from a faulty cassette being checked for light-tightness. The light that has entered the cassette has blackened one side of the film. **(B)** An example of a panoramic image following the graph paper test for film/screen contact. Good film screen contact enables the detailed pattern of the graph paper to be seen.



FIG. 17.24 A simple step-wedge phantom constructed using pieces of lead foil taped to a tongue spatula.

Processing Equipment

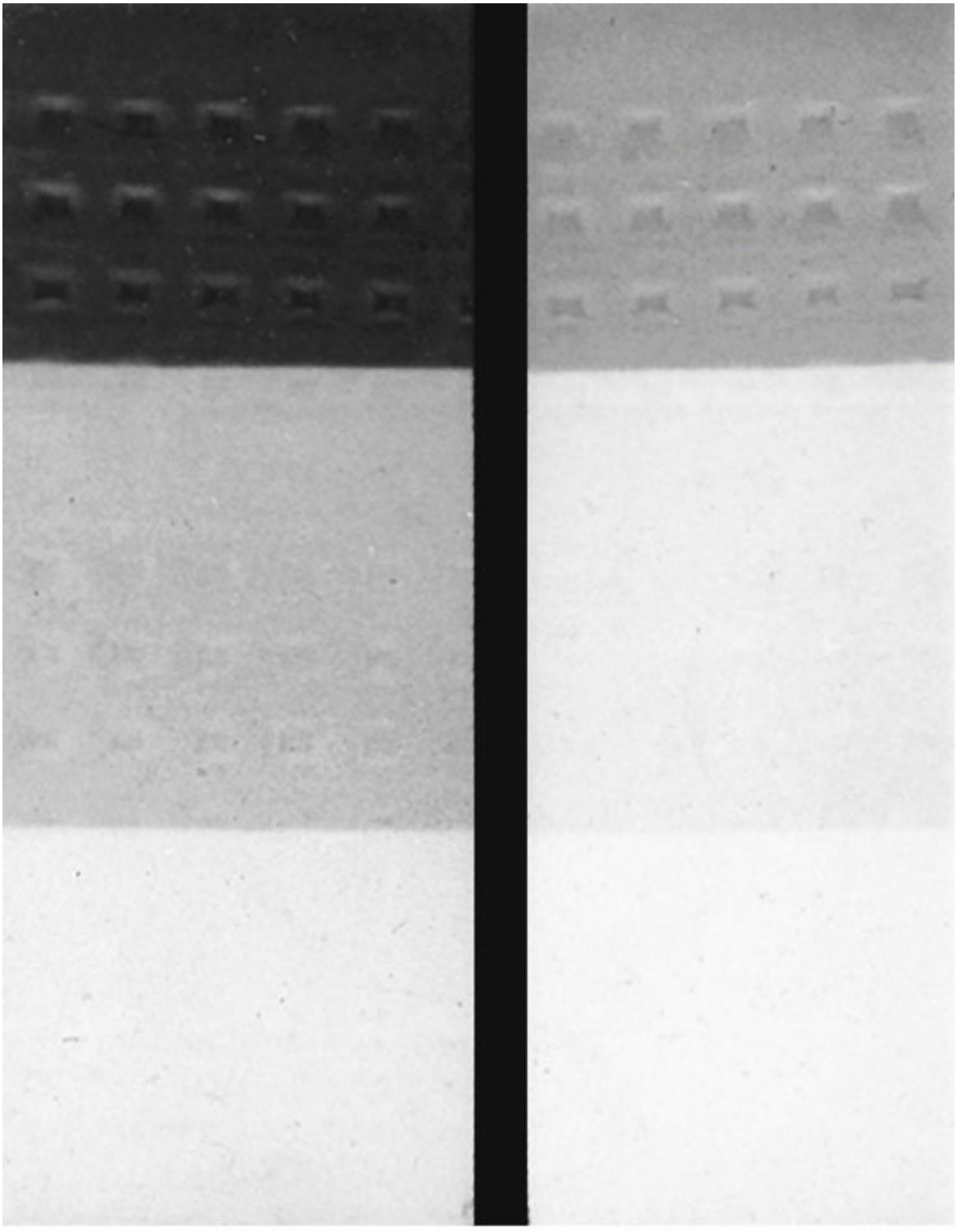
- Manual processing requires the use of accurate timers, thermometers and immersion heaters. Instructions on their proper use should be provided.
- Automatic processors require regular replenishment of chemical solutions and regular cleaning, especially of the rollers. All cleaning procedures should be written down, including how often they should be carried out.
- A record log confirming that all cleaning procedures have been carried out should be kept.

Light Boxes

The performance of viewing light boxes should be checked at least every 6 months.

Patient Preparation and Positioning Technique Errors in Both Digital and Film-Based Imaging

These errors can happen whatever image receptor is being used and were described in detail and illustrated in Chapters 9 , 10 and 15. They are summarized below and can be divided into intraoral and panoramic technique errors (see Fig. 17.26).



(i) (ii)

FIG. 17.25 **(i)** The standard reference film of the step-wedge phantom on day one processed using newly made-up chemical solutions, **(ii)** Test film processed in chemical

solutions 1 week old – note the reduced amount of blackening of the second film owing to the weakened action of the developer.

Intraoral Technique Errors

These can include:

- Failure to position the image receptor correctly to capture the area of interest
- Failure to position the image receptor correctly causing it to bend (if flexible) creating geometrical distortion
- Failure to orientate the image receptor correctly and using it back to front
- Failure to align the X-ray tubehead correctly in the horizontal plane causing:
  - *Coning off* or *cone cutting*
  - Overlapping and geometrical distortion
  - Superimposition
- Failure to align the X-ray tubehead correctly in the vertical plane causing:
  - *Coning off* or *cone cutting*
  - Foreshortening and geometrical distortion
  - Elongation and geometrical distortion

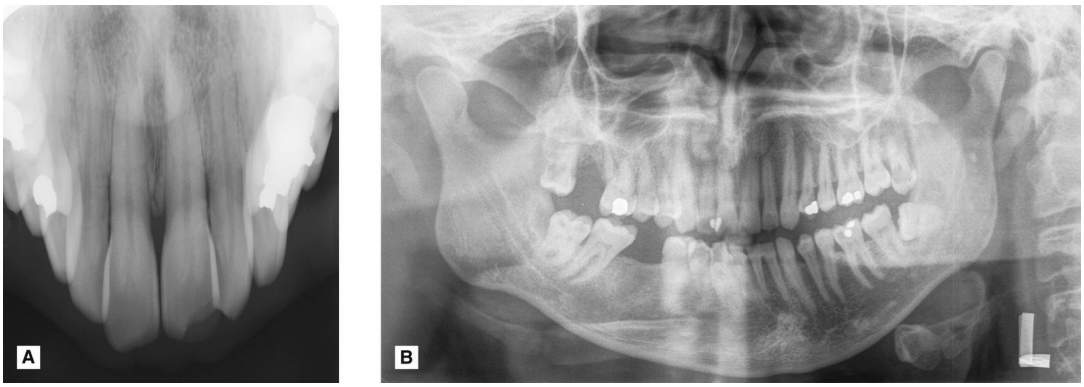


FIG. 17.26 Two examples of positioning (radiographic

technique) errors. **(A)** An upper standard occlusal radiograph – the X-ray tube head positioned at too shallow an angle in the vertical plane – elongation and geometrical distortion of the image. **(B)** Panoramic- patient rotated to the left, LEFT molars narrowed, RIGHT molars widened (horizontal error).

- Failure to instruct the patient to remain still during the exposure with subsequent movement resulting in blurring
- Failure to set correct exposure settings (image too dark or too pale – see earlier)
- Careless inadvertent use of the image receptor twice.

Panoramic Technique Errors

These can include:

- Failure to remove jewellery
- Failure to remove dentures
- Failure to remove orthodontic appliances
- Failure to remove spectacles
- Inappropriate use of a protective lead apron
- Failure to ensure the spine is straight
- Failure to ensure the incisors are biting on the bite- peg (anteroposterior error)
- Failure to use the light beam markers to ensure the mid-sagittal plane is vertical and the Frankfort plane is horizontal (vertical and horizontal errors)
- Failure to instruct the patient to press the tongue against the roof of the mouth
- Failure to instruct the patient to remain still throughout the exposure cycle
- Failure to set machine height adjustment correctly
- Failure to set correct exposure settings (image too dark or too pale – see earlier)
- Failure to use the cassette/image receptor correctly.

Patient Dose and X-Ray Generating Equipment

One of the stated aims of QA is to ensure that radiation doses are kept as low as reasonably practicable. It is therefore necessary to measure patient doses on a regular basis and, if available, compare them against national diagnostic reference levels. The latest diagnostic reference levels (DRLs) in the UK published by Public Health England in 2019 are 1.2 mGy for an adult mandibular molar periapical and 81 mGy cm^2 for an adult panoramic radiograph. The DRLs for a variety of dental radiographs including CBCT are shown in Table 17.6 .

Table 17.6

The latest 2019 UK Diagnostic Reference Levels (DRLs) for a variety of dental radiographs.

X-ray type	Patient size (clinical indication)	Proposed DRL
Intraoral	Adult mandibular molar	1.2 mGy
	Child mandibular molar	0.7 mGy
Panoramic	Adult full jaw	81 mGy cm^2
	Child full jaw	60 mGy cm^2
Cephalometric	Adult lateral	35 mGy cm^2
	Child lateral	24 mGy cm^2
Dental CBCT	Adult (imaging prior to placement of a maxillary molar implant)	265 mGy cm^2
	Child (imaging of an im-pacted maxillary canine of a 12 year old child)	170 mGy cm^2

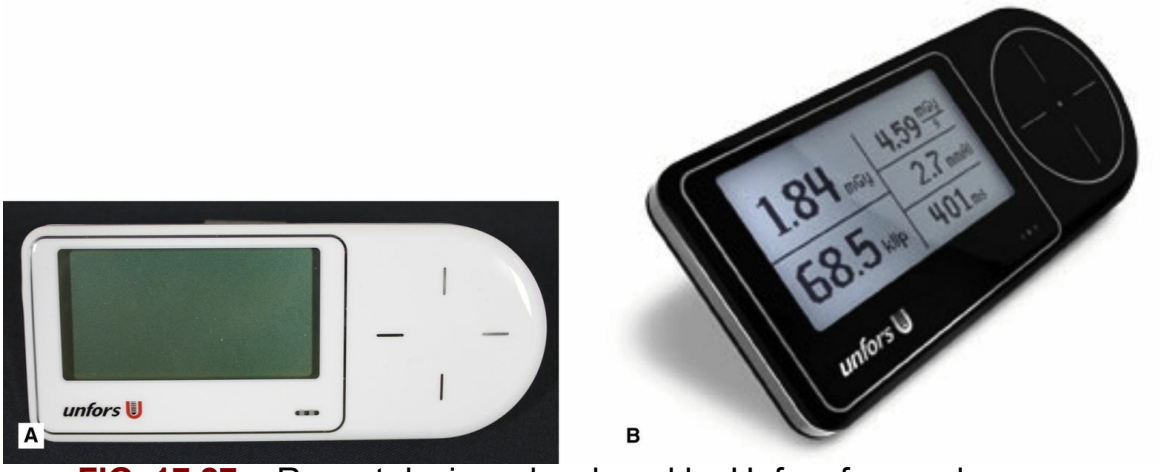


FIG. 17.27 Recent devices developed by Unfors for regular checks on X-ray equipment output. **(A)** The Ray- safe to simply check satisfactory output and **(B)** the more complex Thin-X that produces actual measurements of output. Courtesy Mr M. Chapman.

To try to ensure compliance with these DRLs, typical X-ray generating equipment QA measures include:

- An initial critical examination and report – carried out by the installer.
- An acceptance test – carried out by a radiation protection adviser/medical physicist before equipment is brought into clinical use, which should include measurement of patient dose.
- A re-examination report following any relocation, repair or modification of equipment that may have radiation protection implication.
- Regular checks of important features that could affect radiation protection including:
  - Correct functioning of warning lights and audible alarms
  - Correct operation of safety devices
  - Satisfactory performance of the counterbalance for maintaining the correct position of the tubehead
  - Correct alignment of the beam collimation

  - X-ray equipment output. This can be performed in dental practice using one of the devices shown in Fig. 17.27 .

- Checks on panoramic equipment regarding reproducibility, uniformity, beam alignment and synchronization of the exposure with tube motion. For example, the following simple test could be carried out in dental practice, based broadly on the Institute of Physics and Engineering in Medicine Report 91 (2005):

1. On installation of the equipment a baseline image is created by placing a 1 mm thick copper strip over the X-ray port (to filter the beam), and exposing a cassette containing a film using a standard adult panoramic exposure.
2. The test is repeated every 1–3 months and the subsequent images compared with the baseline image and assessed for reproducibility, uniformity beam alignment and synchronization:
   - Reproducibility and uniformity – the image should be of similar density to the baseline image and there should be no areas of nonuniformity. There will always be a vertical dark central band present on a panoramic image, owing to the higher exposure factors being used at this point in the panoramic cycle for extra penetration of the cervical spine. Any other vertical banding may indicate a fault in the exposure or the rotation system (see Fig. 17.28).
   - Beam alignment and synchronization – the radiation field area should lie completely within the edges of the image receptor.

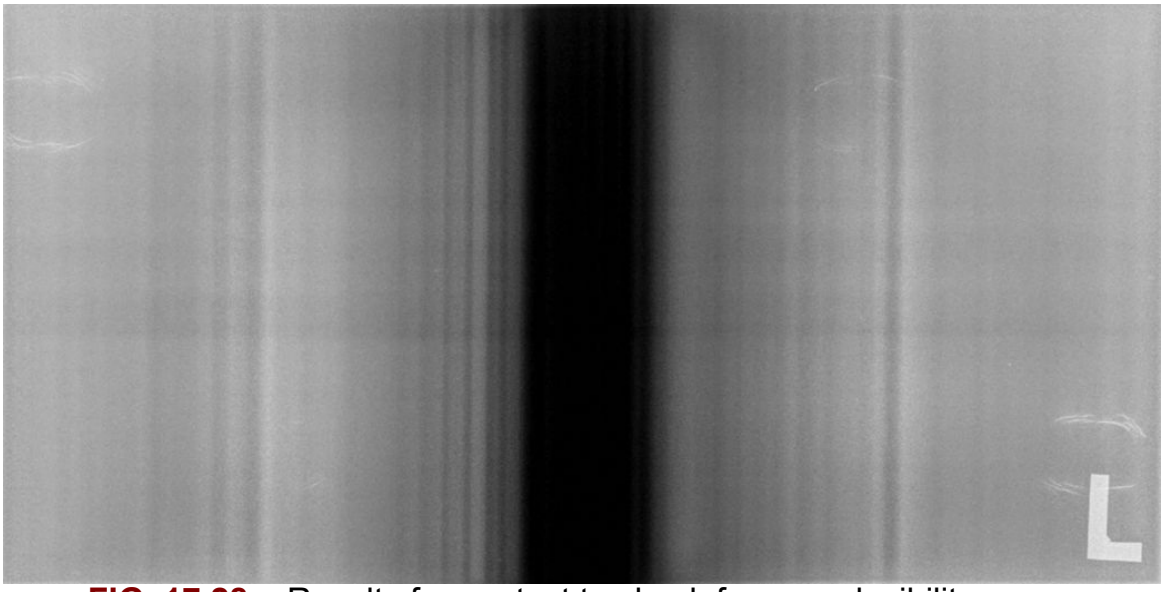


FIG. 17.28 Results from a test to check for reproducibility, uniformity, beam alignment and synchronization during panoramic radiography. The radiation field lies completely within the edges of the image receptor. The central dark band is normal and is due to the increased exposure factors required to compensate for the cervical spine. However, the other pale and dark bands should not be present and may be due to a fault in the exposure or the rotation system.

- Written records and an equipment log should be maintained and include:
  - All installer's formal written reports describing the checks made, the results obtained and action taken
  - Results of all equipment checks in chronological order
  - Details of all routine or special maintenance.
- An up-to-date inventory of each item of X-ray equipment should be maintained, and available, at each practice and contain:
  - Name of the manufacturer
  - Model number
  - Serial number or other unique identifier
  - Year of manufacture
  - Year of installation.

- Compliance with any national medical physics recommendations, e.g. in the UK the *Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems,* Report 91 of the Institute of Physics and Engineering in Medicine, published in 2005.

Working Procedures

These include:

- *Local rules* – required in the UK under the Ionising Radiations Regulations 2017. These rules should contain the procedural and operational elements that are essential to the safe use of X-ray equipment, including guidance on exposure times, and as such should contain much of what is relevant to the maintenance of good standards in QA.
- *Employers' written procedures* – required in The UK under the Ionising Radiation (Medical Exposure) Regulations 2017.
- *Operational procedures* or *systems of work* – these include written procedures that provide for all actions that indirectly affect radiation safety and diagnostic quality, e.g. instructions for the correct preparation and subsequent use of processing chemicals (as explained earlier).
- *Procedures log* – the QA programme should include the maintenance of a procedures log to record the existence of appropriate *Local Rules* and *Employers' Written Procedures* , together with a record of each occasion on which they are reviewed or modified at intervals not exceeding 3 years.

Staff Training and Updating

It is a legal requirement in the UK and in many other countries that all *practitioners* and *operators* are adequately trained and that continuing professional development (CPD) is undertaken. The QA programme should incorporate a register of all staff involved with any aspect of

radiography and should include the following information:

- Name
- Responsibility
- Date, nature and details of training received
- Recommended date for a review of training needs.

Audits

Each procedure within the QA programme will include a requirement for written records to be made by the responsible person at varying intervals. In addition, the person with overall responsibility for the QA programme should check the full programme at intervals not exceeding 12 months. This is an essential feature of demonstrating effective implementation of the programme. Clinical audits may include:

- The QA programme and associated records
- The justification and authorization of radiographs
- The appropriateness of requests/investigations
- The clinical evaluation of radiographs.

Footnote

The requirement for QA and quality control measures, for both digital and film-based imaging, in general dental practice applies equally to specialized hospital radiography departments. However, in view of the cost implications, the expensive, sophisticated equipment, available for precise QA measurements and monitoring used in hospital X-ray departments, is often inappropriate to general dental practice. The practical suggestions in this chapter are designed to satisfy the WHO definition of QA by bringing an element of objectivity to QA in practice, but at the same time being simple, easily done and inexpensive.

To access the self-assessment questions for this chapter, please go to

http://evolve.elsevier.com/Whaites/essentials/

18

Alternative and Specialized Imaging Modalities

Introduction

An array of medical imaging modalities has been developed in recent years and these continue to be developed at a phenomenal rate. Totally new imaging techniques have been introduced, while the resolution and image quality of existing systems are continually being refined and improved. Research and development have focused on manipulating and altering all three of the basic requirements for image production – the patient, the image-generating equipment (to find alternatives to ionizing radiation) and the image receptor. Digital image receptors (solid-state and photostimulable phosphor plates) are now used routinely (see Chapter 4). More and more sophisticated computer software is being developed to manipulate the image itself, once it has been captured. Many of these imaging modalities are playing an increasingly important role in dentistry. As a result, clinicians need to be aware of them and their application in the head and neck region. The main specialized imaging modalities include:

- Contrast studies
- Radioisotope imaging (nuclear medicine)
- Computed tomography (CT)
- Ultrasound examinations
- Magnetic resonance imaging (MRI).

This chapter provides a summary of these modalities and their main applications in the head and neck region.

Contrast Studies

These investigations use *contrast media,* radiopaque substances that have been developed to alter artificially the density of different parts of the patient, so altering *subject contrast* – the difference in the X-ray beam transmitted through different parts of the patient's tissues (see Chapter 17). Thus, by altering the patient, certain organs, structures and tissues, invisible using conventional means, can be seen as shown in Fig. 18.1 . Contrast studies, and the tissues imaged, include:

- Sialography – salivary glands
- Arthrography – joints
- Angiography – blood vessels
- Lymphography – lymph nodes and vessels
- Urography – kidneys
- Barium swallow, meal and enema – gastrointestinal tract
- Computed tomography – general enhancement (see later).

Types of Contrast Media

The main types include:

- Barium sulphate suspensions for investigating the gastrointestinal tract

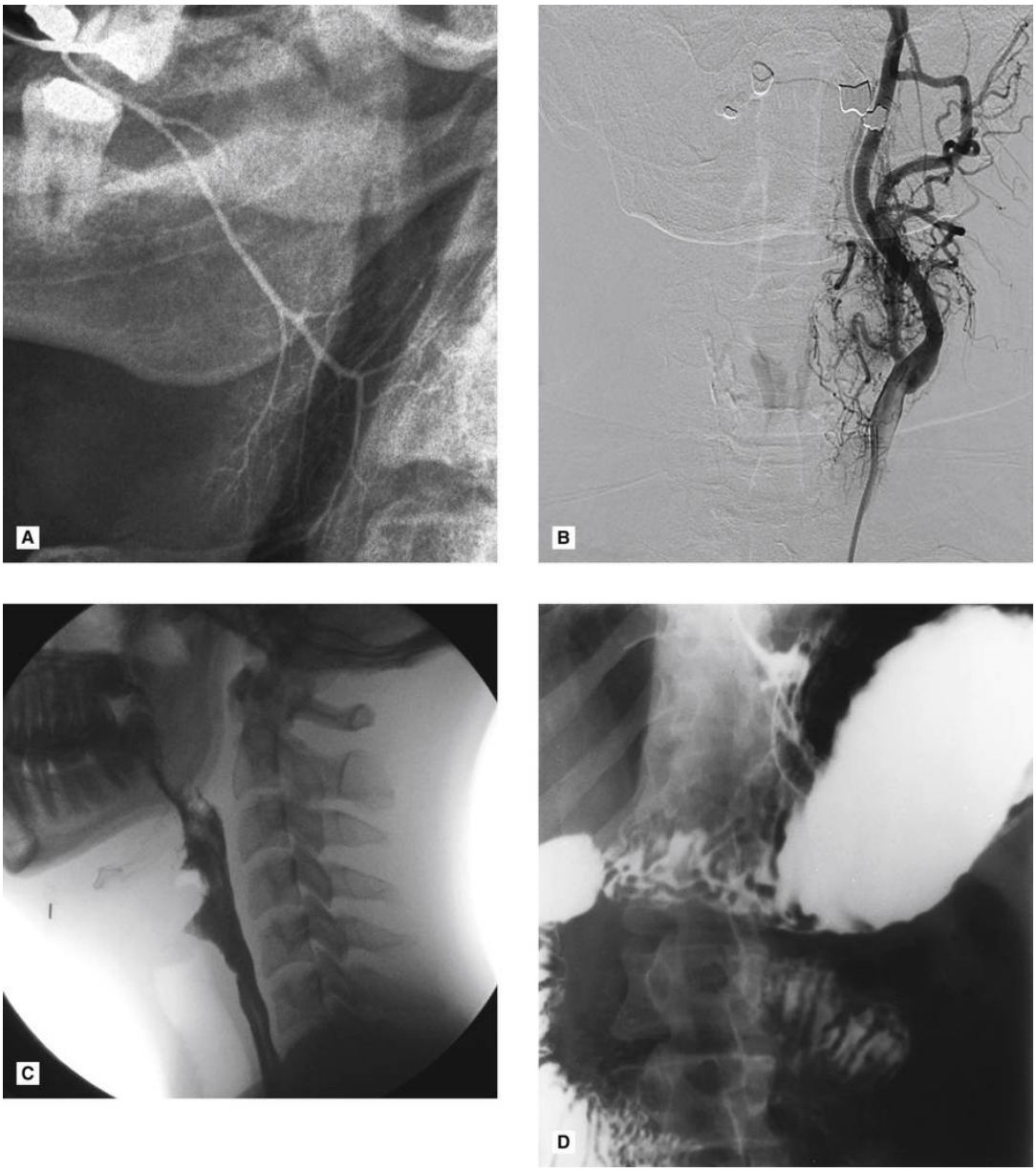


FIG. 18.1 Examples of different contrast studies. **(A)** A left parotid gland sialograph. **(B)** A subtraction angiograph of the left carotid vessels. Note by convention the contrast medium is displayed black. **(C)** A fluoroscopic barium swallow showing contrast medium in the pharynx and oesophagus. Again, the contrast medium is displayed black. (Courtesy of Mr C. Greenall). **(D)** An abdominal radiograph following a barium meal showing contrast medium in the stomach, duodenum and small bowel.

- Iodine-based aqueous solutions used for all other

investigations and divided into:
  - Ionic monomers, including:
    - iothalmate (e.g. Conray®)
    - metrizoate (e.g. Isopaque®)
    - diatrizoate (e.g. Urografin®)
  - Ionic dimers, including:
    - ioxaglate (e.g. Hexabrix®)
  - Nonionic monomers, including:
    - iopamidol (e.g. Niopam®)
    - iohexol (e.g. Omnipaque®)
    - iopromide (e.g. Ultravist®)
    - iodixanol (e.g. Visipaque320®)
- MRI contrast agents (e.g. gadolinium).

Harmful Effects of Contrast Media

Ideally contrast media should have no harmful effects at all. However, there is a small risk associated with their use, especially with the iodine-based aqueous solutions (the so-called *general contrast media*) when they are introduced into the bloodstream. Considering a single dose of contrast medium contains more than 2000 times as much iodine as the body's total physiological content, adverse or residual effects are remarkably rare.

Important Point to Note

Several of the newer imaging modalities now being used more routinely in dentistry, as discussed later, rely heavily on the use of these contrast-enhancing agents and clinicians should therefore be aware of the risks involved.

Complications

The main complications associated with contrast media can be divided into:

- *Mild,* e.g. headache, nausea, warmth and/or pain, flushing, sneezing and constipation (gastrointestinal investigations)
- *Moderate,* e.g. vomiting, bronchospasm, urticaria and hypotension
- *Severe,* e.g. cardiac arrhythmias, cardiac arrest, convulsions, anaphylactic shock and pulmonary oedema
- *Fatal.*

Patients Particularly at Risk

- The elderly and very young children
- Patients with a history of allergy to contrast media
- Patients with diabetes
- Patients suffering from:
  - Cardiac failure
  - Renal failure
  - Severe pulmonary disorders, e.g. asthma.

Main Causes of Complications

- Allergy
- Chemotoxicity
- Osmolality (osmotic pressure of the solution) – with ionic monomer contrast media, the osmolality is three times greater than that of other agents; the risk of complications arising when using these substances is therefore also greater
- Anxiety.

Prophylactic Measures to Minimize Complications

- Use of low osmolality contrast agents
- Skin pre-testing (the value of this is in doubt)
- Prophylactic steroids
- Prophylactic antihistamines

- Reassurance to decrease levels of anxiety
- Ask specifically about previous history of iodine allergy.

Main Contrast Studies Used in the Head and Neck

These include:

- Sialography – (see Chapter 32)
- Arthrography – (see Chapter 28)
- CT – to provide general enhancement (see later)
- Barium swallow – to image the oesophagus
- Angiography – aqueous iodine-based contrast media introduced into selected blood vessels, e.g. the carotids (common, internal or external) or the vertebral arteries.

The procedure usually entails introducing a catheter into a femoral artery followed by selective catheterization of the carotid or vertebral arteries, as required, using fluoroscopic control. Once the catheter is sited correctly, the contrast medium is injected and radiographs of the appropriate area taken (see Fig. 18.1B).

Main Indications for Angiography in the Head and Neck

- To show the vascular anatomy and feeder vessels associated with vascular anomalies such as arteriovenous malformations
- Investigation of suspected subarachnoid haemorrhage resulting from an aneurysm in the Circle of Willis
- Investigation of transient ischaemic attacks possibly caused by emboli from atheromatous plaques in the carotid arteries.

Radioisotope Imaging

Radioisotope imaging relies on altering the patient by making the

tissues radioactive and the patient becoming the source of ionizing radiation. This is done by injecting certain radioactive compounds into the patient that have an affinity for particular tissues – so-called *target tissues.* The radioactive compounds become concentrated in the target tissue and their radiation emissions are then detected and imaged, usually using a stationary *gamma camera* (see Fig. 18.2). This investigation allows the function and/or the structure of the target tissue to be examined under both static and dynamic conditions.

Radioisotopes and Radioactivity

Radioisotopes, as defined in Chapter 2 , are *isotopes with unstable nuclei that undergo radioactive disintegration.* This disintegration is often accompanied by the emission of radioactive particles or radiation. The important emissions include:

- Alpha particles
- Beta $^{-}$ (electron) and beta^{+} (positron) particles
- Gamma radiation.

The main properties and characteristics of these emissions are summarized in Table 18.1 .

Radioisotopes Used in Conventional Nuclear Medicine

Several radioisotopes are used in conventional nuclear medicine, depending on the organ or tissue under investigation. Typical examples together with their *target tissues* or *target diseases* include:

- Technetium (^{99m} Tc) – salivary glands, thyroid, bone, blood, liver, lung and heart
- Gallium (^{67} Ga) – tumours and inflammation
- Iodine (^{123} I) – thyroid
- Krypton (^{81} K) – lung.

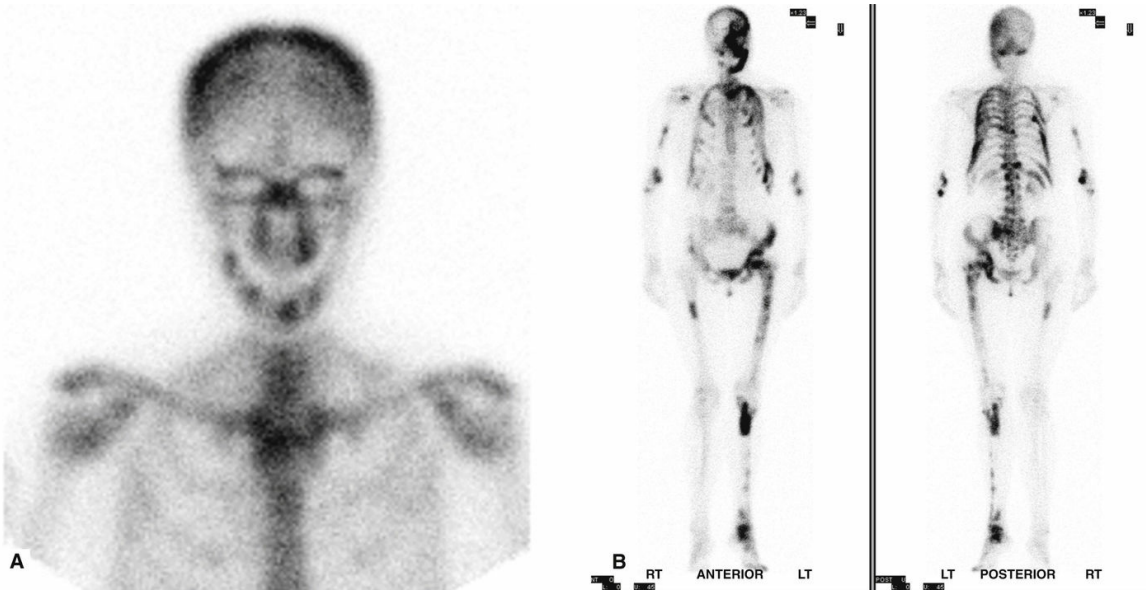


FIG. 18.2 Technetium bone scans of different patients showing **(A)** head and upper chest and **(B)** full skeleton with multiple areas of increased uptake – so-called *hot spots.*
Courtesy of Dr J. Rees.

^{99m}Tc is the most commonly used radioisotope. Its main properties include:

- Single 141 keV gamma emissions which are ideal for imaging purposes
- A short half-life of 6½ hours, which ensures a minimal radiation dose
- It is readily attached to a variety of different substances that are concentrated in different organs, e.g.:
  - Tc+ MPD (methylene diphosphonate) in bone
  - Tc+ red blood cells in blood
  - Tc+ sulphur colloid in the liver and spleen
- It can be used on its own in its ionic form (pertechnetate $^{99m}TcO^{4-}$), because this agent is taken up selectively by the thyroid and salivary glands
- It is easily produced, as and when required, on site.

Main Indications for Conventional Isotope Imaging

in the Head and Neck

- Tumour staging – the assessment of the sites and extent of bone metastases
- Investigation of salivary gland function, particularly in Sjögren's syndrome (see Chapter 32)
- Evaluation of bone grafts
- Assessment of continued growth in condylar hyperplasia
- Investigation of the thyroid
- Brain scans and assessment of a breakdown of the blood–brain barrier.

Advantages Over Conventional Radiography

- Target tissue function is investigated
- All similar target tissues can be examined during one investigation, e.g. the whole skeleton can be imaged during one bone scan
- Computer analysis and enhancement of results are available.

Disadvantages

- There is poor image resolution – often only minimal information is obtained on target tissue anatomy
- The radiation dose to the whole body can be relatively high
- Images are not usually disease specific
- Difficult to localize the exact anatomical site of source of emission
- Some investigations take several hours
- Facilities are not widely available.

Further developments in radioisotope imaging techniques include:

- *Single photon emission computed tomography* (SPECT), where the

photons (gamma rays) are emitted from the patient and detected by a gamma camera rotating around the patient and the distribution of radioactivity is displayed as a cross-sectional image or single photon emission CT scan enabling the exact anatomical site of the source of the emissions to be determined (see Fig. 18.3A).

Table 18.1

Summary of the main properties and characteristics of radioactive emissions

Property	Alpha particles	Beta$^-$ particles	Gamma rays	Beta$^+$ particles
Nature	Particulate – two protons and two neutrons	Particulate – electrons	Electromagnetic radiation – identical to X-rays	Particulate – positron, interacts very rapidly with a negative electron to produce 2 gamma rays – *annihilation radiation* – properties as shown in adjacent column
Size	Large	Small	Nil	
Charge	Positive	Negative	Nil	
Speed	Slow	Fast	Very fast	
Range in tissue	1–2 mm	1–2 cm	As with X-rays	
Energy range carried	4–8 MeV	100 keV–6 MeV	1.24 keV–12.4 MeV	
Damage caused	Extensive ionization	Ionization	Ionization – similar damage to X-rays	
Use in nuclear	Banned	Very limited	Main emission used	Positron emission tomography

- Positron emission tomography (PET). As shown in Table 18.1 , some radioactive isotopes decay by the emission of a positively charged electron (positron) from the nucleus. This positron usually travels a very short distance (1–2 mm) before colliding with a free electron. In the ensuing reaction, the mass of the two particles is annihilated with the emission of two (photons) gamma rays of high energy (511 keV) at almost exactly 180° to each other. These emissions, known as *annihilation radiation* , can then be detected simultaneously (in coincidence) by opposite radiation detectors which are arranged in a ring around the patient. The exact site of origin of each signal is recorded and a cross-sectional slice is displayed as a PET scan (see Fig. 18.3B). The major

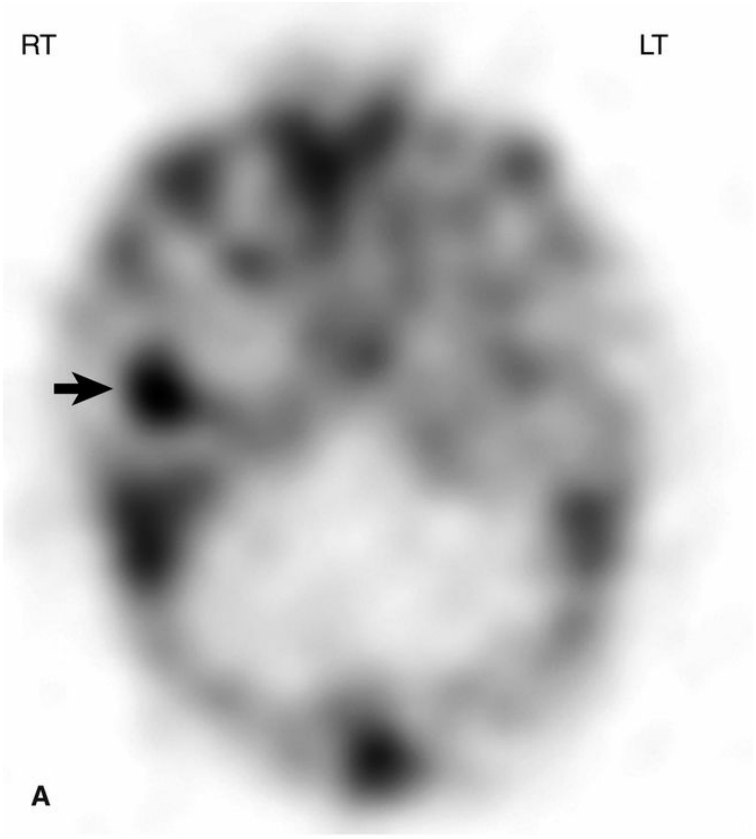
advantages of PET as a functional imaging technique are due to this unique detection method and the variety of new radioisotopes which can now be used clinically. These include:

– Carbon (^{11}C)
– Fluorine (^{18}F)
– Oxygen (^{15}O)
– Nitrogen (^{13}N).

As in conventional nuclear medicine, these radioisotopes can be used on their own or incorporated into diverse and biologically important compounds (e.g. glucose, amino acids and ammonia) and then administered in trace amounts to study:

- Tissue perfusion
- Substrate metabolism, often using ^{18}F-fluorodeoxyglucose (^{18}FDG)
- Cell receptors
- Neurotransmitters
- Cell division
- Drug pharmacokinetics.

PET can therefore be used to investigate disease at a molecular level, even in the absence of anatomical abnormalities apparent on CT or MRI (see later). It is also possible to superimpose a PET scan on a CT scan, by a technique known as *co-registration* , to determine a lesion's exact anatomical position as shown in Fig. 18.3B . Clinically it has been used in the management of patients with epilepsy, cerebrovascular and cardiovascular disease, dementia and malignant tumours.


RT
LT
A

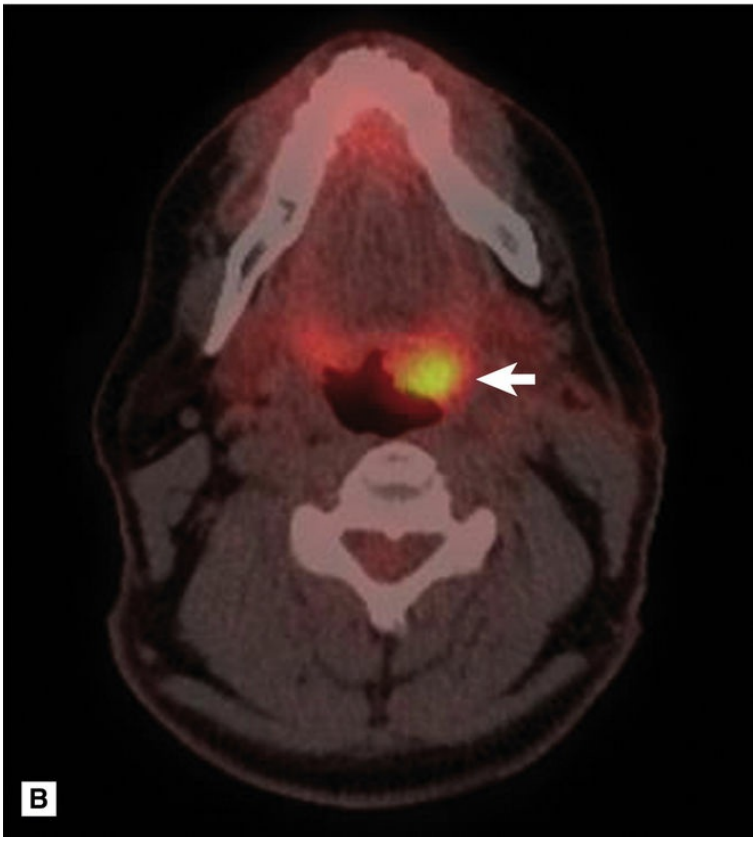

B

FIG. 18.3 **(A)** An axial single photon emission computed tomography (SPECT) scan showing increased activity (*hot spot*) in the right condyle (arrowed). **(B)** An axial co-registered positron emission tomography (PET) and computed tomography (CT) scan showing accumulation of ^{18} FDG in the left tongue base (arrowed).
Courtesy of Dr J. Rees.

Computed Tomography (CT)

CT scanners use X-rays to produce computer generated *tomographs* – sectional or slice images (see Chapter 15). In CT the radiographic film is replaced by very sensitive crystal or gas detectors. The detectors measure the intensity of the X-ray beam emerging from the patient and convert this into digital data which are stored and can be manipulated by a computer (see Chapter 5). This numerical information is converted into a grey scale representing different tissue densities, thus allowing a visual image to be generated as shown in Fig. 18.4 .

Equipment and Theory

The CT scanner is essentially a large square piece of equipment (the gantry) with a central circular hole as shown in Fig. 18.5A . The patient lies down with the part of the body to be examined within this circular hole. The gantry houses the X-ray tubehead and the detectors. The mechanical geometry of scanners varies. In so-called *third-generation scanners* , both the X-ray tubehead and the detector array revolve around the patient, as shown in Fig. 18.5A . In so-called *fourth-generation scanners* , there is a fixed circular array of detectors (as many as 1000) and only the X-ray tubehead rotates as shown in Fig. 18.5B . Whatever the mechanical geometry, each set of detectors produces an attenuation or penetration profile of the slice of the body being examined. The patient is then moved further into the gantry and the next sequential adjacent slice is imaged. The patient is then moved again, and so on until the part of the body under investigation has

been completed. This stop–start movement means the investigation takes several minutes to complete and the radiation dose to the patient is high.



FIG. 18.4 An axial CT image of the head.

As a result, *spiral CT scanning* has been developed in recent years. Acquiring spiral CT data requires a continuously rotating X-ray tubehead and detector system in the case of third-generation scanners or, for fourth-generation systems, a continuously rotating X-ray tubehead. This movement is achieved by slip-ring technology. The patient is now advanced continuously into the gantry while the

equipment rotates, in a spiral movement, around the patient (see Fig. 18.5C). The investigation time has been shortened to only a few seconds with a radiation dose reduction of up to 75%.

Whatever type of scanner is used, the level, plane and thicknesses (usually between 1.5 and 6.0 mm) of the slices to be imaged are selected and the X-ray tubehead rotates around the patient, scanning the desired part of the body and producing the required number of slices. These are usually in the axial plane as shown in Fig. 18.4 .

The sequence of events in image generation can be summarized as follows:

- As the tubehead rotates around the patient, the detectors produce the attenuation or penetration profile of the slice of the body being examined.
- The computer calculates the absorption at points on a grid or matrix formed by the intersection of all the generation profiles for that slice.

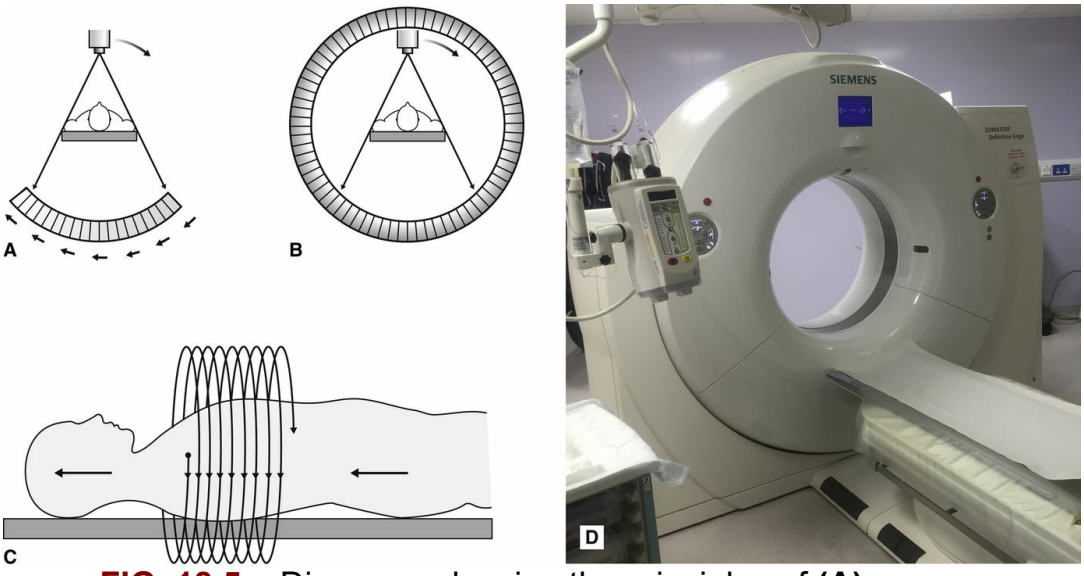


FIG. 18.5 Diagrams showing the principles of **(A)** a *third-generation* computed tomography scanner – both the X-ray tubehead and the detector array rotate around the patient, **(B)** a *fourth-generation* computed tomography scanner – the X-ray tubehead rotates within

a stationary ring of detectors, and **(C)** *spiral* computed tomography – the tubehead and detectors move in a continuous spiral motion around the patient as the patient moves continuously into the gantry in the direction of the solid arrows. **(D)** The Siemens Somatom *Definition Edge* computed tomography scanner.

- Each point on the matrix is called a *pixel* and typical matrix sizes comprise either 512 × 512 or 1024 × 1024 pixels. The smaller the individual pixel, the greater the resolution of the final image (as described for digital imaging in Chapters 4 and 5).
- The area being imaged by each pixel has a definite volume, depending on the thickness of the tomographic slice, and is referred to as a *voxel* (see Fig. 18.6).
- Each voxel is given a *CT number* or *Hounsfield unit* between, for example, +1000 and –1000, depending on the amount of absorption within that block of tissue (see Table 18.2).
- Each CT number is assigned a different degree of greyness, allowing a visual image to be constructed and displayed on the monitor.
- The patient moves through the gantry and sequential adjacent sections are imaged.
- The selected images are stored in a suitable Picture Archiving and Communication System (PACS) ready for manipulation.

Table 18.2

Typical computed tomography numbers for different tissues

Tissue	Computed tomography number	Colour
Air	-1000	Black
Fat	-100 to -60	
Water	0	
Soft tissue	+40 to +60	
Blood	+55 to +75	
Dense bone	+1000	White

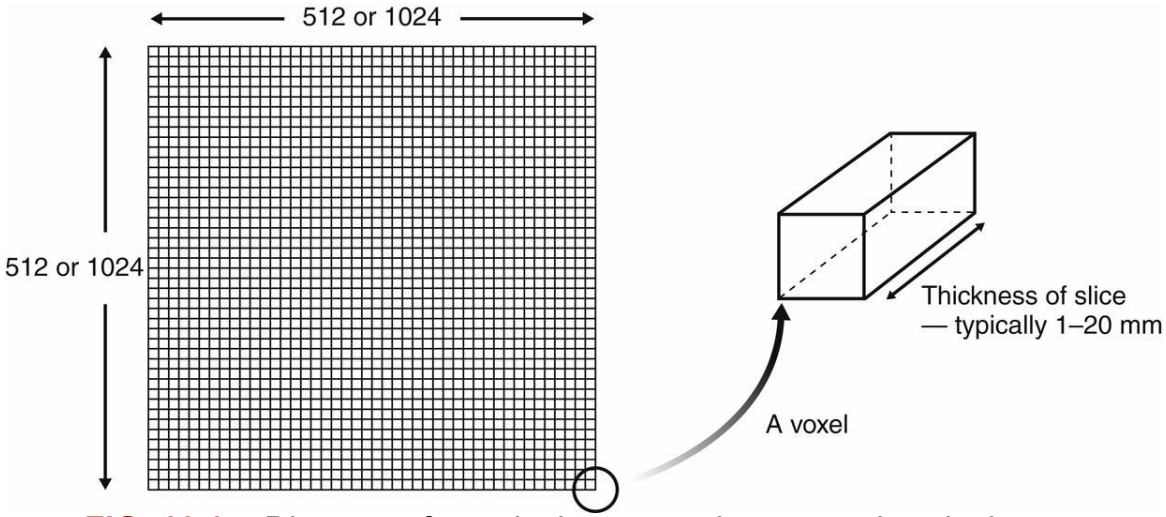


FIG. 18.6 Diagram of a typical computed tomography *pixel* matrix and an individual *voxel.*

Image Manipulation

The major benefits of computer-generated images are the facilities to manipulate or alter the image and to reconstruct new ones, without the patient having to be re-exposed to ionizing radiation (see also Chapter 7).

Window Level and Window Width

These two variables enable the visual image to be altered by selecting the optimal range and level of densities to be displayed.

- **Window level** – this is the CT number selected for the centre of the range, depending on whether the lesion under investigation is in soft tissue or bone.
- **Window width** – the range selected to view on the screen for the various shades of grey, e.g. a narrow range allows subtle differences between very similar tissues to be detected.

Reconstructed Images

The information obtained from the original axial scan can be manipulated by the computer to reconstruct tomographic sections in the coronal, sagittal or any other plane that is required, or to produce three-dimensional images as shown in Fig. 18.7 . However, to minimize the *step effect* evident in these reconstructed images, the original axial scans need to be very thin and contiguous or overlapping with a resultant relatively high dose of radiation to the patient.



FIG. 18.7 A reconstructed 3-D CT image of the skull and facial bones.

Main Indications for CT in the Head and Neck

- Investigation of intracranial disease including tumours, haemorrhage and infarcts
- Investigation of suspected intracranial and spinal cord damage after trauma to the head and neck
- Assessment of fractures involving:
- The orbits and naso-ethmoidal complex
  - The cranial base
  - The odontoid peg
  - The cervical spine

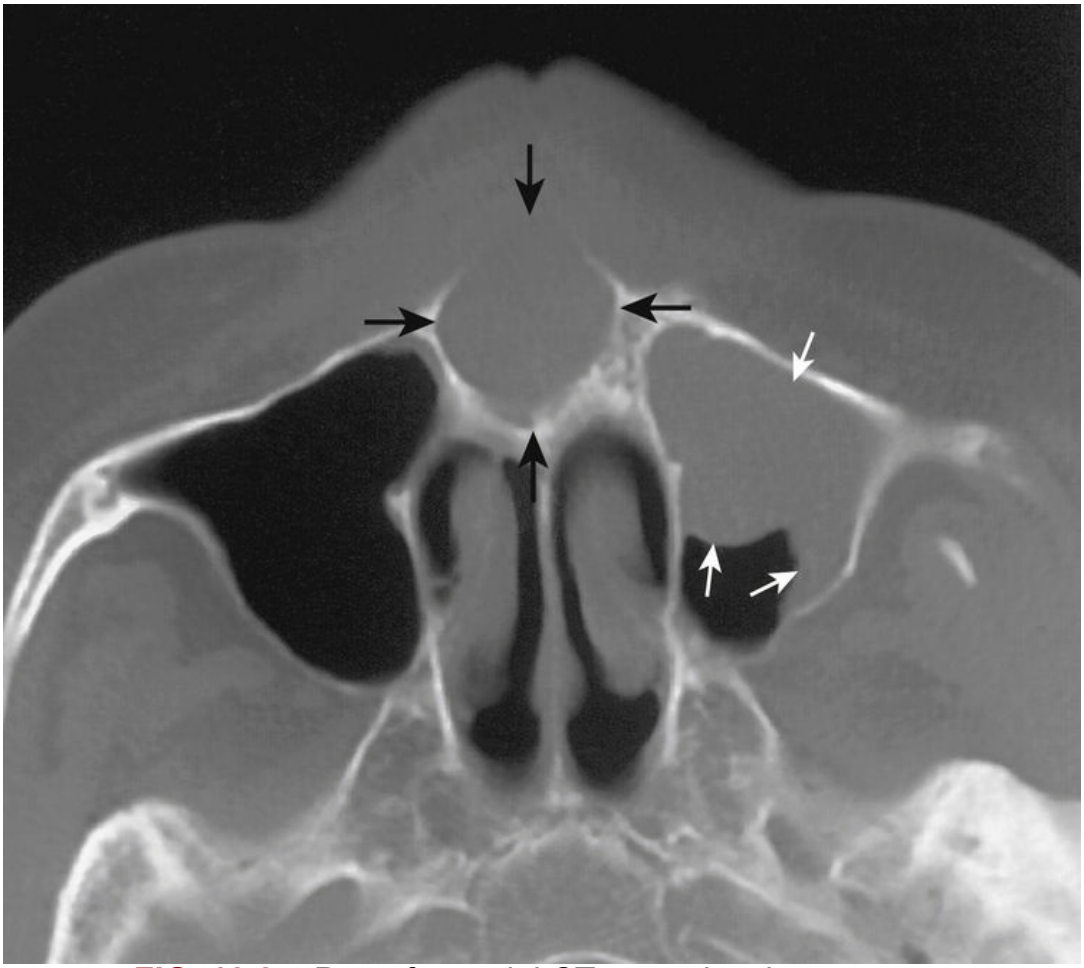


FIG. 18.8 Part of an axial CT scan showing an expansive cystic lesion in the anterior palate (black

arrows). Mucosal thickening within the antrum is also evident (white arrows).
Courtesy of Dr J. Kabala and Dr J. Luker.

- Assessment of the site, size and extent of cysts, giant cell and other bone lesions (see Fig. 18.8)
- Assessment of disease within the paranasal air sinuses (see Chapter 31)
- Tumour staging – assessment of the site, size and extent of tumours, both benign and malignant, affecting:
  - The maxillary antra
  - The base of the skull
  - The pterygoid region
  - The pharynx
  - The larynx
- Investigation of tumours and tumour-like discrete swellings both intrinsic and extrinsic to the salivary glands
- Investigation of osteomyelitis
- Investigation of the temporomandibular joint (TMJ)
- Preoperative assessment of maxillary and mandibular alveolar bone height and thickness before inserting implants (see Chapter 23).

Advantages Over Conventional Film-based Tomography

- Very small amounts, and differences, in X-ray absorption can be detected. This in turn enables:
  - Detailed imaging of intracranial lesions
  - Imaging of **hard** and **soft** tissues
  - Excellent differentiation between different types of tissues, both normal and diseased
- Images can be manipulated
- Axial tomographic sections are obtainable
- Reconstructed images can be obtained from information

obtained in the axial plane
- Images can be enhanced by the use of intravenous contrast media to delineate blood vessels.

Disadvantages

- The equipment is very expensive
- Very thin contiguous or overlapping slices result in a generally high dose investigation (see Chapter 6)
- Metallic objects, such as fillings, may produce marked streak or *star* artefacts across the CT image
- There are inherent risks associated with intravenous contrast agents (see earlier).

Ultrasound Examinations

Diagnostic ultrasound examinations are now established as the first choice imaging modality for soft tissue investigations of the face and neck, particularly of the salivary glands (see Chapter 32). It is a non-invasive investigation that uses a very high frequency (7.5–20 MHz) pulsed ultrasound beam, rather than ionizing radiation, to produce high-resolution images of more superficial structures. The use of colour power Doppler allows blood flow to be detected.

Equipment and Theory

Several machines are available – an example is shown in Fig. 18.9 . The high-frequency ultrasound beam is directed into the body from a transducer placed in contact with the skin. Jelly is placed between the transducer and the skin to avoid an air interface as shown in Fig. 18.10A . As the ultrasound travels through the body, some of it is reflected back by tissue interfaces to produce *echoes,* which are picked up by the same transducer and converted into an electrical signal and then into a real-time black, white and grey visual *echo picture,* which is displaced on a computer screen. Examples are shown in Fig. 18.10 .


PHILIPS
Mid Trans
Left

FIG. 18.9 The Philips EPIQ 5G diagnostic ultrasound machine.

The ultrasound image is also a sectional image or *tomograph* , but it represents a topographical map of the depth of tissue interfaces, just like a sonar picture of the seabed. The thickness of the section is determined by the width of the ultrasound beam. Areas of different density in the black/white echo picture are described as *hypoechoic* (dark) or *hyperechoic* (light).

Use of the Doppler effect – a change in the frequency of sound reflected from a moving source – allows the detection of arterial and/or venous blood flow as shown in Fig. 18.10 . As can be seen, the computer adds the appropriate colour, red or blue, to the vascular structures in the visual echo picture image, making differentiation between structures straightforward.

The ultrasound wave must be able to travel through the tissue to return to the transducer. If it is blocked by the tissue, no image will result. Because air, bone and other calcified materials block nearly all the low-frequency ultrasound beam, its diagnostic use is limited. However, the newer high-frequency machines enable penetration of more superficial structures to provide high-resolution images.

Main Indications for Ultrasound Examinations in the Head and Neck

- Evaluation of swellings of the neck, particularly those involving the thyroid, cervical lymph nodes or the major salivary glands – ultrasound is now regarded as the investigation of choice for detecting solid and cystic soft tissue masses
- Detection of salivary gland and duct calculi (see Chapter 32)
- Determination of the relationship of vascular structures and vascularity of masses with the addition of colour flow Doppler imaging
- Assessment of blood flow in the carotids and carotid body

tumours
- Assessment of the ventricular system in babies by imaging through the open fontanelles
- Therapeutically, in conjunction with the sialolithotripter, to break up salivary calculi into approximately 2-mm fragments which can then pass out of the ductal system so avoiding major surgery
- Ultrasound-guided fine-needle aspiration (FNA) biopsy.

Advantages Over Conventional X-ray Imaging

- Sound waves are NOT ionizing radiation
- There are no known harmful effects on any tissues at the energies and doses currently used in diagnostic ultrasound examinations

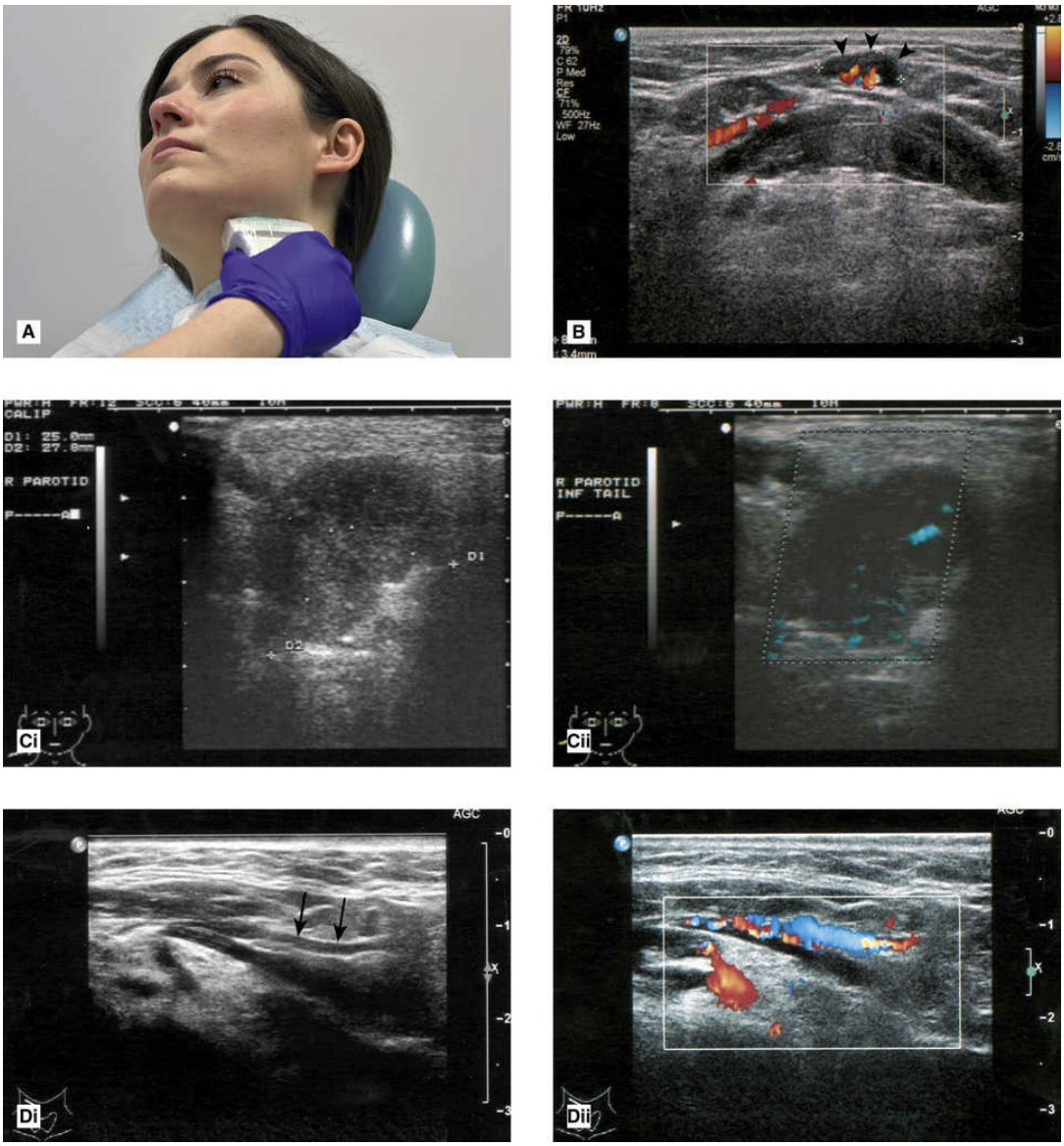


FIG. 18.10 **(A)** A patient undergoing an ultrasound investigation of the left submandibular salivary gland. The transducer is placed against the skin overlying the gland. Note the jelly between the transducer and the skin. **(B)** Ultrasound image of the submental region showing the use of Doppler colour flow imaging to detect blood flow in the hilar vessels of a small submental lymph node (arrowheads). **(C) (i)** Ultrasound image of a pleomorphic adenoma in the parotid gland showing a hypoechoic (dark) mass with a well-defined, lobulated outline; **(ii)** ultrasound image of the same patient with colour power Doppler showing blood flow in the fine vessels within the benign tumour. **(D)** Ultrasound image of the submental region demonstrating the value of

colour Doppler imaging in differentiating vessels from other structures; **(i)** shows a submental vessel (arrowed) and **(ii)** illustrates blood flow within the vessel.
Figures B, C and D - Courtesy of Mrs J.E. Brown.

- Images show good differentiation between different soft tissues and are very sensitive for detecting focal disease in the salivary glands
- The technique is widely available and relatively inexpensive.

Disadvantages

- Ultrasound has limited use in the head and neck region because sound waves are blocked by bone; its use is therefore restricted to the superficial structures
- The technique is operator-dependent
- Images can be difficult to interpret for inexperienced operators
- Real-time imaging means that the radiologist must be present during the investigation.

Magnetic Resonance Imaging (MRI)

MRI is another specialized three-dimensional imaging modality that does not involve the use of ionizing radiation. Individual images are another example of sectional images or *tomographs* that at first glance can resemble a CT image.

Equipment and Theory

An example of an MRI machine is shown in Fig. 18.11 . The detailed physics of MR image production are beyond the scope of this book and are comparatively very complex when compared with other imaging methods. However, the basic principles can be summarized as follows.

- MRI involves the behaviour of protons (positively charged

nuclear particles; see Chapter 2) in a magnetic field.

- The simplest atom is hydrogen, consisting of one proton in the nucleus and one orbiting electron; the hydrogen nuclei (protons) are not static, but rotate or spin on a moving axis in a movement called *precessing* as shown in Fig. 18.12 .
- This precessing has a net magnetic field, and can be drawn as a magnetic vector (much like a very small compass). The body contains many billions of hydrogen atoms, most bonded to oxygen to make water, some bonded to other molecules. At rest, all these tiny *compasses* point in random directions so a person's net magnetic vector is zero. When the patient is placed inside a very strong magnet (called B0), all the *compasses* (hydrogen nuclei) line up with the strong magnetic field as shown in Fig. 18.13 .



FIG. 18.11 The Siemens Magnetom Aera 1.5T magnetic resonance scanner.

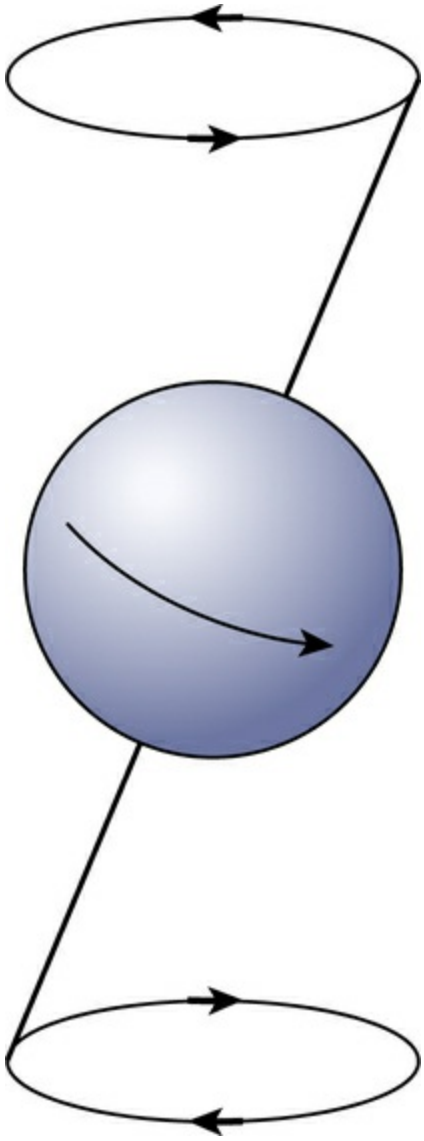


FIG. 18.12 Diagram illustrating the *precessing* movement of a hydrogen nucleus (proton) as it rotates/spins on a moving axis.
Courtesy of Mr S. Harvey

- The 'strong magnet' is often produced by a superconductor with helium cooling. The magnet strengths in widespread clinical use range from 1 to 3 tesla (T). For reference, the magnetic strength of the surface of the Earth is around 60 μT; thus, a 3T MRI machine is 50,000 times more powerful.
- If a radio frequency pulse is matched to the precession frequency, then the net magnetic vector of those protons can

be tilted to the side, against the main strong magnet. This creates *transverse magnetisation.* The transverse magnetisation will diminish (called *T2 decay*) as the net magnetic vector of that proton returns to match the main strong magnet (called *T1 recovery*). These processes give off a radio frequency pulse which can be detected.

- It is this radiofrequency pulse, and the timing of T2 decay and T1 recovery, which are measured by the MR machine. Different soft tissues will show different T2 decay and T1 recovery times.
- Finally, not all MR images are the same – different *sequences* are used depending on the radiofrequency pulse timings and strength to image different tissue characteristics. The most commonly used sequences are either *T1* or *T2* resulting in *T1-weighted* or *T2 -weighted* images. At a basic level, some radiologists would say "T1 is good for anatomy and T2 is good for disease", but both are used in the detection of disease.
- The descriptive terms *radiolucent* and *radiopaque* do not apply to MRI – they only apply to X-ray–based imaging. The descriptive MRI terms used are *low signal* (dark) and *high signal* (bright). Some common sequences and the appearances of a selection of different tissues is shown in Table 18.3 and examples of MRI images are shown in Figs. 18.14 –18.15 .
- Dense tissues such as cortical bone, enamel and dentine contain only 'trapped' water, so they give very low signal on all sequences.

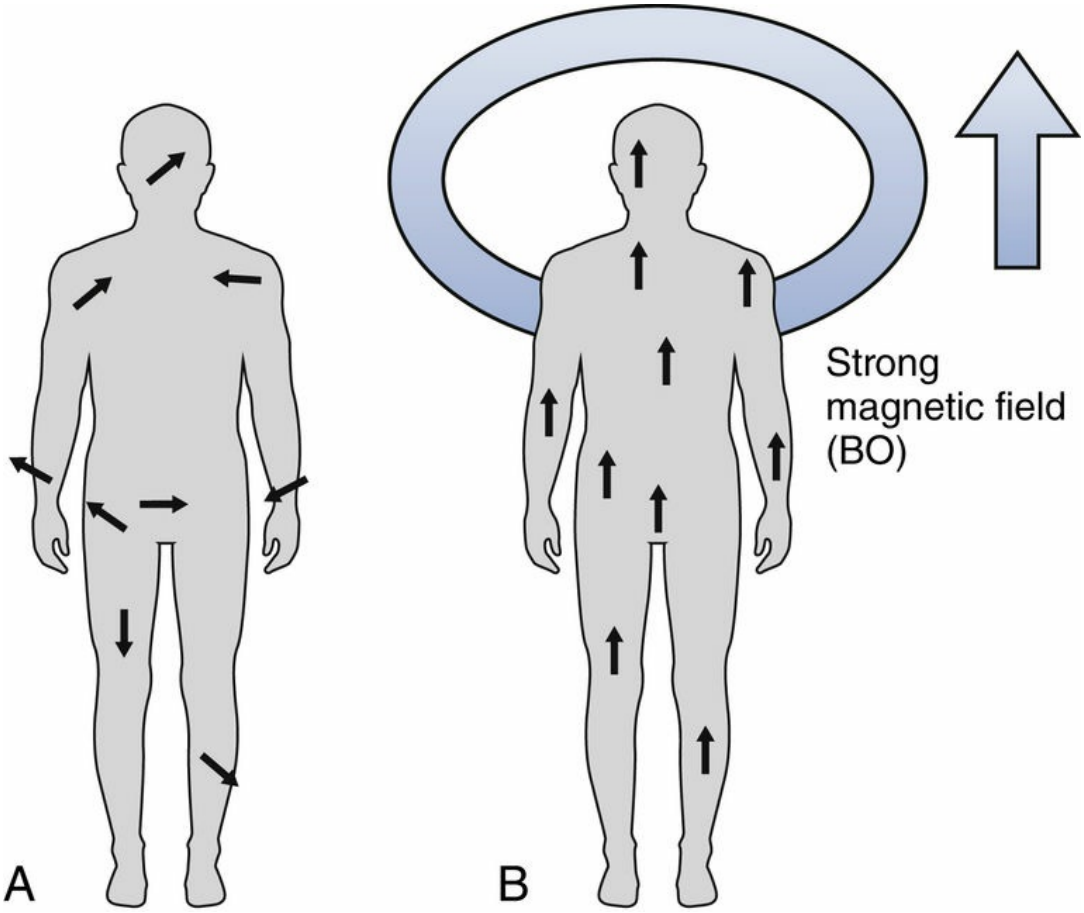


FIG. 18.13 Diagrams showing **(A)** a person at rest – all the tiny hydrogen proton *compasses* point in a random direction so the person's net magnetic vector is zero and **(B)** a person in a strong magnet – all the hydrogen proton *compasses* line up with the main magnetic field.
Based on an original drawing by Mr S. Harvey

- Diffusion-weighted imaging and apparent diffusion coefficient mapping is a development in MRI that relies on the movement of water molecules to produce contrast within the tissues. These techniques are increasingly being used in oncology to predict response to treatment and in the detection of recurrent disease.

Table 18.3

Different tissues and how they appear on T1-weighted and T2-weighted magnetic resonance imaging sequences

	T1	T2
Water	Dark	Bright
Fat	Bright	Medium
Cortical bone	Very dark	Very dark
Most pathology	Dark	Medium
Temporomandibular joint disc	Dark	Very dark
Air	Very dark	Very dark

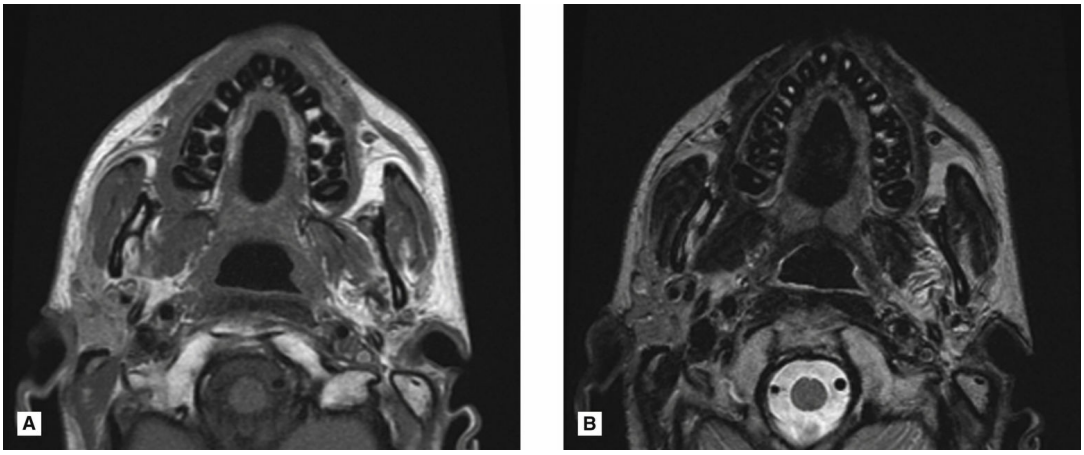


FIG. 18.14 Axial magnetic resonance (MR) images through the maxilla at a similar level. **(A)** On the T1-weighted image fat gives a high signal and appears bright. **(B)** On the T2-weighted image the cerebrospinal fluid gives a high signal and so appears bright. Note on both images the cortical bone appears black (low signal).

Courtesy of Dr M. Hourihan.

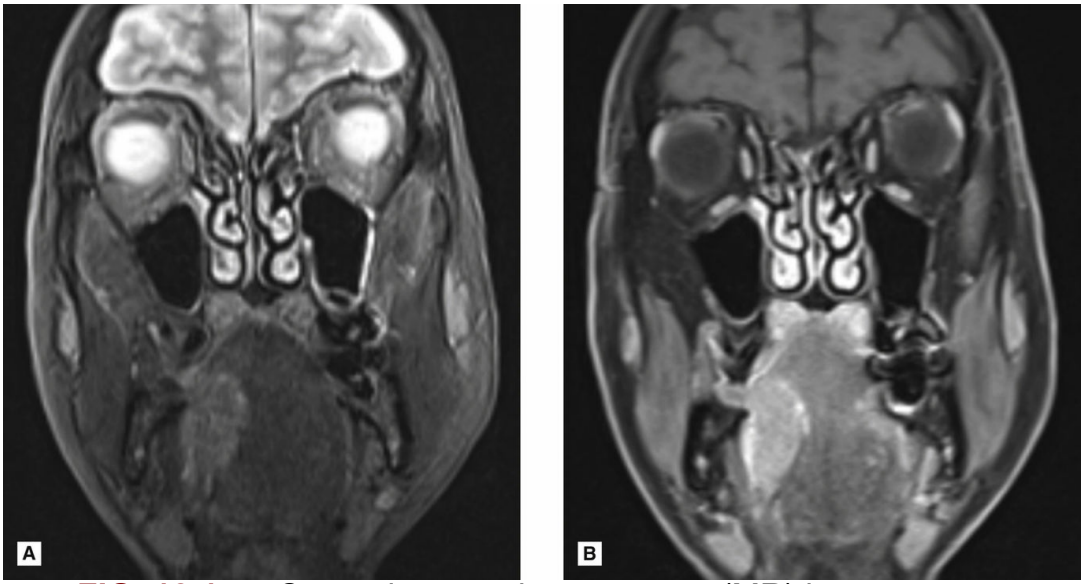


FIG. 18.15 Coronal magnetic resonance (MR) images through the tongue and identifying a mass on the right lateral aspect. **(A)** T2-weighted image. **(B)** T1-weighted, fat-suppressed, post-gadolinium contrast showing the mass enhanced.
Courtesy of Mr S. Harvey.

- Gadolinium-containing contrast agents, e.g. *gadoterate meglumine (Dotarem®)* is used in MRI in a similar way to X-ray contrast media in that it selectively *enhances* certain tissues to improve the image (see Fig. 18.15). Generally, disease *enhances.* Contrast can be used with any sequence; however, it is most frequently used on a T1 sequence in which the fat is *suppressed* to make fat appear very dark (black).
- Typically MR *tomographic* images are acquired in the specific plane required depending on the clinical indication. For example, for a suspected tongue base lesion, axial and sagittal sections are normally required, for sinus disease, coronal slices are often used and for the temporomandibular joint parasagittal sections along the line of the joint are often used. Multiplanar reconstruction is possible but due to the relatively thicker slices used in MRI (compared with CT and cone beam CT) the images can be suboptimal.

Main Indications for MRI in the Head and Neck

- Investigation of the salivary glands (see Chapter 32)
- Tumour staging – evaluation of the site, size and extent of soft and hard tissue tumours, including nodal involvement, affecting in particular:
    - The salivary glands
    - The tongue and floor of mouth
    - The pharynx
    - The larynx
    - The oral cavity
    - The paranasal sinuses
    - The orbits
    - The jaws to assess bony invasion
- Investigation of the temporomandibular joint to show both the bony and soft tissue components of the joint including the disc position (see Chapter 30). MRI may be indicated:
    - When diagnosis of internal derangement is in doubt
    - As a preoperative assessment before disc surgery
- Investigation and diagnosis of bone necrosis such as osteoradionecrosis, medication-related osteonecrosis of the jaw (MRONJ) (see Chapter 28) and infective bone disease (osteomyelitis)
- Implant assessment (see Chapter 23).

Advantages

- Excellent soft tissue contrast
- Bone marrow changes visualized – important for assessing invasion (e.g. cancer) or disease spread (e.g. osteomyelitis)
- Considered safe – no radiation exposure
- Contrast (gadolinium) can be used to enhance images
- High signal-to-noise ratio.

Disadvantages

- Expensive – machine cost, Faraday cage room, specialist staff, time-consuming imaging method
- Claustrophobic
- Noisy
- Unsuitable for those with shrapnel or loose metallic foreign bodies
- Multiple 'sequences' needed (see above for common sequences)
- Time consuming
- Movement artefact more likely owing to long scanning times
- Small metal wires (e.g. for ECG) may heat up and cause skin burns
- Higher tesla magnets (e.g. 7T) may induce temporary peripheral neuropathy
- Contrast unsuitable for those with nephropathy or allergy.

Important Points to Note

- Owing to the strong magnet, MRI machines need to be situated in a special area enclosed by a Faraday cage. This stops ferromagnetic items outside the room being attracted to the magnet. There have tragically been recorded deaths caused by the projectile effect of metallic objects (such as oxygen cylinders) being brought into the MR room, and attracted to the magnet – striking people in the process.
- MRI departments should have a warning zone, marked on the floor and possibly with a door, beyond which ferromagnetic objects should not be taken. There should also be a second warning on the door of the MR room.
- It is common practice to take a conventional X-ray image of patients who report metallic objects inside them before MRI. For medical items/devices to be brought into the MR room, they must be certified *MR safe.* Most modern cardiac

pacemakers are now MR safe, although this should be verified.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

PART IV
Radiology

OUTLINE

19. Introduction to Radiological Interpretation

20. Dental Caries and the Assessment of Restorations

21. The Periapical Tissues

22. The Periodontal Tissues and Periodontal Disease

23. Implant Assessment

24. Developmental Abnormalities

25. Radiological Differential Diagnosis – Describing a Lesion

26. Differential Diagnosis of Radiolucent Lesions of the Jaws

27. Differential Diagnosis of Lesions of Variable Radiopacity in the Jaws

28. Bone Diseases of Radiological Importance

29. Trauma to the Teeth and Facial Skeleton

30. The Temporomandibular Joint

31. The Maxillary Antra

32. The Salivary Glands

19

Introduction to Radiological Interpretation

Interpretation of radiographs can be regarded as an unravelling process – uncovering all the information contained within the black, white and grey radiographic images. The main objectives are:

- To identify the presence or absence of disease
- To provide information on the nature and extent of the disease
- To enable the formation of a differential diagnosis.

To achieve these objectives and maximize the diagnostic yield, interpretation should be carried out under specified conditions, following ordered, systematic guidelines.

Unfortunately, interpretation is often limited to a cursory glance under totally inappropriate conditions. Clinicians often fall victim to the problems and pitfalls produced by *spot diagnosis* and *tunnel vision*. This is despite their knowing that in most cases radiographs are their main diagnostic aid.

This chapter provides an introductory approach to how traditional two-dimensional radiographs should be interpreted, specifying the viewing conditions required and suggesting systematic guidelines.

Essential Requirements for Interpretation

The essential requirements for interpreting dental radiographs can be summarized as follows:

- Optimum viewing conditions
- Understanding the nature and limitations of the black, white and grey radiographic image
- Knowledge of what the radiographs used in dentistry should look like, so a critical assessment of individual image quality can be made
- Detailed knowledge of the range of radiographic appearances of normal anatomical structures
- Detailed knowledge of the radiographic appearances of the pathological conditions affecting the head and neck
- A systematic approach to viewing the entire radiograph and to viewing and describing specific lesions
- Access to previous images for comparison.

Optimum Viewing Conditions

For *digitally-captured images* these include:

- A clean, bright, high-resolution monitor (see Fig. 19.1) that has undergone quality assurance calibration/checks for:
  - distortion
  - grey scale reproduction
  - luminescence
  - uniformity and
  - resolution at both high and low contrast.
- A quiet, darkened viewing room.

Table 19.1 outlines the minimum and ideal specifications of the monitor (image display device) as recommended in the UK by Public Health England and by the Royal College of Radiologists.



FIG. 19.1 Eizo high-resolution medical grade image monitor.

For *film-captured images* these include:

- An even, uniform, bright light viewing screen (preferably of variable intensity to allow viewing of films of different densities) (see Fig. 19.2)
- A quiet, darkened viewing room
- The area around the radiograph should be masked by a dark surround so that light passes only through the film

TABLE 19.1

Summary of the minimum and ideal specification for the monitor when viewing digital images

	Minimum specification	Ideal specification
	>1280 x 1024 (>1.3 megapixels)	>1500 x 2000

Screen resolution	≥1280 × 1024 (~1.3 megapixels)	≥1500 × 2000
Screen size (viewable diagonal)	≥42 cm (~17″)	≥50 cm (~20″)
Maximum luminance	≥170 cd/m^2	≥500 cd/m^2
Luminance contrast ratio	≥250:1	≥500:1
Greyscale bit depth	8-bit greyscale (24-bit colour)	≥10-bit greyscale

- Use of a magnifying glass to allow fine detail to be seen more clearly on intraoral films
- The radiographs should be dry.

These ideal viewing conditions give the observer the best chance of perceiving all the detail contained within the radiographic image. With many simultaneous external stimuli, such as extraneous light and inadequate viewing conditions, the amount of information obtained from the radiograph is decreased. Film-captured radiographs should be viewed once they have dried because films still wet from processing may show some distortion of the image.

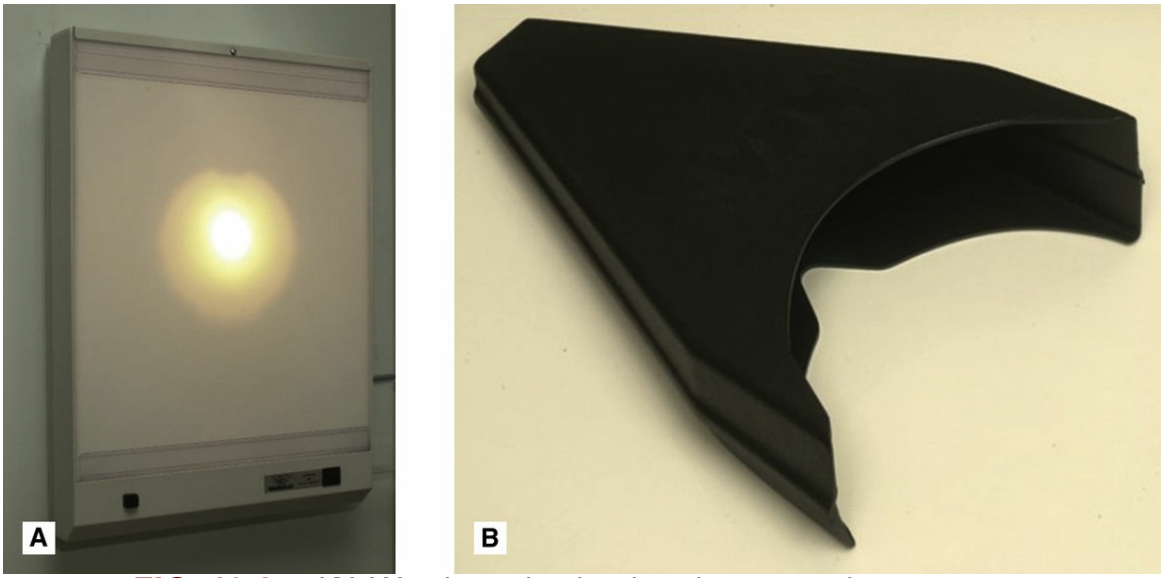


FIG. 19.2 **(A)** Wardray viewing box incorporating an additional central bright-light source for viewing over-exposed dark films. **(B)** The SDI X-ray reader – an extraneous light-excluding intraoral film viewer with built-in magnification.

The Nature and Limitations of Traditional Two-dimensional Radiographic Images

The importance of understanding the nature of different traditional radiographic images – digitally or film-captured (depending on the type of image receptor used) and their specific limitations was explained in Chapter 1 . How the visual images are created by processing – computer or chemical – was explained in Chapter 5 . Revision of both of these chapters is recommended. To reiterate, the final traditional image whether captured digitally or on film is 'a two-dimensional picture of three-dimensional structures superimposed on one another and represented as a variety of black, white and grey shadows' – a *shadowgraph.*

Critical Assessment of Image Quality

To be able to assess and interpret any radiographic image correctly, clinicians have to know what that image should look like, how it was captured, and which structures should be shown. It is for this reason that the chapters on radiography included:

1. WHY each projection was taken
2. HOW the projections were taken using different image receptors
3. WHAT the resultant radiographic image should look like
4. WHICH anatomical structures they showed.

With this practical knowledge of radiography, clinicians are in a position to make an overall critical assessment of individual digital and film-captured images.

Digitally-captured Images

The practical factors that can affect digitally-captured images, how the images are created and how they can be altered using computer software were discussed in Chapter 5 and included:

- The image receptor – solid-state or photostimulable phosphor plate
- Computer image processing and enhancement
- The patient
- The operator and radiographic technique.

A critical assessment of digital images can be made by combining these factors and by asking a series of questions about the final image. These questions relate to:

- Radiographic technique
- Image processing.

Here are some typical examples:

Radiographic Technique (see Fig. 19.3)

- Which technique has been used?
- How were the patient, digital receptor and X-ray tubehead positioned?
- Is this a good example of this particular radiographic projection?
- How much distortion is present?
- Has the whole area of interest been included?
- Is the image foreshortened or elongated?
- Is there any rotation or asymmetry?
- How good are the image resolution and sharpness?
- Which artefactual shadows are present?
- How do these technique variables alter the final radiographic image?

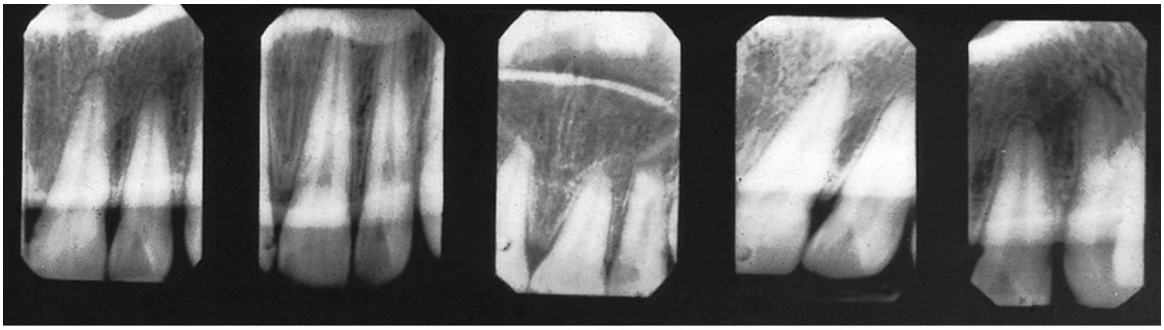


FIG. 19.3 Examples of how variations in radiographic technique can alter the images – digital or film – produced of the same object. **(A)** Correct projection. **(B)** Incorrect vertical angulation producing an elongated image. **(C)** Incorrect vertical angulation producing a foreshortened image. **(D** and **E)** Incorrect horizontal angulations producing distorted images.

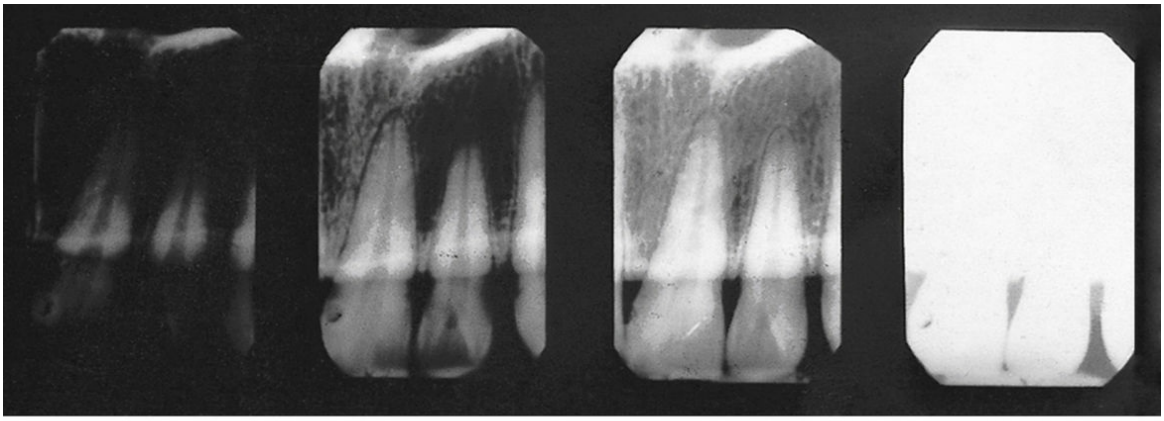


FIG. 19.4 The effect on the degree of blackening by altering the *brightness* control for digital images OR altering *exposure* (mAs – current and/or exposure time) for film-captured images.

Image Processing (see Fig. 19.4)

- Is the contrast optimal?

- Is the brightness optimal?
- Is the image enhancement optimal?
- Is the magnification optimal?

Film-captured Images

The practical factors that can influence film quality were discussed in Chapter 17 , and included:

- The X-ray equipment
- The image receptor – film or film/screen combination
- Processing
- The patient
- The operator and radiographic technique.

As with digital images a critical assessment of film-captured images can be made by combining these factors and by asking a series of questions about the final image. These questions relate to:

- Radiographic technique
- Exposure factors and film density
- Processing.

Here are some typical examples:

Radiographic Technique (see Fig. 19.3)

- Which technique has been used?
- How were the patient, film and X-ray tubehead positioned?
- Is this a good example of this particular radiographic projection?
- How much distortion is present?
- Is the image foreshortened or elongated?
- Is there any rotation or asymmetry?
- How good are the image resolution and sharpness?

- Has the film been fogged?
- Which artefactual shadows are present?
- How do these technique variables alter the final radiographic image?

Exposure Factors and Film Density (see Fig. 19.4)

- Is the radiograph correctly exposed for the specific reason it was requested?
- Is it too dark and so possibly overexposed?
- Is it too light/pale and so possibly underexposed?
- How good is the contrast?
- What effect will exposure factor variation have on the zone under investigation?

Processing

- Is the radiograph correctly processed?
- Is it too dark and so possibly overdeveloped?
- Is it too pale and so possibly underdeveloped?
- Is it dirty with emulsion still present and so underfixed?
- Is the film wet or dry?

With experience, this critical assessment of image quality is not a lengthy procedure, but it is never one that should be overlooked. A poor radiographic image is a poor diagnostic aid and sometimes may be of no diagnostic value at all. Clinicians used to using film-captured images who decide to 'go digital' should take time to understand the nature of the digital image, the effect on the image of using powerful computer software manipulation and the importance of viewing digital images on high resolution, calibrated monitors.

Detailed Knowledge of Normal Anatomy

A detailed knowledge of the radiographic appearances of **normal**

anatomical structures is necessary if clinicians are to be able to recognize the **abnormal** appearances of the many diseases that can affect the jaws.

Not only is a comprehensive knowledge of hard and soft tissue anatomy required but also a knowledge of:

- The type of radiograph being interpreted (e.g. conventional radiograph or tomograph)
- The position of the patient, image receptor and X-ray tubehead.

Only with all this information can clinicians appreciate how the various normal anatomical structures, through which the X-ray beam has passed, will appear on any particular radiograph.

Detailed Knowledge of Pathological Conditions

Radiological interpretation depends on recognition of the typical patterns and appearances of different diseases. The more important appearances are described in Chapters 20 –32 .

Systematic Approach

A systematic approach to viewing radiographs is necessary to ensure that no relevant information is missed. This systematic approach should apply to:

- The entire radiograph
- Specific lesions.

The Entire Radiograph

Any systematic approach will suffice as long as it is logical, ordered and thorough. Several suggested sequences are described in later chapters. By way of an example, a suggested systematic approach to the overall interpretation of panoramic radiographs (see Chapter 15)

is shown in Fig. 19.5 .

This type of ordered sequential viewing of radiographs requires discipline on the part of the observer. It is easy to be sidetracked by noticing something unusual or abnormal, thus forgetting the remainder of the radiograph.

Specific Lesions

A systematic description of a lesion should include its:

- Site or anatomical position
- Size
- Shape
- Outline/edge or periphery
- Relative radiodensity and internal structure
- Effect on adjacent surrounding structures
- Time present, if known.

Making a radiological differential diagnosis depends on this systematic approach. It is described in detail and expanded on later (see Chapter 25).

Comparison with Previous Images

The availability of previous images for comparative purposes is an invaluable aid to radiographic interpretation. The presence, extent and features of lesions can be compared to ascertain the speed of development and growth, or the degree of healing.

NOTE : Care must be taken that views used for comparison have been taken with a comparable technique and are of comparable density.



General overview of the entire image
1 Note the chronological and development age of the patient.
2 Trace the outline of all normal anatomical shadows and compare their shape and radiodensity.

The teeth
3 Note particularly:
- a The number of teeth present
- b Stage of development
- c Position
- d Condition of the crowns
  - (i) Caries
  - (ii) Restorations
- e Condition of the roots
  - (i) Length
  - (ii) Fillings
  - (iii) Resorption
  - (iv) Crown/root ratio.

The apical tissues
4 Note particularly:
- a The integrity of lamina dura
- b Any radiolucencies or opacities associated with the apices.

The peridontal tissues
5 Note particularly:
- a The width of the periodontal ligament
- b The level and quality of crestal bone
- c Any vertical or horizontal bone loss
- d Any furcation involvements
- e Any calculus deposits.

The body and ramus of the mandible
6 Note:
- a Shape
- b Outline
- c Thickness of the lower border
- d Trabeculae pattern
- e Any radiolucent or radiopaque areas
- f Shape of the condylar heads.

Other structures
7 These include:
- a The antra, note:
  - (i) The outline of the floor, medial and posterior walls
  - (ii) Radiodensity
- b Nasal cavity
- c Styloid processes

FIG. 19.5 An example of a panoramic radiograph and a suggested systematic sequence for viewing this type of radiograph.

Conclusion

Successful interpretation of radiographs, no matter what the quality, relies ultimately on clinicians understanding the radiographic image, being able to recognize the range of normal appearances as well as knowing the salient features of relevant pathological conditions.

The following chapters are designed to emphasize these requirements and to reinforce the basic approach to interpretation

outlined earlier.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

20

Dental Caries and the Assessment of Restorations

Introduction

Dental caries includes the invisible *caries process* and the potentially visible (radiographically and/or clinically) *carious lesion.* Understanding this different terminology is important if the role and value of radiography is to be understood.

The *caries process* is the interaction of the dysbiotic biofilm of plaque with the dental hard tissues. The *biofilm* consists of a community of metabolically active micro-organisms capable of fermenting sugars (e.g. sucrose or glucose) to produce acid, which can lower the pH to 5 in 1–3 minutes and produce *demineralization* of the dental hard tissues. The acid can be neutralized by saliva and mineral regained resulting in *remineralization.* Together these processes produce the *carious lesion,* which may or may not be visible clinically and/or radiographically. Being able to see the lesion depends on the extent and balance between demineralization and remineralization.

The first half of this chapter concentrates on the detection of carious lesions in posterior teeth from bitewing radiographs. The second half summarizes the important features to observe when assessing restorations and outlines a systematic approach to interpreting bitewing radiographs.

Classification of Caries

Carious lesions are usually classified and/or described by the anatomical site of the tooth affected. Terminology used includes:

- Pit or fissure caries
- Smooth surface caries
- Enamel caries
- Root caries
- Primary caries – caries developing on unrestored surfaces
- Secondary caries or caries associated with restorations and sealants (CARS)
- Residual caries – demineralized tissue left behind before filling the tooth.

Carious lesions are also classified and/or described by the activity of the *caries process.* Terminology used includes:

- Active caries including early childhood caries
- Arrested or inactive caries.

Levels of Disease

Caries is also described by the extent or size of the lesion. Typically 4 *levels of disease* are used:

- D1 Clinically detectable enamel lesions with intact surfaces
- D2 Clinically detectable cavities limited to enamel
- D3 Clinically detectable lesions in dentine
- D4 Lesions into the pulp.

These distinctions are important with regard to management. Lesions at levels Dl and D2 are generally managed using preventative measures, whereas lesions at the D3 or D4 level are likely to require restorative treatment. Detection of carious lesions and being able to assess the level of disease are therefore crucial factors in determining clinical treatment.

Diagnosis and Detection of Caries

Diagnosis has been defined as identifying a disease from its signs and symptoms. In caries diagnosis that would involve both detecting the lesion and determining the activity of the process. Dental radiography is one method used to detect the lesion, but it gives no information on the activity of the process. Various detection methods are available for different sites.

Occlusal Caries

- Clinical examination using direct vision of clean, dry teeth
- Bitewing radiography
- Laser fluorescence (DIAGNOdent [KaVo], Germany)
- Electrical conductance measurements.

Proximal Caries

- Clinical examination using direct vision of clean, dry teeth
- Gentle probing with ball-ended explorers
- Bitewing radiography in adults and children (posterior teeth)
- Paralleling technique periapical radiography (anterior teeth)
- Fibreoptic transillumination (FOTI)
- Light fluorescence (QLF)
- Elective temporary tooth separation
- Ultrasound.

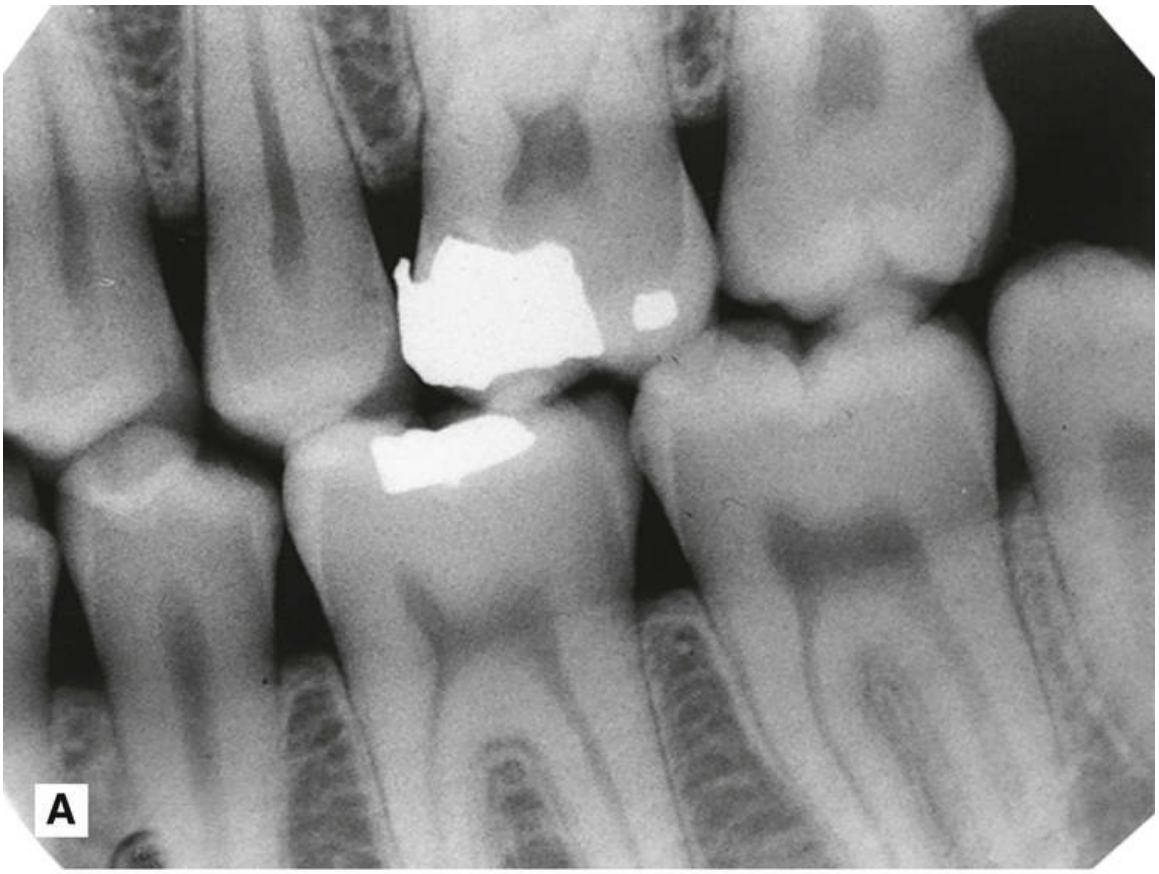
Secondary Caries or Caries Associated with Restorations and Sealants (CARS)

- Clinical examination using direct vision of clean, dry teeth
- Gently probing with ball-ended explorers
- Bitewing radiography.

Radiographic Detection of Carious Lesions

Bitewing radiographic techniques, using both digital sensors (solid-state and phosphor plates) and film packets as the image receptor, were described in Chapter 10 . For caries detection, phosphor plates and film packets are preferred as the imaging area of the equivalent-sized solid-state sensors is smaller. It has been reported that on average three fewer proximal tooth surfaces are shown per image.

Proximal carious lesions are detectable radiographically only when there has been between 30% and 40% demineralization, so allowing the lesion to be differentiated from normal enamel and dentine. The importance of optimum viewing conditions for both digital and film images, as described in Chapter 19 , cannot be overemphasized when looking for these early subtle changes. Magnification is of particular importance as shown in Fig. 20.1 .


A

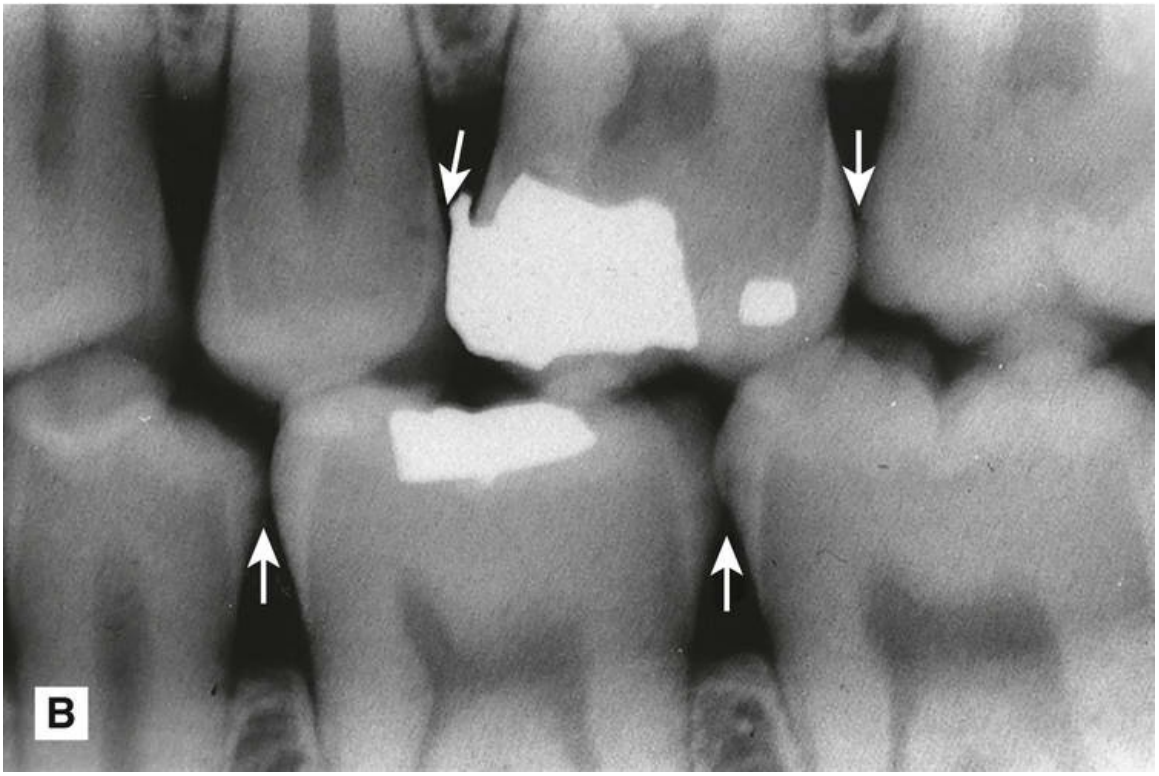

B

FIG. 20.1 The effect of magnification. (A) Bitewing radiograph showing almost invisible very early proximal lesions in the molar and premolar teeth. (B) Magnified central portion of the same bitewing showing the proximal lesions (arrowed) more clearly.

Radiographic Assessment of Caries Activity

A single bitewing radiograph may illustrate one or more carious lesions, but it gives no information on caries activity. Since caries is a slowly progressing disease, this progression, and therefore caries activity, can be assessed over time by periodic radiographic investigations.

In the UK, the 2013 Faculty of General Dental Practice (UK)'s booklet *Selection Criteria for Dental Radiography* (updated in 2018) recommends that the frequency of these follow-up radiographs be linked to the *caries risk susceptibility* of the patient. There are three risk categories – high, moderate and low risk – for both children and adults. The *Selection Criteria* booklet contains a number of evidence-based recommendations, the main ones of which are summarised in Table 20.1 . As can be seen for *high-risk* children and adults 6-monthly time intervals are recommended, for *moderate-risk* patients 12-monthly intervals, for *low-risk* children 12 to 18-month intervals and for *low-risk* adults 2-yearly intervals.

TABLE 20.1

Summary of the main recommendations for using radiographs for the diagnosis of dental caries (linked to caries risk) based on the Faculty of General Dental Practice (UK)'s 2013 *Selection Criteria for Dental Radiography*, 3rd Ed, (updated in 2018).

Recommendation	Evidence-based grading*
All *children* designated as *high caries risk* should have 6-monthly posterior bitewings taken until no new or active lesions are apparent and the individual has entered another risk category (*bitewings should not be taken more frequently and it is imperative to reassess caries risk to justify using this interval again*).	B

All *children* designated as *moderate caries risk* should have annual posterior bitewings taken until no new or active lesions are apparent and the individual has entered another risk category.	B
All *children* designated as *low caries risk* should have posterior bitewings taken at approximately 12 to 18-month intervals in the primary dentition and at approximately 2-yearly intervals in the permanent dentition. More extended radiographic recall intervals may be used if there is explicit evidence of continuing low caries risk.	B
All *adults* designated as *high caries risk* should have 6-monthly posterior bitewings taken until no new or active lesions are apparent and the individual has entered another risk category (*bitewings should not be taken more frequently and it is imperative to reassess caries risk to justify using this interval again. It is also important to remember that rates of caries progress in enamel and dentine will differ and that rates in adults may well be slower than in children*).	C
All *adults* designated as *moderate caries risk* should have annual posterior bitewings taken until no new or active lesions are apparent and the individual has entered another risk category.	C
All *adults* designated as *low caries risk* should have posterior bitewings taken at approximately 2-yearly intervals. More extended radiographic recall intervals may be used if there is explicit evidence of continuing low caries risk.	C
The taking of 'routine' radiographs based solely on time elapsed since the last examinations is not supportable.	C
Intervals between subsequent radiographic examinations must be reassessed for each new period as patients can move in and out of caries risk categories over time.	C
CBCT should not be used as a routine method of caries diagnosis.	B

* Evidence-based grading B = based on evidence from well conducted clinical studies but with no specific *in vitro* validation studies; C = based on evidence from expert committee reports or opinions and/or clinical experience of respected authorities and indicates an absence of directly applicable studies of good quality.

The European Academy of Paediatric Dentistry (EAPD) has also developed guidelines on the use of bitewing radiography for caries diagnosis in children and adolescents who are classified simply as either *high risk* or *low risk.* The timing of subsequent bitewing radiographs is based on previous findings including the number and extent of proximal lesions. The European Academy of Paediatric Dentistry guidelines are provided in Table 20.2 .

Radiographic Appearance of Carious Lesions

As carious lesions progress and enlarge, they appear as differently shaped areas of radiolucency in the crowns or necks of the teeth. These shapes are fairly characteristic and vary according to the *site* and *size* of the lesion. They are illustrated diagrammatically in Fig. 20.2 and examples are shown in Fig. 20.3 .

TABLE 20.2

The European Academy of Paediatric Dentistry recommended baseline examinations and intervals to the next bitewing examination

Baseline bitewing examination	Interval to next bitewing examination	
At age	Low risk	High risk
5 years	3 years	1 year
8–9 years	3–4 years	1 year
12–16 years	2 years	1 year
16 years	3 years	1 year

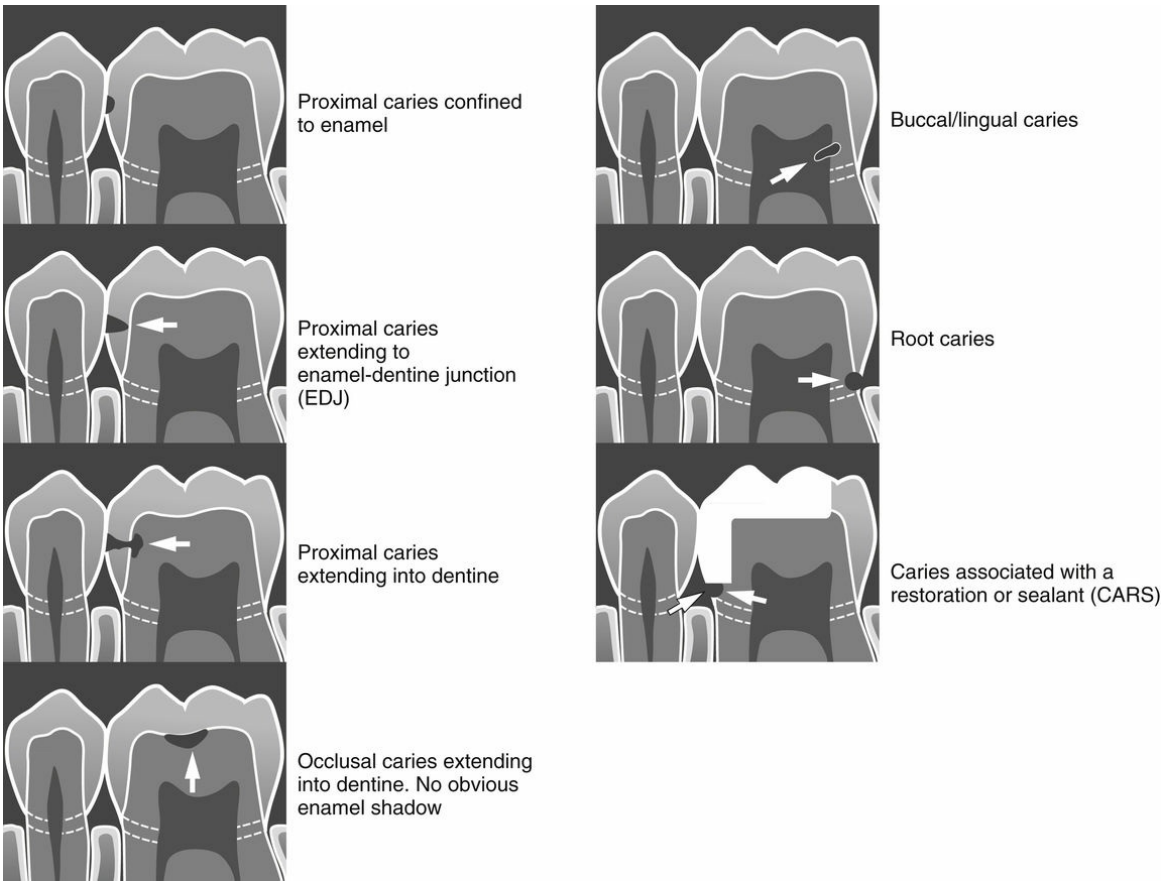


FIG. 20.2 Diagrams illustrating the radiographic appearances and shapes of various carious lesions.

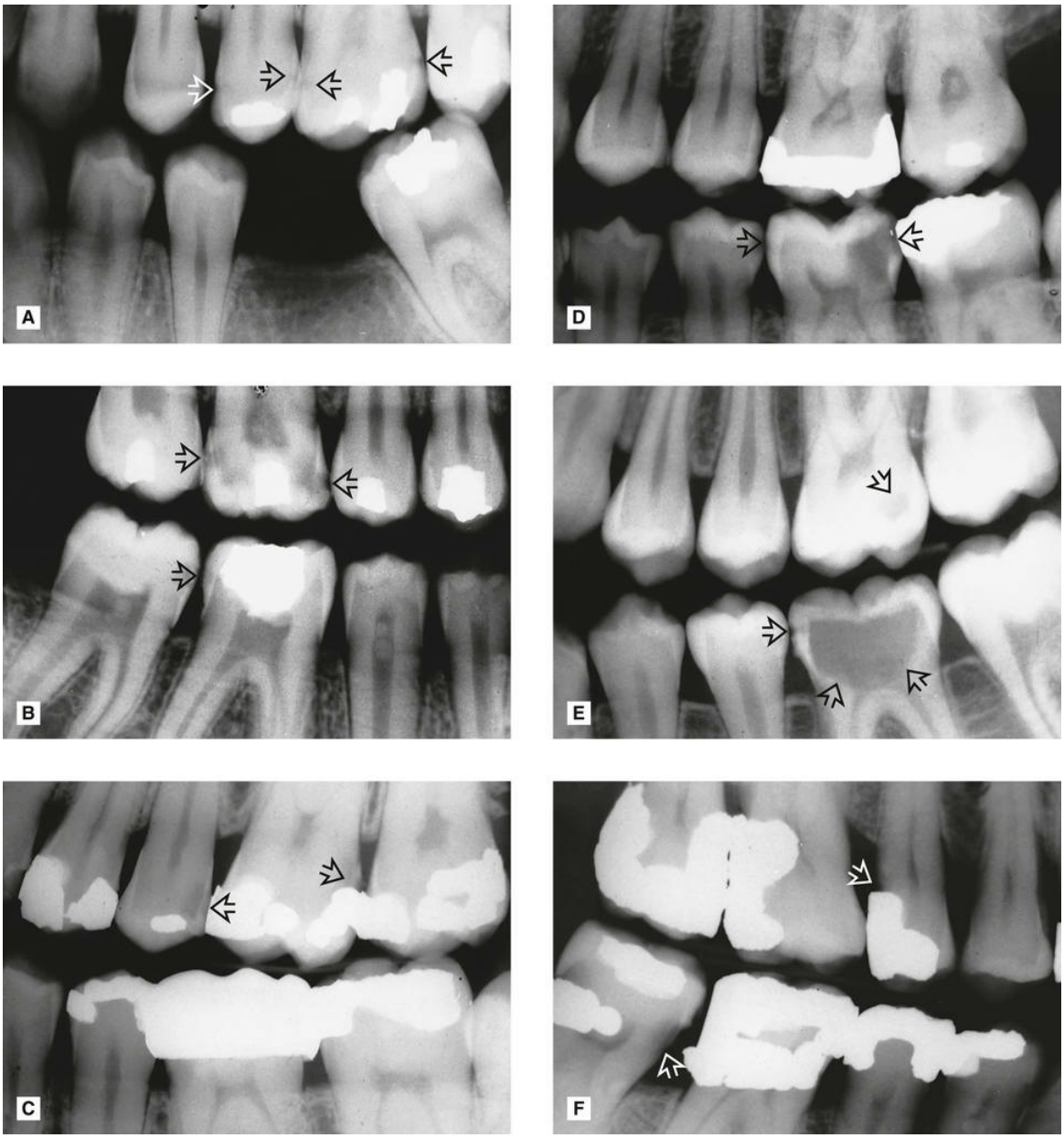


FIG. 20.3 Bitewing radiographs showing examples of typical carious lesions (arrowed). (A) Small proximal lesions $\lfloor\overline{56}$. (B) Large proximal lesions with extensive dentine involvement $6\rfloor$ and a small lesion $\overline{6}$. (C) Proximal lesion extending into dentine $\lfloor 5$ and caries associated with a restoration $\lfloor 6$. (D) Small and extensive proximal lesions $\lceil\overline{6}$. (E) Small occlusal lesion $\lfloor 6$ and extensive occlusal lesion $\lceil\overline{6}$; apart from the small proximal enamel lesion, the enamel cap appears intact. (F) Root caries $7\rceil$ and caries associated with a restoration $5\rfloor$.

Other Important Radiographic Appearances

Radiographic detection of carious lesions is not always straightforward. It can be complicated by:

- Residual caries
- Radiodensity of adhesive restorations
- Cervical *burn-out* or cervical translucency
- Dentinal changes beneath restorations.

Residual Caries

The rationale for the removal of caries has changed in recent years. The primary aim nowadays when excavating carious dentine is to remove only the highly infected, irreversibly demineralized dentine to allow effective restoration of the cavity and surface anatomy of the tooth and to prevent disease progression. In other words, demineralized tissue (*caries-affected dentine*) is retained in the base of the cavity and the tooth restored. Radiographically this *inactive caries* may show a zone of radiolucency beneath the restoration. This appearance is identical to that of an *active carious lesion* under a restoration (see Fig. 20.4).

Radiodensity of Adhesive Restorations

The development of successful adhesive restorative materials in recent years, including dentine-bonding agents and glass-ionomer cements, has resulted in many teeth being restored with non-metallic fillings. These various adhesive materials vary considerably in their radiodensity and do not appear as white on radiographic images as traditional amalgam, as shown in Fig. 20.5 . Identifying subtle radiolucent carious lesions adjacent to these materials can be very difficult, if not impossible.

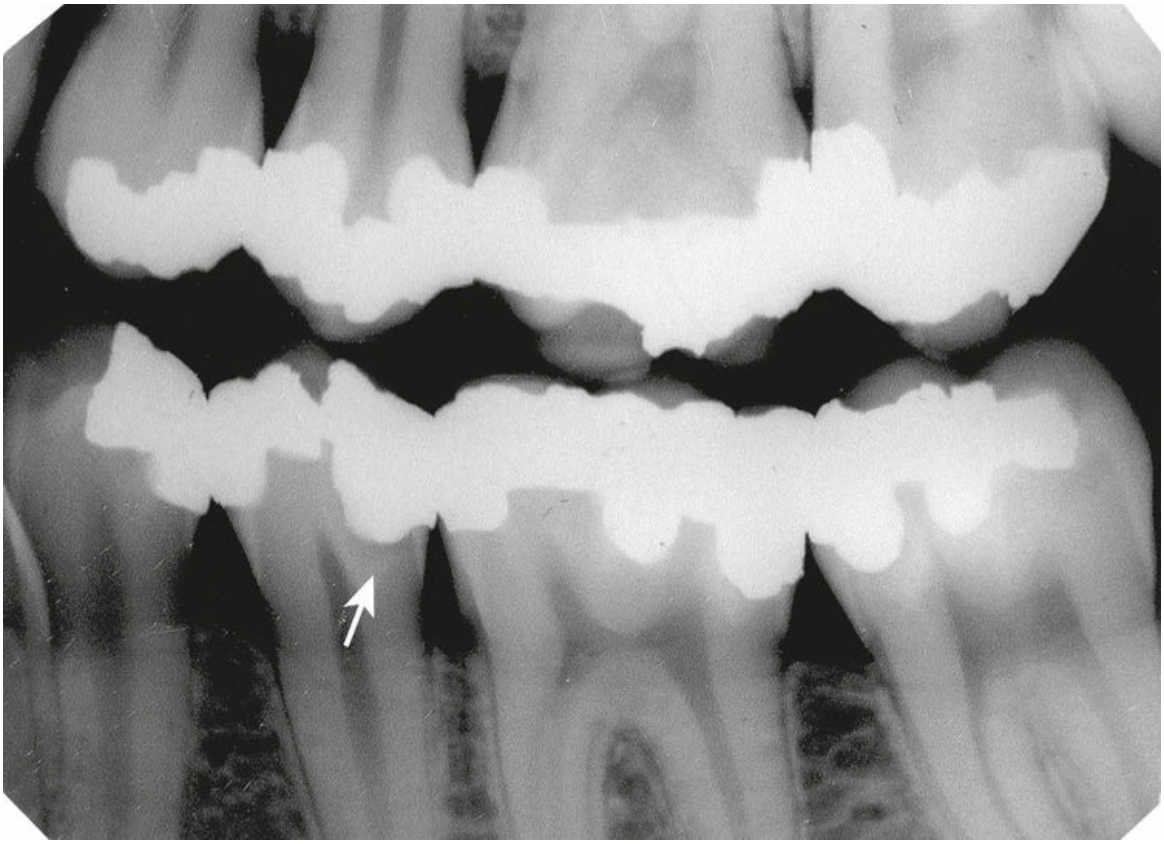


FIG. 20.4 Bitewing showing the radiolucency of residual caries beneath the restoration in ⌋5 (arrowed). It is impossible to assess whether the lesion is *active* or *inactive.*



FIG. 20.5 Left bitewing showing numerous posterior teeth that have been restored with adhesive restorations. Note: the restorations look less radiopaque than amalgam, and as a result the reduced contrast difference between dentine and restoration makes identification of adjacent radiolucent caries difficult.

Courtesy of Prof A. Banerjee.

Added to this, the radiodensities of contemporary dental adhesives, used to bond such materials to tooth structure, can also complicate the differential diagnosis of radiolucencies beneath these types of dental restorations.

Cervical Burn-out or Cervical Translucency

This radiolucent shadow is often evident at the neck of the teeth as illustrated in Fig. 20.6 . It is an artefactual phenomenon created by the anatomy of the teeth and the variable penetration of the X-ray beam.

Cervical *burn-out* can be explained by considering **all** the different parts of the tooth and supporting bone tissues that the same X-ray beam has to penetrate:

- In the crown – the dense enamel cap and dentine

- In the neck – only dentine
- In the root – dentine and the buccal and lingual plates of alveolar bone (see Fig. 20.7).

Thus, at the edges of the teeth in the cervical region, there is **less** tissue for the X-ray beam to pass through. Less attenuation therefore takes place and virtually no opaque shadow is cast of this area on the radiograph. It therefore appears radiolucent, as if some cervical tooth tissue does not exist or that it has been apparently *burnt-out.*

Cervical *burn-out* is of diagnostic importance because of its similarity to the radiolucent shadows of cervical caries and caries associated with restorations and sealants (CARS). However, *burn-out* can usually be distinguished by the following characteristic features:

- It is located at the neck of the teeth, demarcated above by the enamel cap or restoration and below by the alveolar bone level
- It is triangular in shape, gradually becoming less apparent towards the centre of the tooth
- Usually all the teeth on the radiograph are affected, especially the smaller premolars.

In contrast, root caries and caries associated with restorations and sealants (CARS), although they also often affect the cervical region, have no apparent upper and lower demarcating borders. These lesions are saucer-shaped and tend to be localized (see Fig. 20.2). If in doubt, the diagnosis should be confirmed clinically by direct vision and gentle probing having cleaned and dried the area.

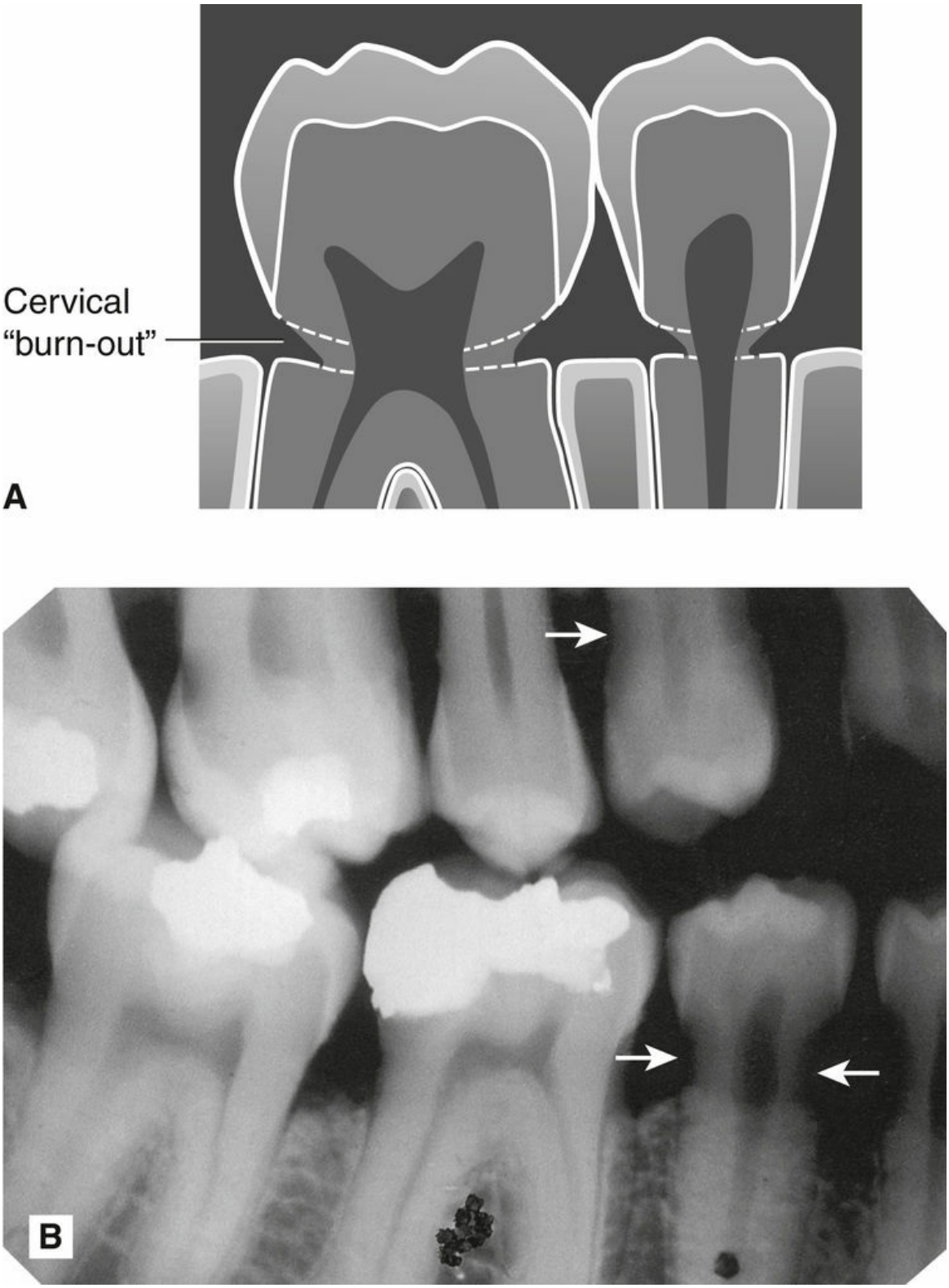


FIG. 20.6 (A) Diagram illustrating the radiographic appearance of cervical *burn-out.* (B) Bitewing radiograph showing extensive cervical *burn-out* of the premolars

(arrowed). Compare this with the appearance of cervical caries on distal aspect 6 .

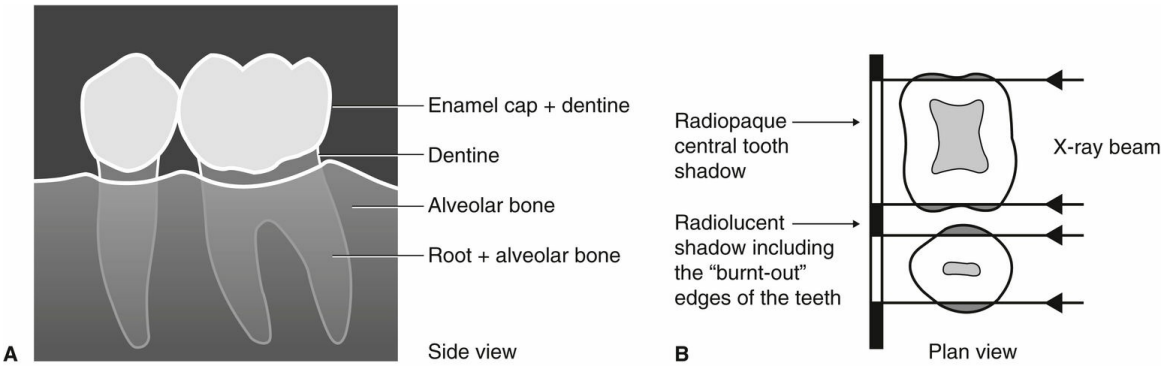


FIG. 20.7 (A) Diagrammatic representation of 56 from the side showing the three-dimensional structures involved in the formation of the radiographic image. Note that in the cervical region there is less tissue present. (B) Plan view at the level of the necks of the teeth. Through the centre of the teeth there is a large mass of dentine to absorb the X-ray beam, while at the edges there is only a small amount. The edges of the necks of the teeth are therefore not dense enough to stop the X-ray beam, so their normally opaque shadows do not appear on the final radiograph.

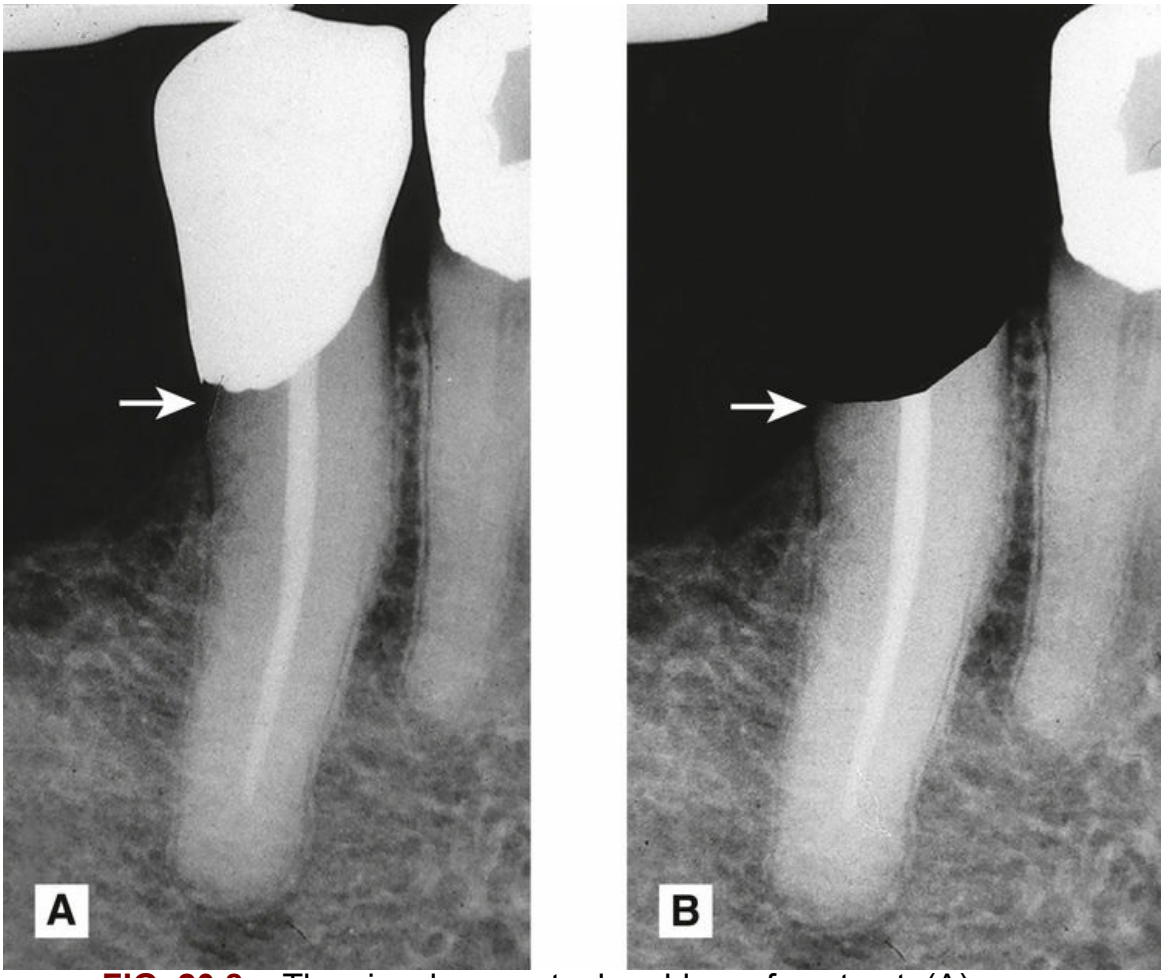


FIG. 20.8 The visual perceptual problem of contrast. (A) The zone at the distal cervical margin (arrowed), directly beneath the white metallic restoration shadow, appears radiolucent in the . (B) The same image but with the white restoration blacked out. The zone beneath the restoration (arrowed) now appears less radiolucent.

Important Points to Note

- *Burn-out* is more obvious when the exposure factors are increased, as required ideally for detecting proximal caries.
- It is also more apparent, by the perceptual problem of contrast, if the tooth contains a metallic restoration, which may make the zone above the cervical shadow completely radiopaque (see Fig. 20.8 ; see Chapter 1 and Fig. 1.16). As this area is also

the main site for caries associated with restorations and sealants (CARS) diagnosis is further complicated.

Dentine Changes Beneath Amalgam Restorations

Following attack by the caries process, posterior teeth are still commonly restored using dental amalgam. An *amalgam* is defined as an alloy of mercury with another metal or metals. In dental amalgam, mercury is mixed with an alloy powder. The alloy powders available principally contain silver, tin and copper with small amounts of zinc. It has been shown that, with time, tin and zinc ions are released into the underlying demineralized (but not necessarily infected) dentine producing a radiopaque zone within the dentine that follows the S-shaped curve of the underlying tubules (see Fig. 20.9). The radiopacity of this zone may make the normal dentine on either side appear more radiolucent by contrast. This somewhat more radiolucent normal dentine may simulate the radiolucent shadows of caries and lead to difficulties in diagnosis.

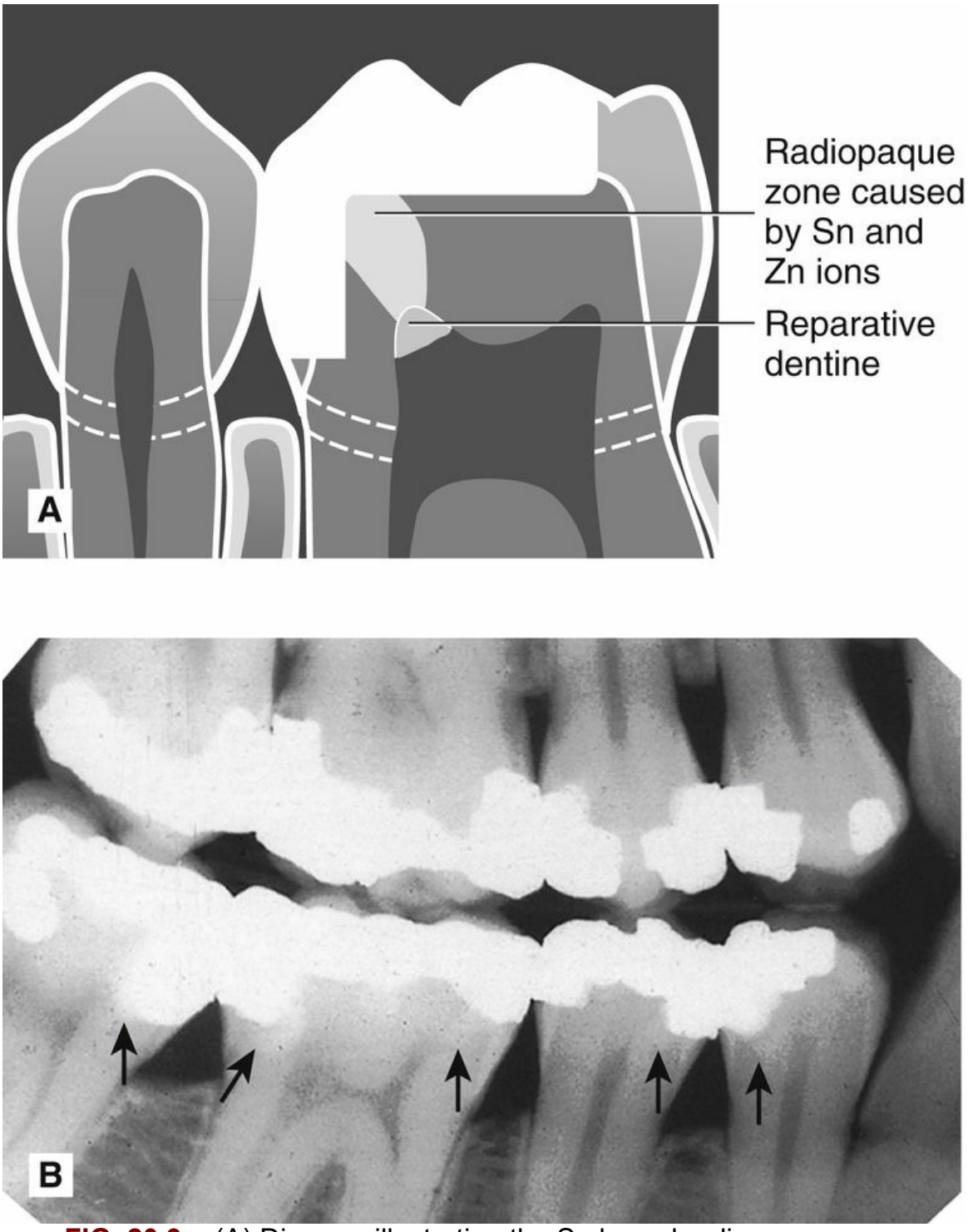


FIG. 20.9 (A) Diagram illustrating the S-shaped radiopaque zone caused by tin and zinc ions released into the underlying demineralized dentine beneath an amalgam restoration and the appearance of reparative dentine. (B) Bitewing radiograph showing the S-shaped radiopaque shadows (arrowed) in the heavily restored lower teeth.

In addition, the pulp may also respond to both the carious attack and subsequent restorative treatment by laying down *reparative tertiary dentine* which reduces the size of the pulp chamber.

Limitations Of Radiographic Detection of Caries

In addition to the problems of detection caused by the radiolucent and radiopaque shadows mentioned earlier, further limitations are imposed by the conventional two-dimensional radiographic image. The main problems include the following:

- Carious lesions are usually larger clinically than they appear radiographically and very early lesions are not evident at all.
- Radiography cannot accurately predict whether cavitation has taken place. This is important because operative treatment is often determined by the presence of cavitation. The deeper the lesion has progressed through the dentine, the more likely it is to have cavitated at the surface. Some authorities suggest that if the lesion has progressed radiographically more than one-third into dentine, then operative treatment is advised.
- Technique variations in image receptor and X-ray beam positions can affect considerably the image of the carious lesion – varying the horizontal tubehead angulation can make a lesion confined to enamel appear to have progressed into dentine (see Fig. 20.10) – hence the need for accurate, reproducible techniques as described in Chapter 10 .
- Exposure factors can have a marked effect on the overall radiographic contrast (see Fig. 20.11) on film-captured images and thus affect the appearance or size of carious lesions on the film.
- Superimposition and a two-dimensional image (digital or film) mean that the following features cannot always be determined:

– The exact site of a carious lesion, e.g. buccal or lingual
– The bucco-lingual extent of a lesion
– The distance between the carious lesion and the pulp horns; these two shadows can appear to be close together or even in contact but they may not be in the same plane
– The presence of an enamel lesion – the density of the overlying enamel may obscure the zone of decalcification
– The presence of caries adjacent to restorations may be completely obscured by the restoration (see Fig. 20.12).

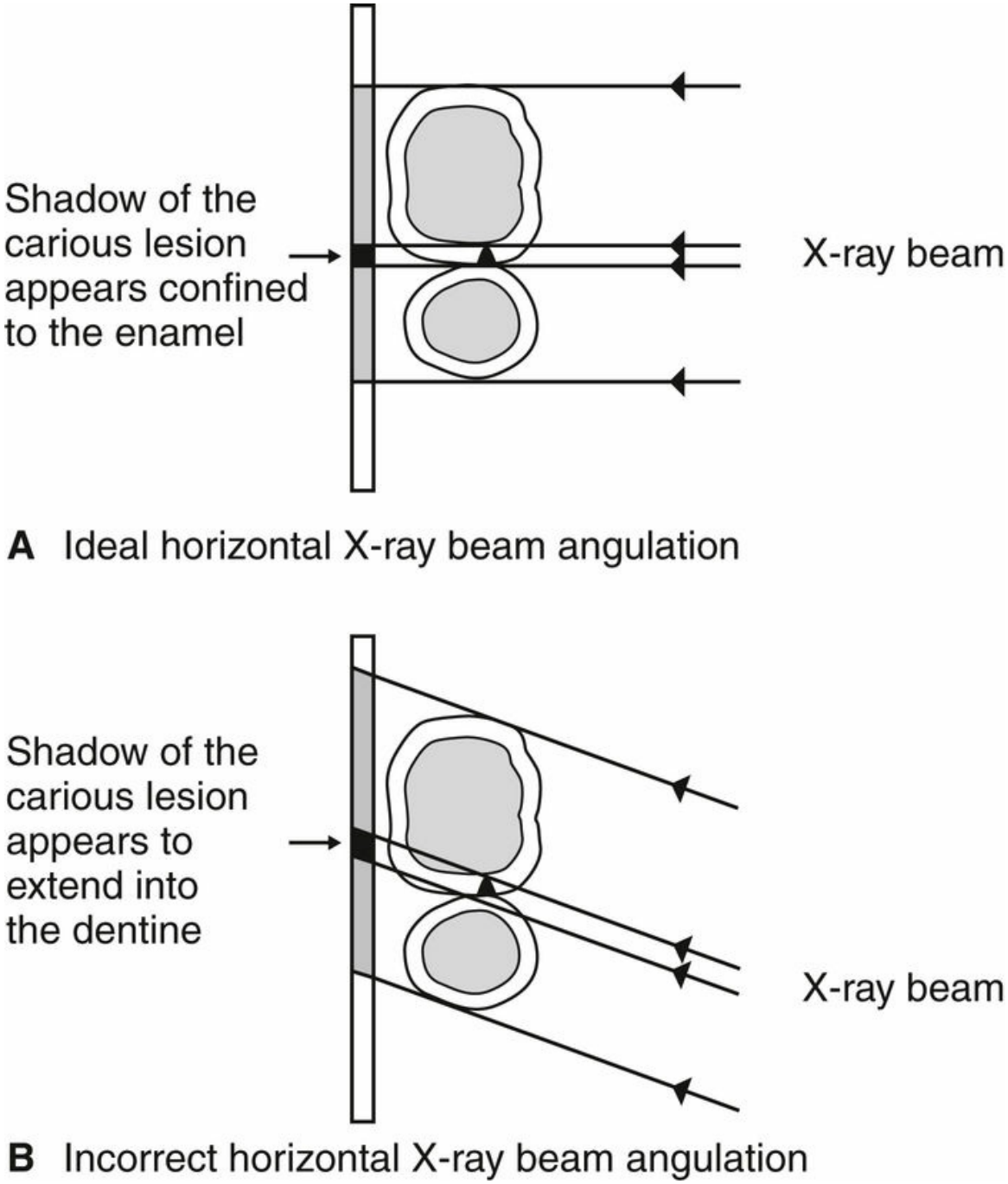


FIG. 20.10 Diagrams showing how the appearance and extent of a carious lesion confined to enamel alters with different horizontal X-ray beam angulations.

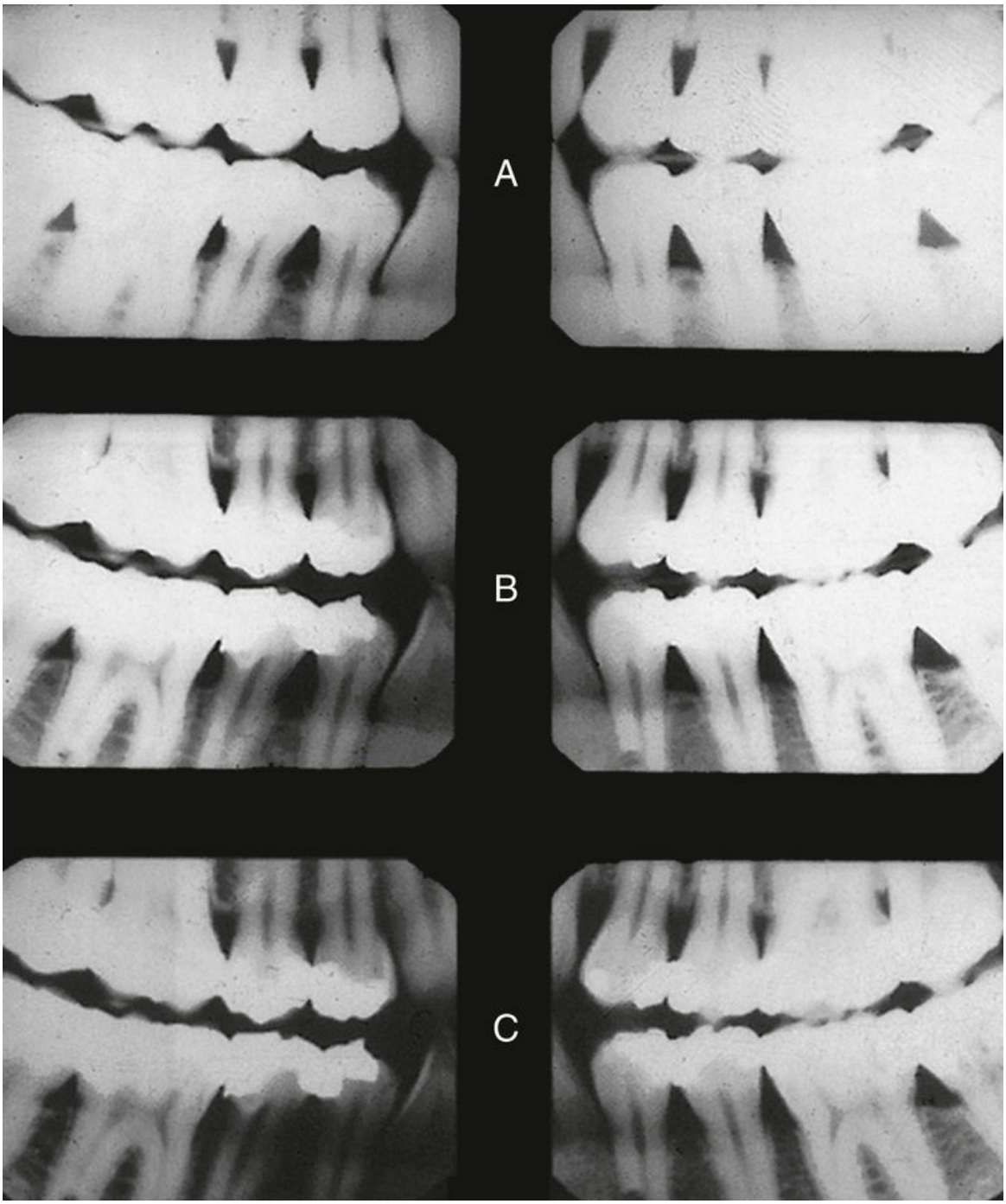


FIG. 20.11 Three pairs of film-captured bitewings taken with different exposure factors. (A) Considerably reduced exposure. (B) Slightly reduced exposure. (C) Slightly increased exposure. Note the varying contrast between enamel, dentine and the pulp.

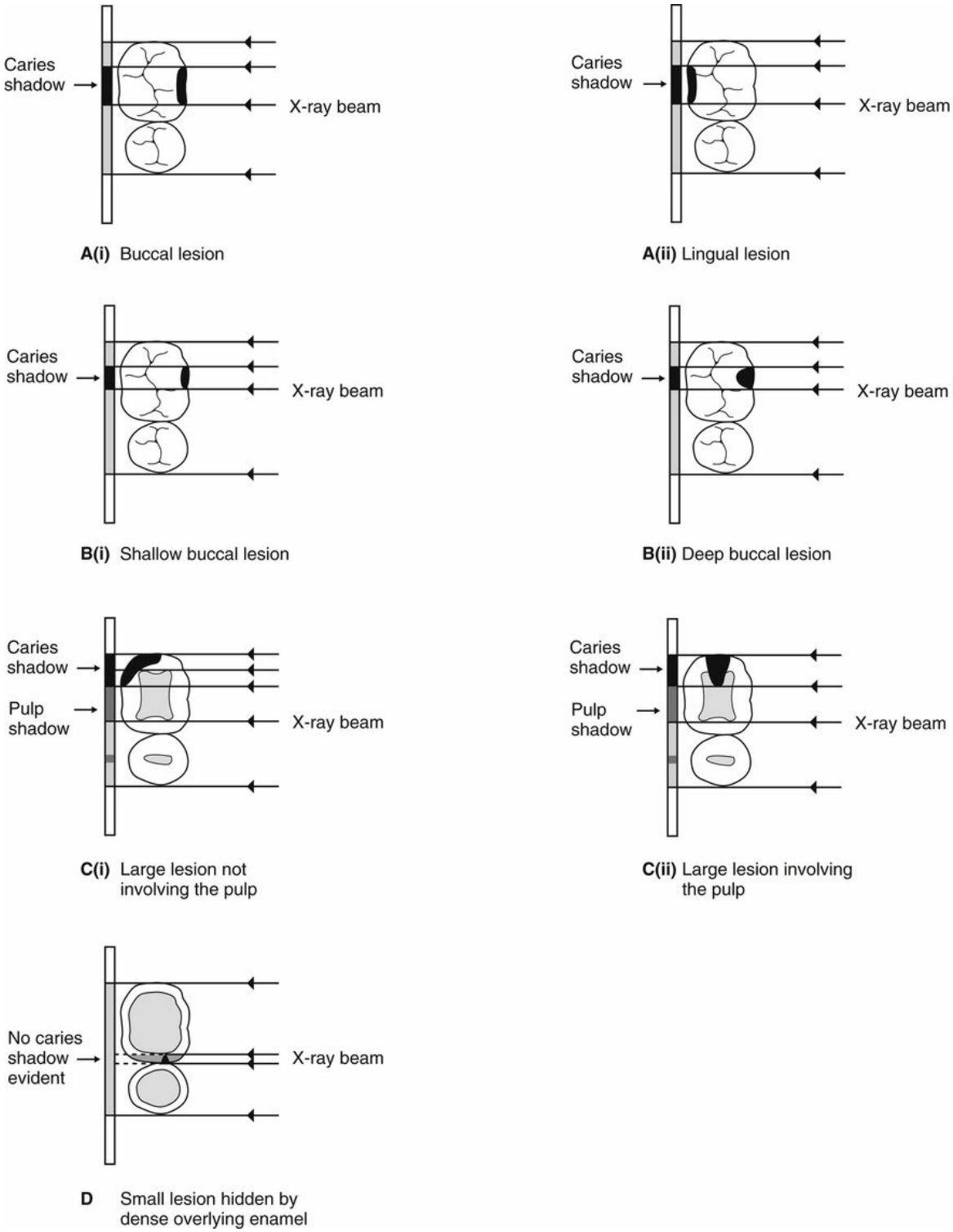


FIG. 20.12 (A) Diagrams showing differently positioned carious lesions – (i) buccal and (ii) lingual – producing similar radiographic shadows. (B) Diagrams showing different sized buccal lesions – (i) shallow and (ii) deep – producing similar radiographic shadows. (C) Diagrams showing (i) a large

proximal lesion superimposed over, but not involving the pulp and (ii) a large proximal lesion involving the pulp, both producing similar radiographic shadows. (D) Diagram showing how a small lesion may not be evident radiographically if dense radiopaque enamel shadows are superimposed.

Radiographic Assessment of Restorations

Critical Assessment of the Restoration

The important features to note include:

- The type and radiodensity of the restorative material, e.g.:
  - amalgam
  - cast metal
  - adhesive materials such as resin composite or glass-ionomer (see earlier and Fig. 20.5)
- Overcontouring
- Overhanging ledges
- Undercontouring
- Negative or reverse ledges
- The presence of contact points
- Adaptation of the restorative material to the base of the cavity
- Marginal fit of cast restorations
- The presence or absence of pulp protective material and/or a dental adhesive
- Radiodensity of the pulp protective material and/or a dental adhesive.

Assessment of the Underlying Tooth

The important features to note include:

- Caries associated with restorations and sealants (CARS)
- Residual caries (see earlier and Fig. 20.4)
- Radiopaque shadow of released tin and zinc ions (see earlier and Fig. 20.9)
- Size of the pulp chamber
- Internal resorption
- Presence of root-filling material in the pulp chamber
- Presence and position of pins or posts.

Examples showing several of these features are shown in Fig. 20.13 .

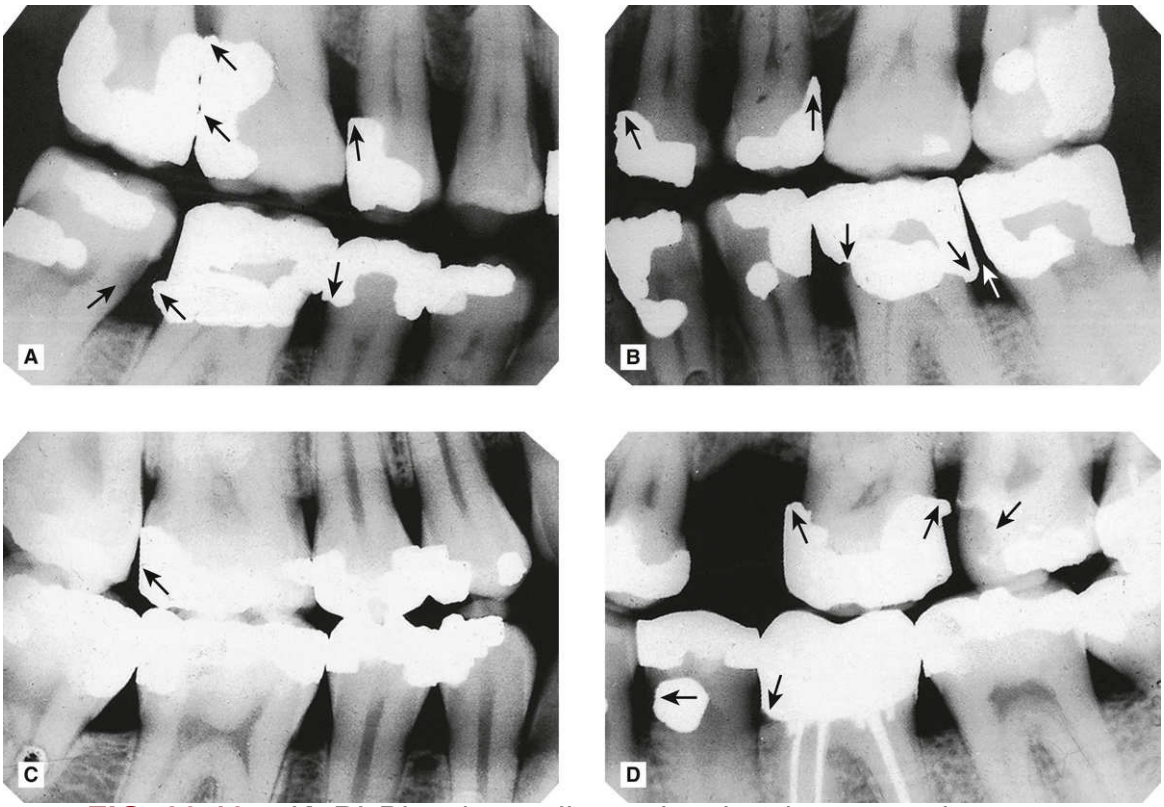
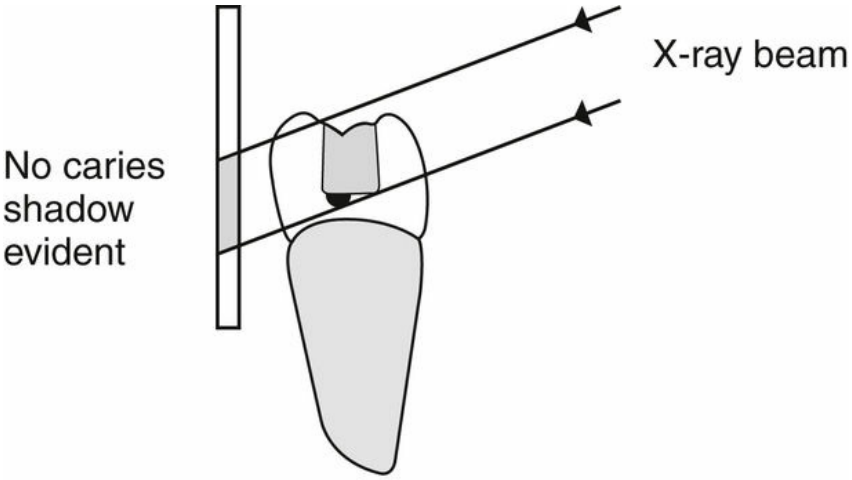


FIG. 20.13 **(A-D)** Bitewing radiographs showing examples of heavily restored teeth. The major areas of concern – overhanging ledges, poor contour, defective contact points and caries associated with restorations – are arrowed.

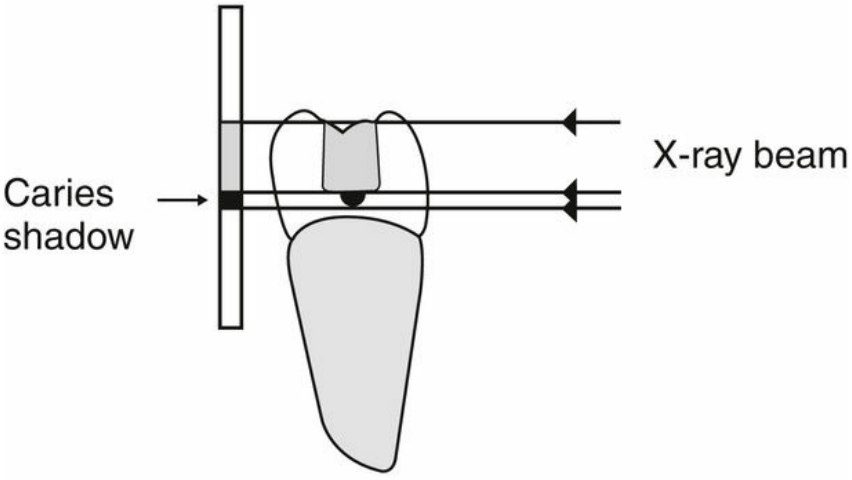
Limitations of the Radiographic Image

Once again, the radiographic image provides only limited information when assessing restorations. The main problems include:

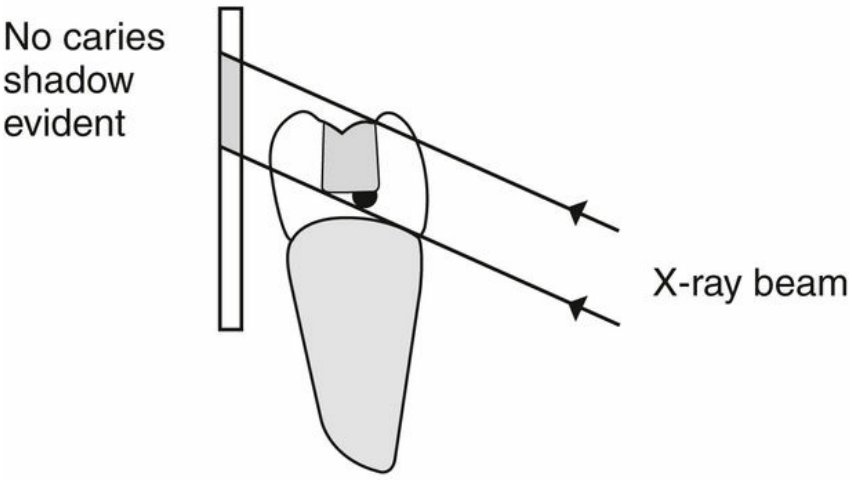
- Technique variations in X-ray tubehead position may cause caries associated with restorations and sealants (CARS) to be obscured (see Fig. 20.14)
- Cervical *burn-out* shadows tend to be more obvious when their coronal borders are demarcated by dense white restorations because of the increased contrast differences (see Fig. 20.8)



A Incorrect vertical X-ray beam angulation



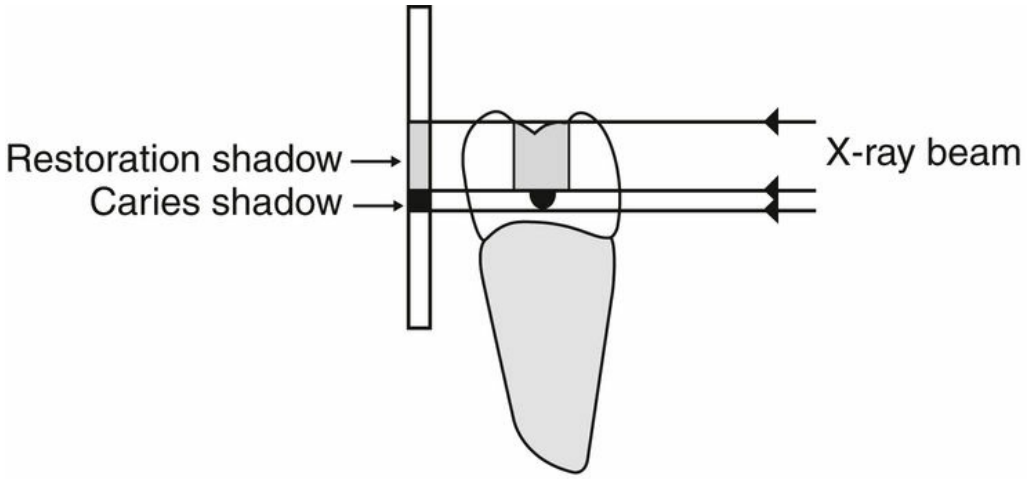
B Ideal vertical X-ray beam angulation



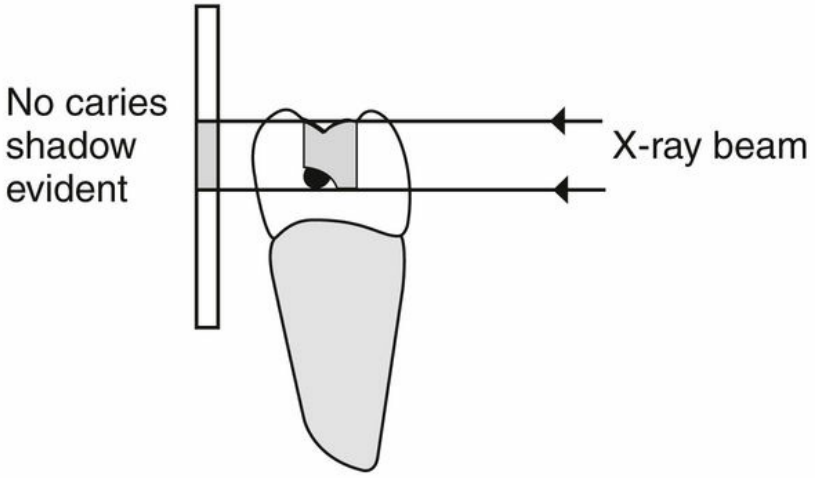
C Incorrect vertical X-ray beam angulation

FIG. 20.14 (A–C) Diagrams illustrating the effect of incorrect vertical X-ray beam angulation in diagnosing carious lesions adjacent to the base of a restoration box.

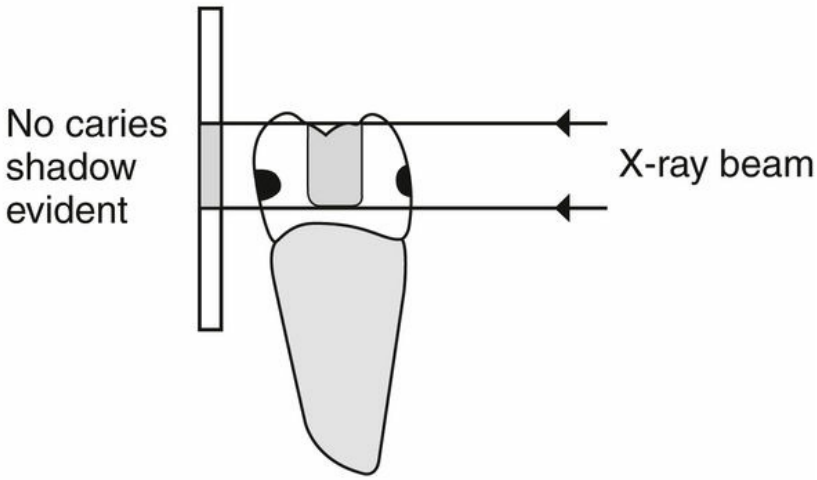
- Superimposition and a two-dimensional image mean that:
  - Only part of a restoration can be assessed radiographically
  - A dense radiopaque restoration may totally obscure a carious lesion in another part of the tooth
  - Caries adjacent to the base of an interproximal restoration box may not be detected (see Fig. 20.15).



A (i) Lesion beneath the restoration



A (ii) Lesion hidden by the restoration



B Buccal and lingual lesions hidden by the restoration

FIG. 20.15 (A) Diagrams illustrating the difficulty of assessing carious lesions beneath a restoration. (B) Diagram showing the difficulty of assessing buccal and lingual lesions in restored teeth.

Suggested Guidelines for Interpreting Bitewing Images

Overall Critical Assessment

A series of critical questions that should be asked about the quality of a bitewing image, based on the *ideal quality criteria* described in Chapter 10 , include questions on technique, exposure factors and image processing. Examples of typical questions are shown below.

Technique (Digital or Film-captured Images)

- Are all the required teeth shown?
- Are the crowns of upper and lower teeth shown?
- Is the occlusal plane horizontal?
- Are the contact areas overlapped?
- Has there been any *coning off* or *cone cutting?*
- Are the buccal and lingual cusps overlapped?
- Is it geometrically comparable to previous radiographs?

Exposure Factors (Film-captured Images)

- Is the image too dark – and so possibly overexposed?
- Is the image too light – and so possibly underexposed?
- Is the exposure sufficient to allow the enamel-dentine junction to be seen?
- What effect do the exposure factors have on the structures shown?
- How noticeable is the cervical burn-out?

Computer Processing (Digitally-captured Images)

- Is the contrast optimal?
- Is the brightness optimal?
- Is image enhancement optimal?
- Is magnification optimal?

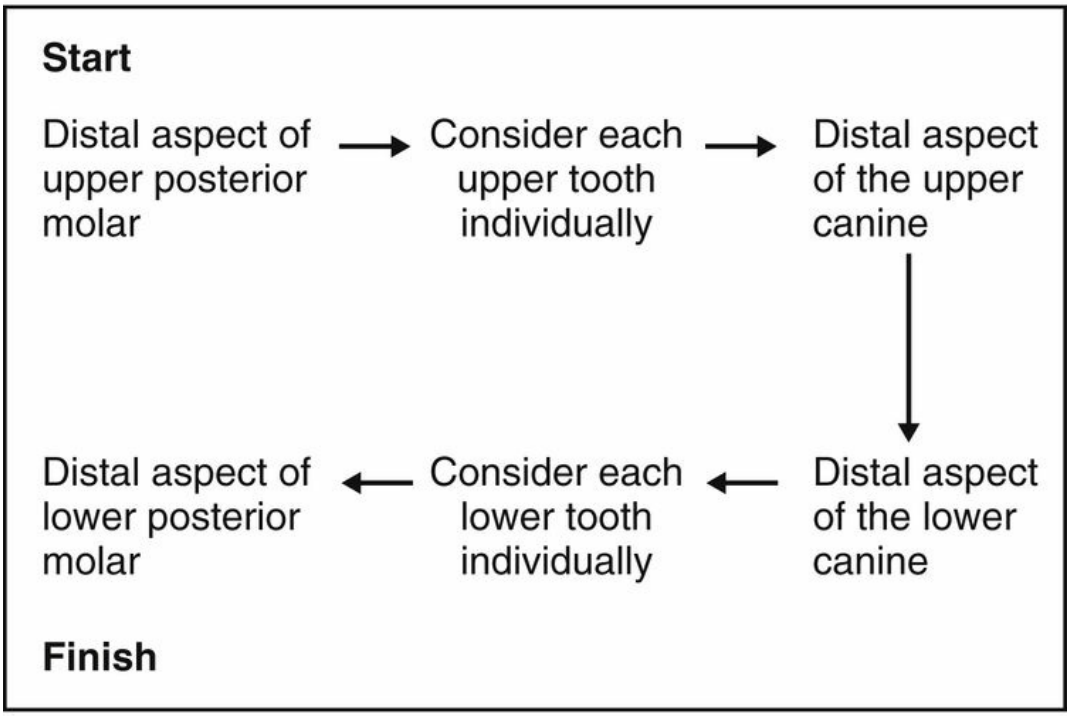
Chemical Processing (Film-captured Images)

- Is the radiograph correctly processed?
- Is it overdeveloped?
- Is it underdeveloped?
- Is it correctly fixed?
- Has it been adequately washed?

Systematic Viewing

Suggested systematic approaches to viewing bitewing radiographs are shown in Figs. 20.16 and 20.17 .


A


Start
Distal aspect of upper posterior molar
Consider each upper tooth individually
Distal aspect of the upper canine
Distal aspect of the lower canine
Consider each lower tooth individually
Distal aspect of lower posterior molar
Finish

B

FIG. 20.16 (A) Example of a right bitewing radiograph. (B) Suggested sequence for systematically viewing the right bitewing to ensure all teeth and individual tooth surfaces are examined.

Crown

1. Trace the outline of the edge of the enamel cap
2. Trace the outline of the enamel-dentine junction (EDJ)
3. Note any alteration in the outline shape, e.g. possible cavitation
4. Note any alteration in the interproximal enamel density, e.g. radiolucent triangular shadows caused by carious lesions
5. Note any alteration in the dentine density, e.g.:
   - Radiolucent saucer-shaped shadows of:
     (i) Proximal caries
     (ii) Occlusal caries
   - Radiolucent oval/round shadows of superimposed smooth-surface buccal/lingual caries
   - Radiopaque zones caused by zinc and tin ions
6. Note the presence and state of existing restorations, e.g.:
   - Overcontoured
   - Undercontoured
   - Adaptation
   - Ledges/overhangs
   - Adjacent caries (CARS)
7. Trace the outline/shape of the pulp chamber and note:
   - Size of the pulp chamber
   - Presence of reactionary dentine
   - Presence/number of pulp stones

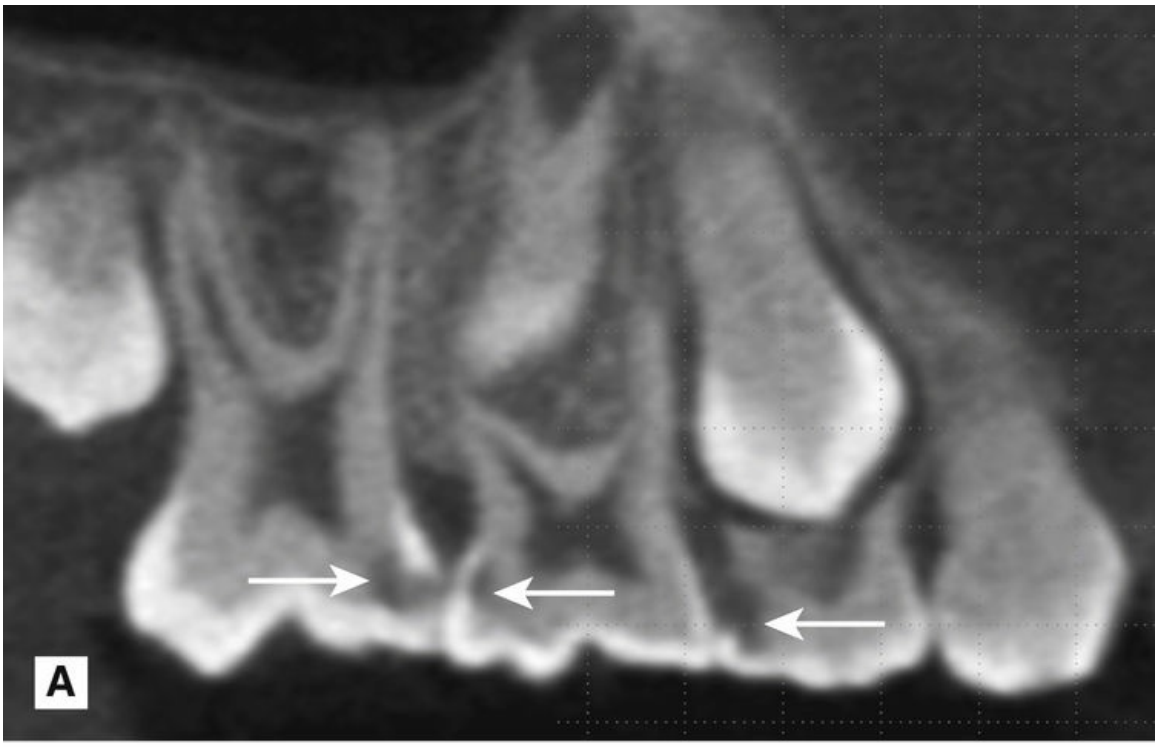
Neck/root

8. Trace the outline of the neck and cervical 1/3 of the root of the tooth
9. Note any alteration in the outline, e.g. possible cavitation caused by root caries
10. Note any alteration in the density of the root dentine, e.g.:
    - Radiolucent saucer-shaped shadow of root caries
    - Radiolucent triangular-shaped shadows of cervical burn-out or cervical translucency

FIG. 20.17 Suggested sequence for examining each individual tooth.

Cone Beam Computed Tomography

In the absence of existing amalgam restorations, cone beam computed tomography (CBCT) has been shown to be more sensitive in the detection of proximal caries than traditional two-dimensional imaging. It has also been shown to be better at demonstrating cavitation than plain views. However, existing restorations cause significant artefacts that can mimic caries and mask real carious lesions (see Fig. 20.18). In addition, the radiation dose from CBCT is higher than conventional radiography and the equipment is more expensive. For these reasons, CBCT cannot be recommended to be used routinely for caries detection, but if a CBCT scan has been performed of the teeth and jaws, and there are no restorations present, then the images should be examined for carious lesions.


A

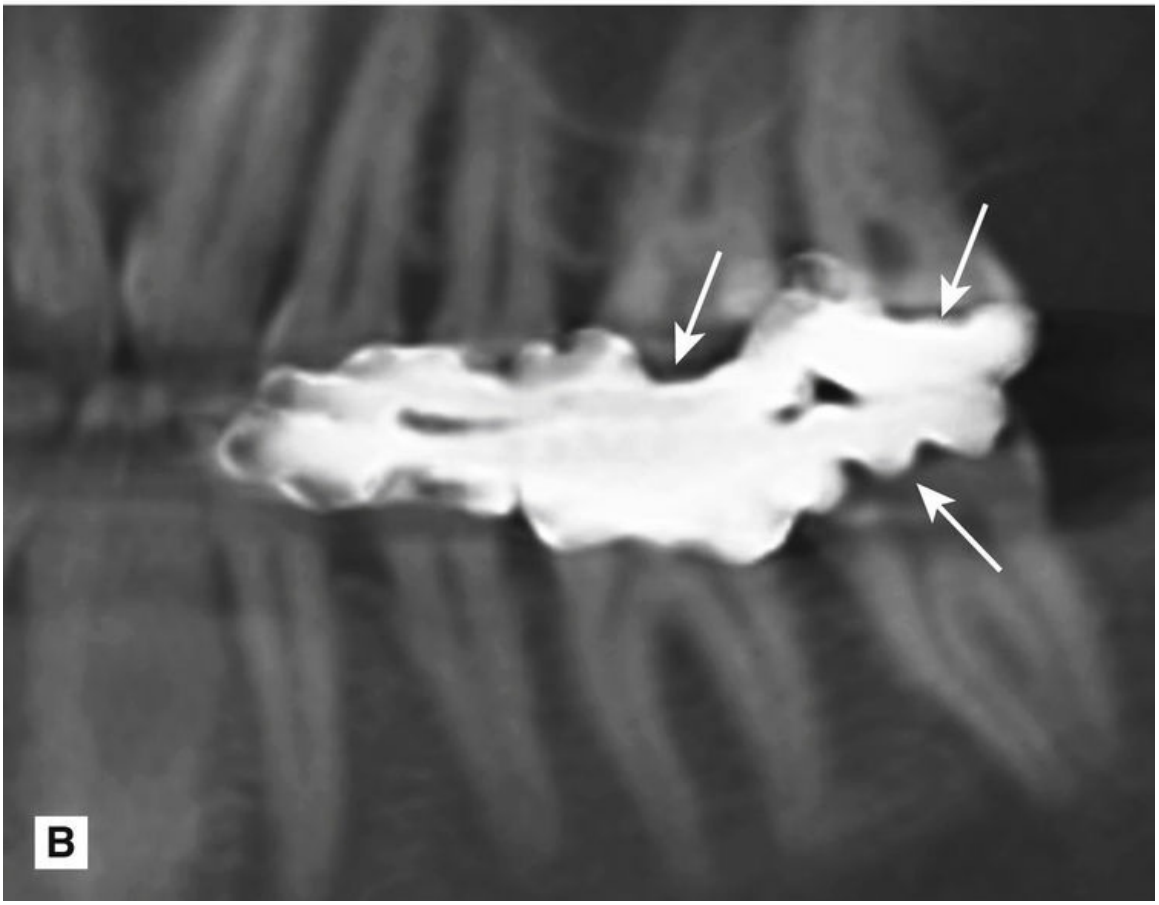

B

FIG. 20.18 (A) CBCT scan showing proximal carious lesions (arrowed). (B) CBCT scan showing numerous amalgam restorations and the resultant radiolucent artefacts (arrowed) mimicking the appearance of CARS.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

21

The Periapical Tissues

Introduction

This chapter explains how to interpret the radiographic appearances of the periapical tissues by illustrating the various normal appearances, as shown on conventional periapical and panoramic radiographs, and describing in detail the typical changes associated with apical infection and inflammation following pulpal necrosis. To help explain the different radiographic appearances, they are correlated with the various underlying pathological processes. In addition, there is a summary of the other, sometimes sinister, lesions that can affect the periapical tissues and may simulate simple inflammatory changes.

A reminder of the complex three-dimensional anatomy of the hard tissues surrounding the teeth in the mandible and maxilla, which contributes to the two-dimensional periapical and panoramic radiographic image, originally illustrated in Chapter 1 , is shown in Fig. 21.1 .

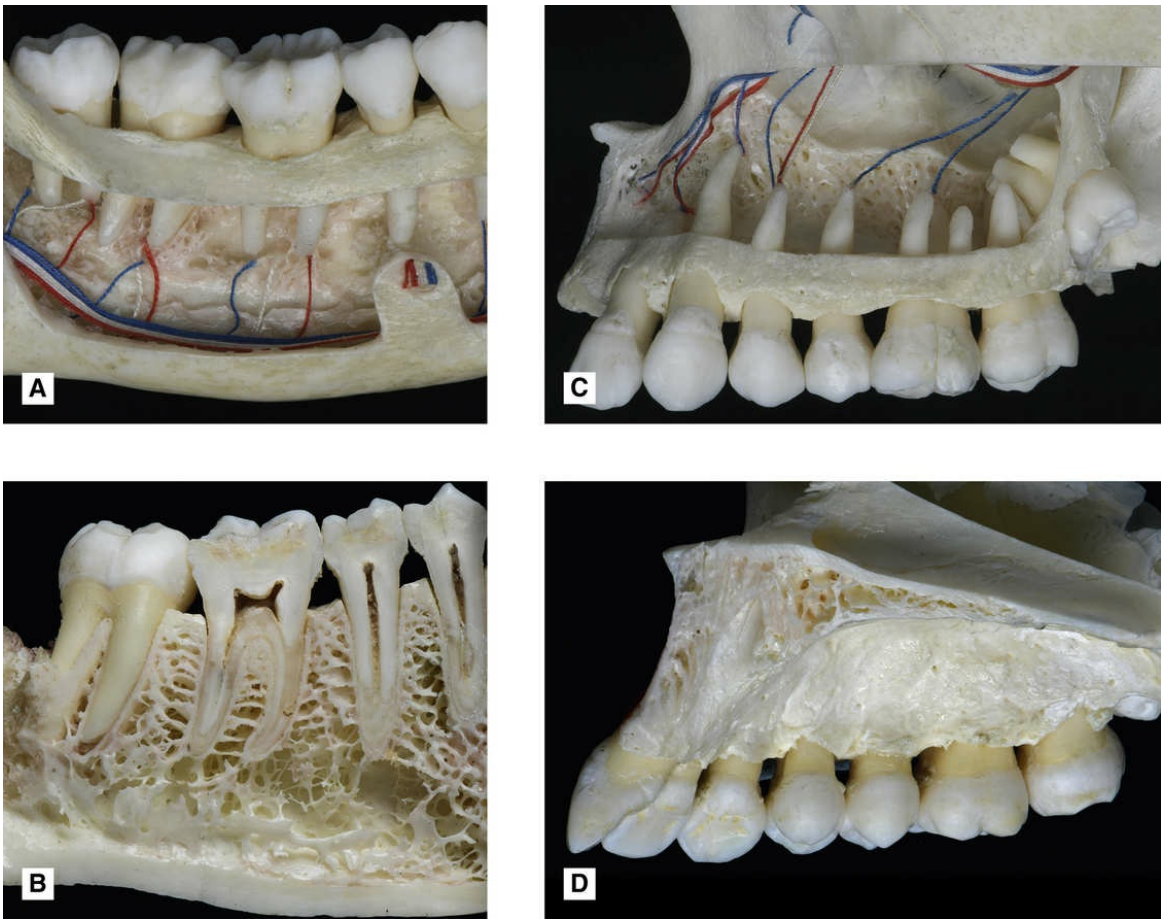


FIG. 21.1 Photographs showing the three-dimensional bony anatomy surrounding the teeth **(A, B)** in the mandible and **(C, D)** in the maxilla.

Normal Radiographic Appearances

The appearances of normal, healthy, periapical tissues vary from one patient to another, from one area of the mouth to another and at different stages in the development of the dentition. These different normal appearances are described below.

The Periapical Tissues of Permanent Teeth

The three most important features to observe are shown in Fig. 21.2 and include:

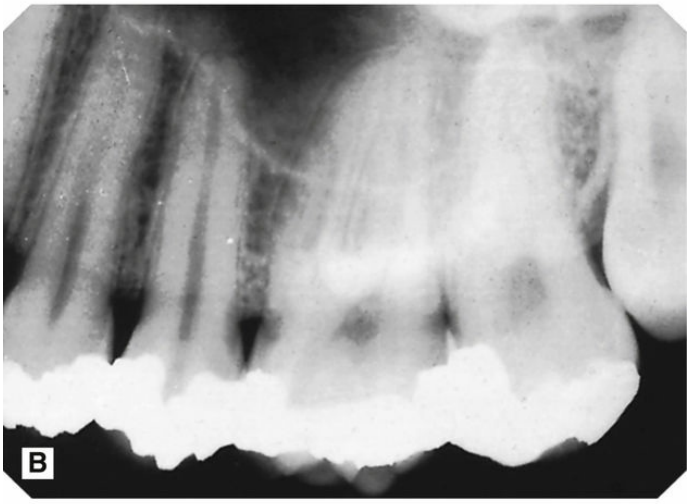
- The radiolucent line that represents the periodontal ligament space and forms a thin continuous *black* line around the root outline
- The radiopaque line that represents the lamina dura of the bony socket and forms a thin, continuous, *white* line adjacent to the black line
- The trabecular pattern and density of the surrounding bone:
    - In the mandible, the trabeculae tend to be relatively thick and close together, and are often aligned horizontally
    - In the maxilla, the trabeculae tend to be finer, and more widely spaced. There is no predominant alignment pattern.

These features hold the key to the interpretation of periapical radiographs, since changes in their thickness, continuity and radiodensity reflect the presence of any underlying disease, as described later.

Important Points to Note

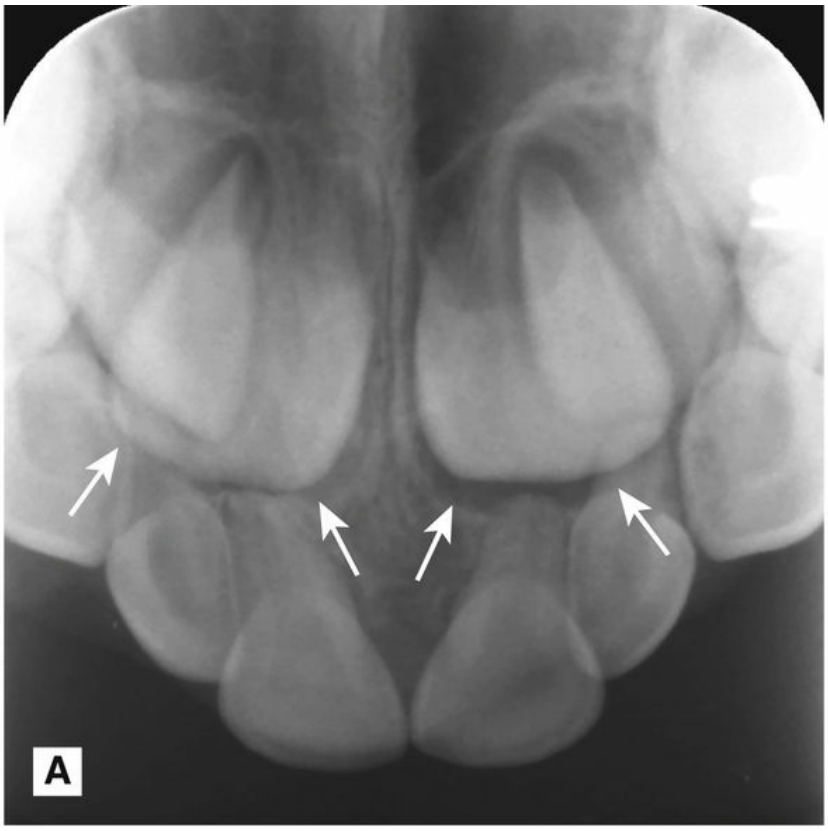
- There is considerable variation in the definition and pattern of these features from one patient to another and from one area of the jaws to another, owing to variation in the density, shape and thickness of the surrounding bone.
- The limitations imposed by contrast, resolution and superimposition can make radiographic identification of these features particularly difficult, hence the need for ideal viewing conditions and digital image enhancement software.


A


B


C

FIG. 21.2 Periapical radiographs of (A) 32 , (B) 4567 , and (C) 765 showing the normal radiographic anatomy of the periapical tissues in different parts of the jaws. Note the thin *black* line of the periodontal ligament space and the *white* line of the lamina dura outlining the roots.


A

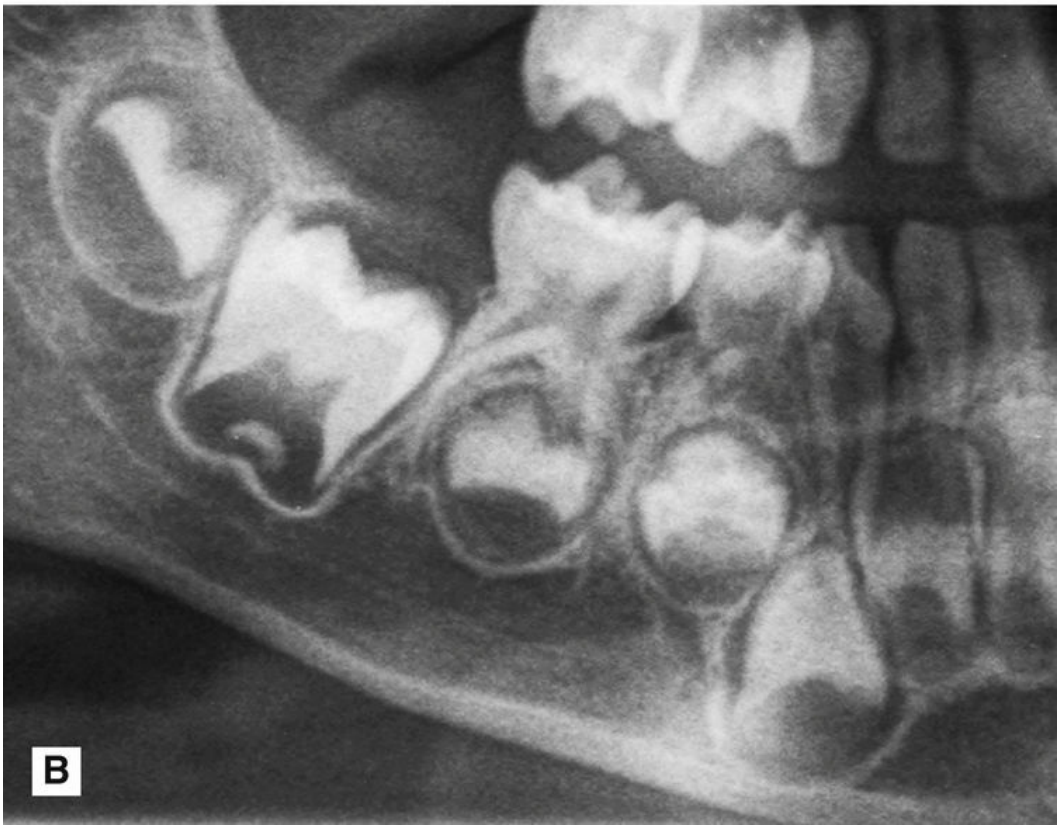

B

FIG. 21.3 (A) Periapical radiograph of $\underline{BA|AB}$ in a 4-year-old child showing normal periapical tissues. Note the confusing shadows created by the radiopaque crowns and radiolucent follicles (arrowed) of the developing permanent incisors. (B) Part of a panoramic radiograph of a 5-year-old child showing the normal periapical tissues of $\overline{EDC|}$.

The Periapical Tissues of Deciduous Teeth

The important features of normality (thin lamina dura and periodontal ligament shadows) are the same as for permanent teeth as shown in Fig. 21.3 , but can be complicated by:

- The presence of an underlying permanent tooth and its crypt, the shadows of which may overlie the deciduous tooth apex
- Resorption of the deciduous tooth root during the normal exfoliation process.


A

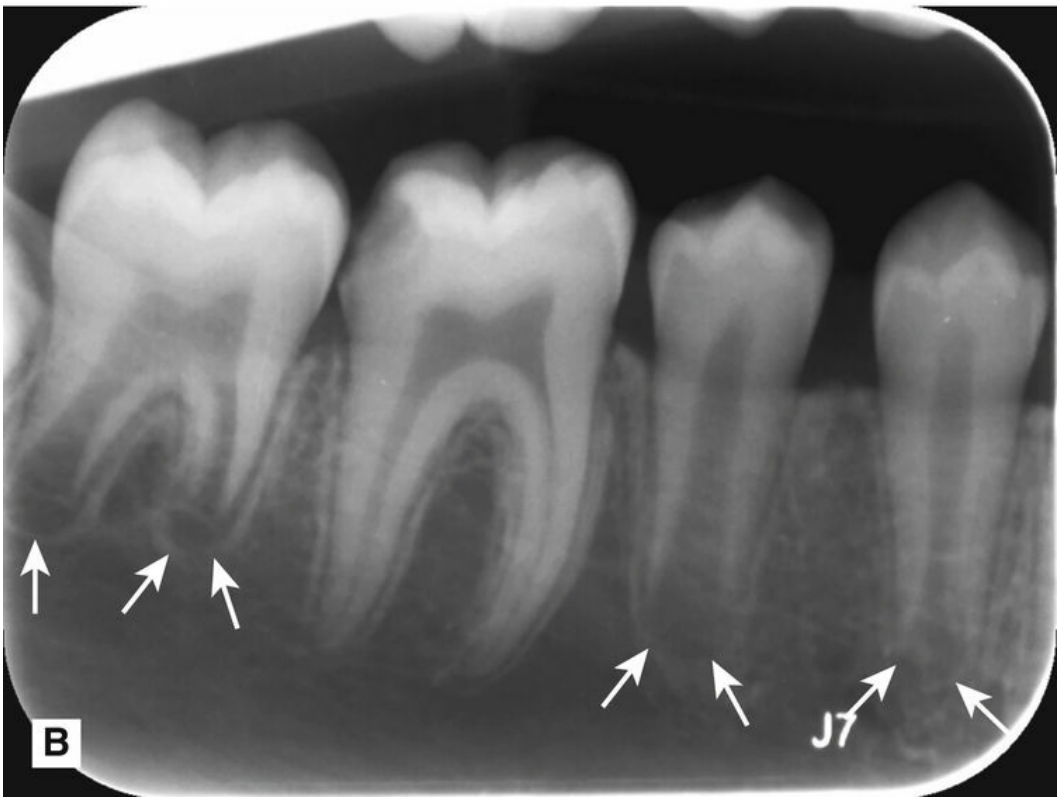

B
J

FIG. 21.4 (A) Part of a panoramic radiograph showing the normal developing periapical tissues of the $\overline{8|}$. (B) Periapical radiograph showing the normal developing periapical tissues of the $\overline{7\,5\,4|}$. Note the circumscribed area of radiolucency of the radicular papillae (arrowed) and the funnel-shaped roots.

The Periapical Tissues of Developing Teeth

The important features or normal apical tissues (see Fig. 21.4), where the root is partially formed and the radicular papilla still exists, include:

- A circumscribed area of radiolucency at the apex
- The radiopaque line of the lamina dura is intact around the papilla
- The developing root is funnel-shaped
- Only after root development is complete does the thin continuous radiolucent line become evident.

The Effects of Normal Superimposed Shadows

Normal anatomical shadows superimposed on the apical tissues can be either *radiolucent* or *radiopaque,* depending on the structure involved.

Radiolucent Shadows

Examples include:

- The maxillary antra
- The nasopalatine foramen
- The mental foramina.

Such cavities in the alveolar bone decrease the total amount of bone

that would normally contribute to the final radiographic image, with the following effects:

- The radiolucent line of the periodontal ligament may appear MORE radiolucent or widened, but will still be continuous and well-demarcated
- The radiopaque line of the lamina dura may appear LESS obvious and may not be visible
- There will be an area of radiolucency in the alveolar bone at the tooth apex (see Figs. 21.5 and 21.6).

Important Points to Note

- The fact that the radiopaque lamina dura shadow may not be visible does not mean that the bony socket margin is not present clinically. It only means that there is now not enough total bone in the path of the X-ray beam to produce a visible opaque shadow. Since the bony socket is in fact intact, it still defines the periodontal ligament space. Thus, the radiolucent line representing this space still appears continuous and well-demarcated.
- Although confusing, this effect of normal anatomical radiolucent shadows on the apical tissues is very important to appreciate, so as not to mistake a normal area of radiolucency at the apex for a pathological lesion.

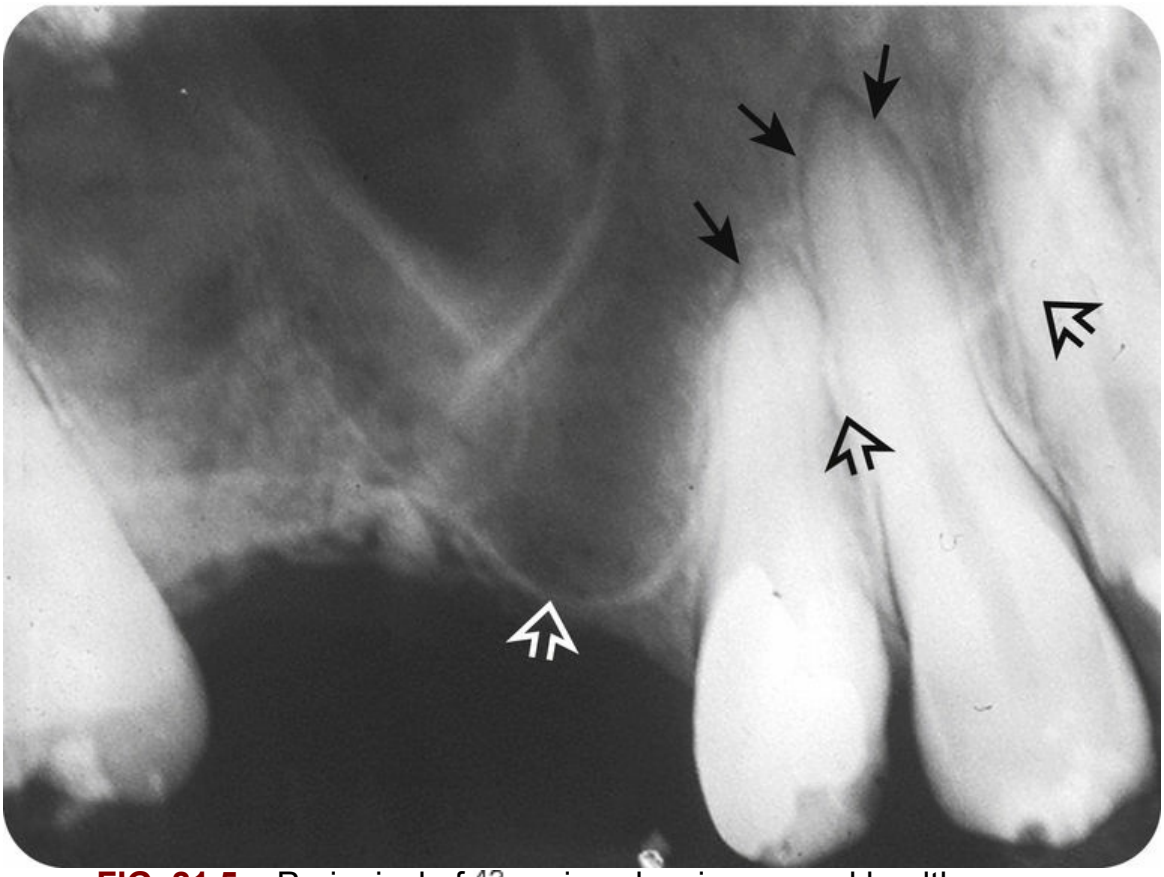


FIG. 21.5 Periapical of 43 region showing normal healthy apical tissues but with the radiolucent shadow of the antrum superimposed (the antral floor is indicated by the open arrows). As a result the radiolucent line of the periodontal ligament seems to be widened and more obvious around the apices of the canine and premolar, but it is still well-demarcated, while the radiopaque line of the lamina dura is almost invisible (solid arrows).

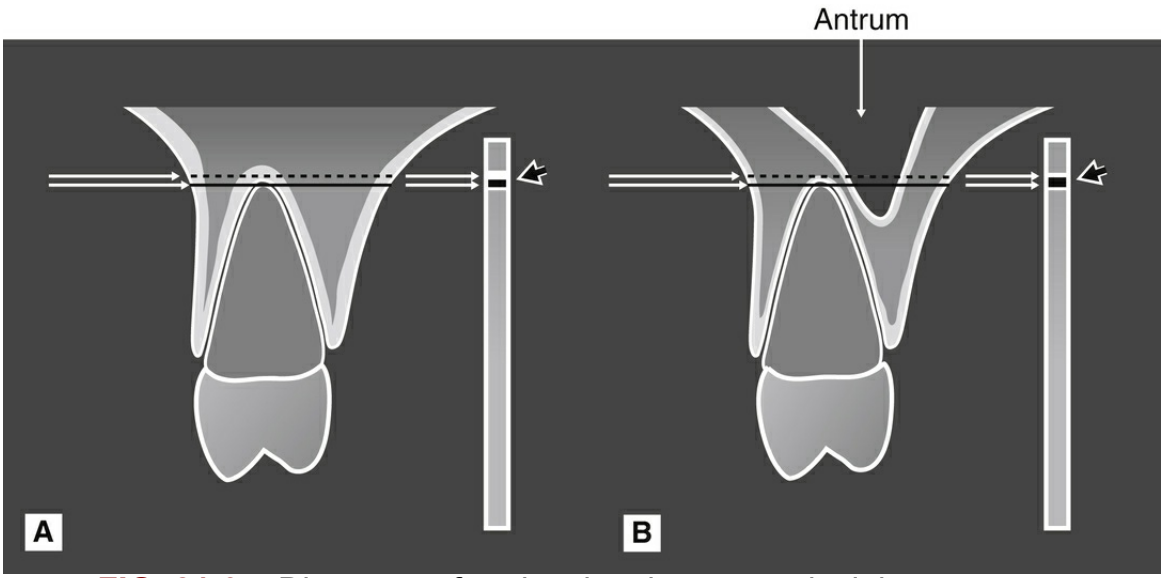


FIG. 21.6 Diagrams of 5 showing the anatomical tissues that the X-ray beam has to pass through to reach the image receptor. (A) Without a normal anatomical cavity superimposed. (B) With the antral cavity in the path of the X-ray beam. The different thicknesses of the resultant *white* lines of the lamina dura and the *black* lines of the periodontal ligament space are shown on the image receptors (arrowed).

Radiopaque Shadows

Examples include:

- The mylohyoid ridge
- The body of the zygoma
- Areas of sclerotic bone (so-called *dense bone islands*).

Such radiopacities complicate periapical interpretation by obscuring or obliterating the detailed shadows of the apical tissues as shown in Fig. 21.7 .

Radiographic Appearances of Periapical Inflammatory Changes

Types of Inflammatory Changes

After pulpal necrosis, either an acute or chronic inflammatory response is initiated in the apical tissues – identical to that set up elsewhere in the body from other toxic stimuli.

Cardinal Signs of Acute Inflammation

These include:

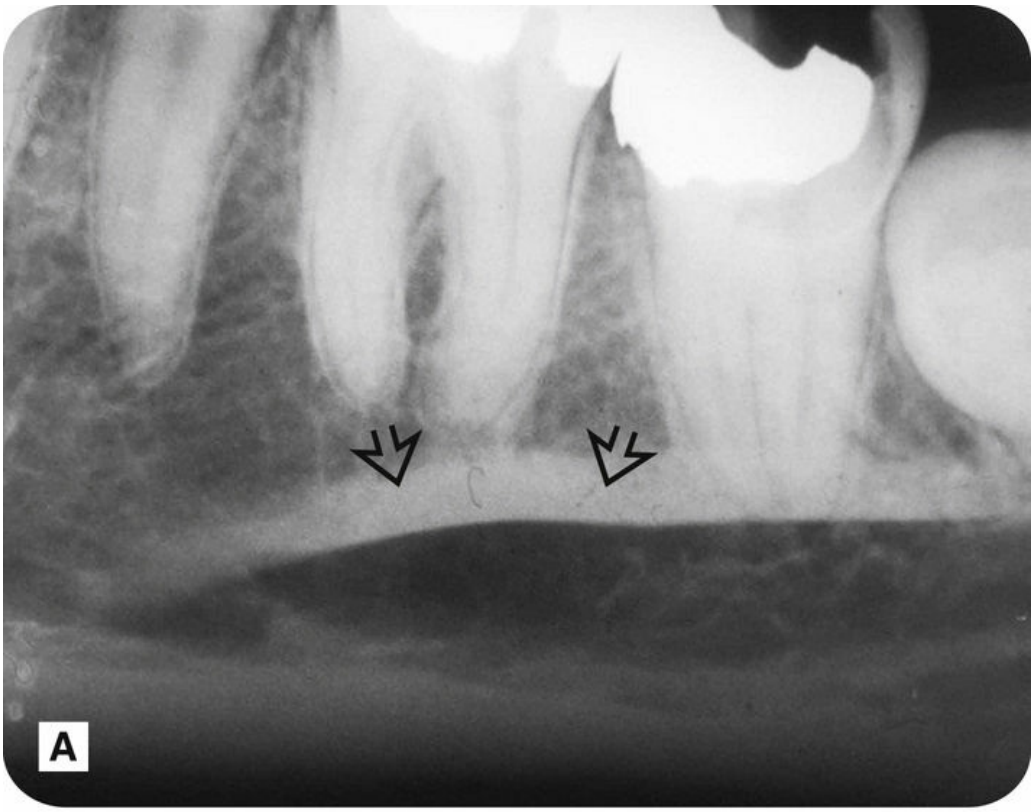
- Swelling – *tumour*
- Redness – *rubor*
- Heat – *calor*
- Pain – *dolor*
- Loss of function – *functio laesa.*

In the apical tissues, inflammatory exudate accumulates in the apical periodontal ligament space *(swelling),* setting up an **acute apical periodontitis** . The affected tooth becomes periostitic or tender to pressure *(pain),* and the patient avoids biting on the tooth *(loss of function). Heat* and *redness* are clinically undetectable. These signs are accompanied by destruction and resorption of the surrounding bone and occasionally of the tooth root, as a **periapical abscess develops** , and radiographically a periapical radiolucent area becomes evident.

Hallmarks of Chronic Inflammation

These include the processes of *destruction* and *healing* , which are going on simultaneously, as the body's defence systems respond to, and try to confine, the spread of the infection. In the apical tissues, a **periapical granuloma** forms at the apex and dense bone starts to be laid down around the area of resorption. Radiographically, the apical radiolucent area becomes circumscribed and surrounded by dense sclerotic bone *(sclerosing osteitis)* . Occasionally, under these conditions of chronic inflammation, the epithelial cell rests of Malassez are stimulated to proliferate and give rise to an inflammatory periapical

radicular cyst (see Chapter 26) or there is an acute exacerbation producing another abscess (the so-called *phoenix abscess*).


A

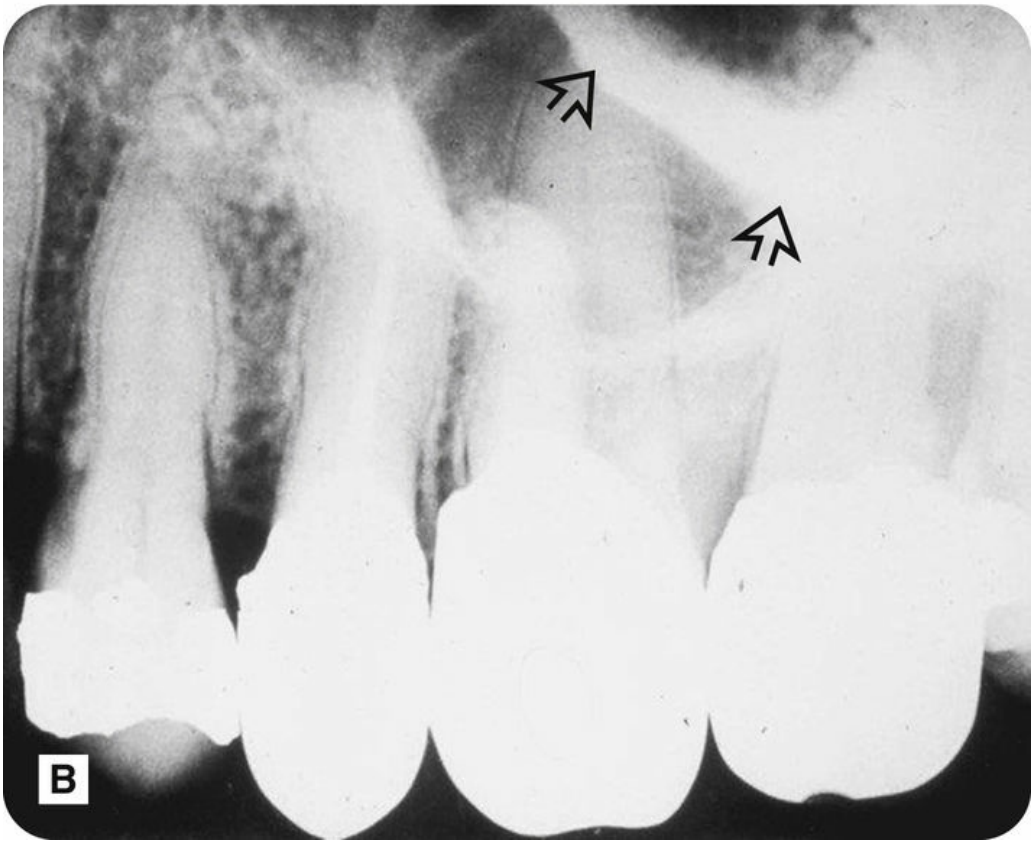

B

FIG. 21.7 Periapicals showing superimposed radiopaque shadows overlying the apical tissues. (A) Mylohyoid ridge obscuring 7 . (B) Zygomatic buttress obscuring 4567 .

The type and progress of the inflammatory response at the apex and the subsequent spread of apical infection is dependent on several factors relating to:

- The infecting organism, including its virulence
- The body's defence systems.

A summary of the different inflammatory effects and the resultant spectrum of radiographic appearances is presented in Table 21.1 . The effects are shown diagrammatically in Fig. 21.8 . Various examples are shown in Figs. 21.9 –21.12 .

TABLE 21.1

Summary of the effects of different inflammatory processes on the periapical tissues and the resultant radiographic appearances

State of inflammation	Underlying inflammatory changes	Radiographic appearances
Initial acute inflammation	Inflammatory exudate accumulates in the apical periodontal ligament space – *acute apical periodontitis*	Widening of the radiolucent line of the periodontal ligament space OR no apparent changes evident
Initial spread of inflammation	Resorption and destruction of the apical bony socket – *periapical abscess*	Loss of the radiopaque line of the lamina dura at the apex
Further spread of inflammation	Further resorption and destruction of the apical alveolar bone	Area of bone loss at the tooth apex
Initial low-grade chronic inflammation	Minimal destruction of the apical bone. The body's defence systems lay down dense bone in the apical region	No apparent bone destruction but dense sclerotic bone evident around the tooth apex *(sclerosing osteitis)*
Latter stages of chronic inflammation	Apical bone is resorbed and destroyed and dense bone is laid down around the area of resorption – *periapical granuloma* or *radicular cyst*	Circumscribed, well-defined radiolucent area of bone loss at the apex, surrounded by dense sclerotic bone

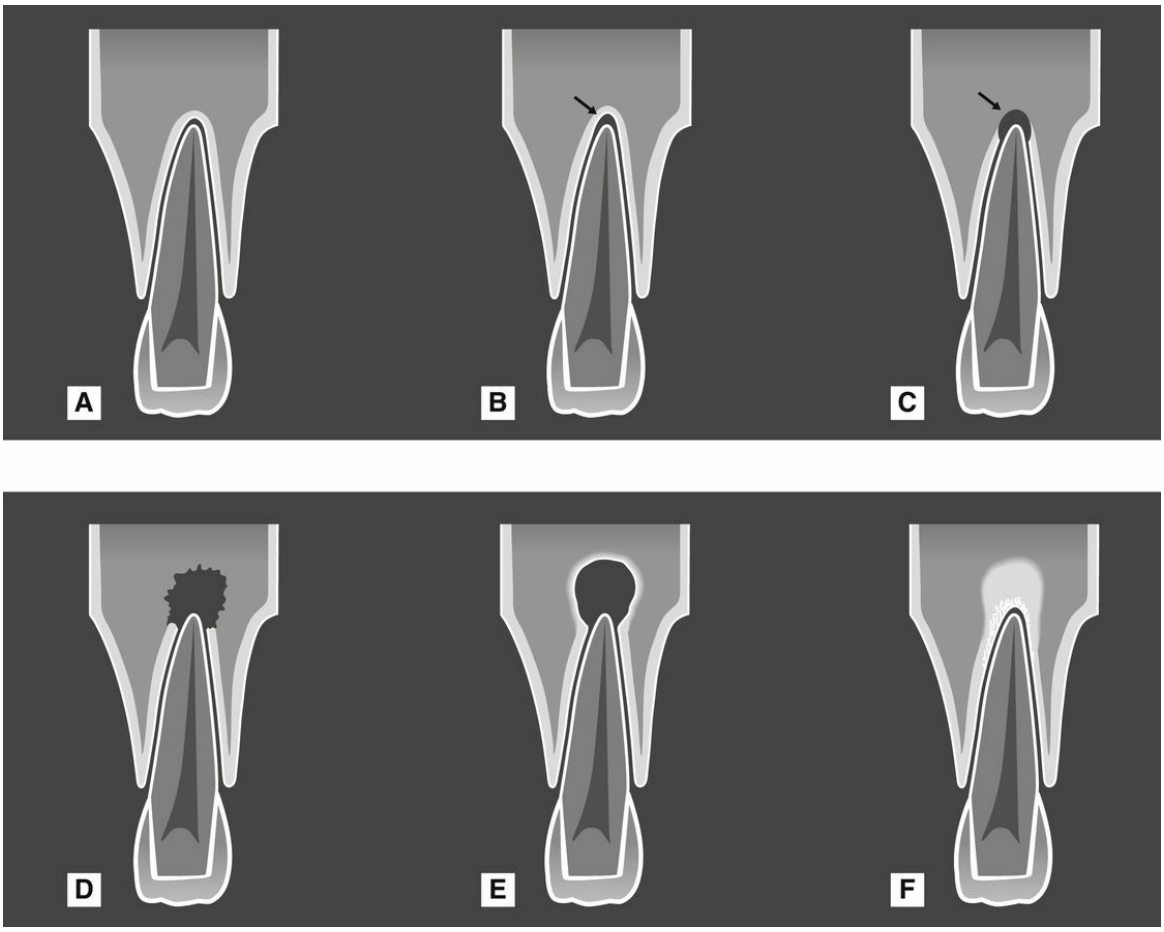


FIG. 21.8 The various radiographic appearances of infection and inflammation in the apical tissues. (A) Normal. (B) Early apical change – widening of the radiolucent periodontal ligament space (*acute apical periodontitis*) (arrowed). (C) Early apical change – loss of the radiopaque lamina dura (*early periapical abscess*) (arrowed). (D) Extensive destructive acute inflammation – diffuse, ill-defined area of radiolucency at the apex (*periapical abscess*). (E) Longstanding chronic inflammation – well-defined area of radiolucency surrounded by dense sclerotic bone (*periapical granuloma or radicular cyst*). (F) Low-grade chronic inflammation – diffuse radiopaque area at the apex (*sclerosing osteitis*).

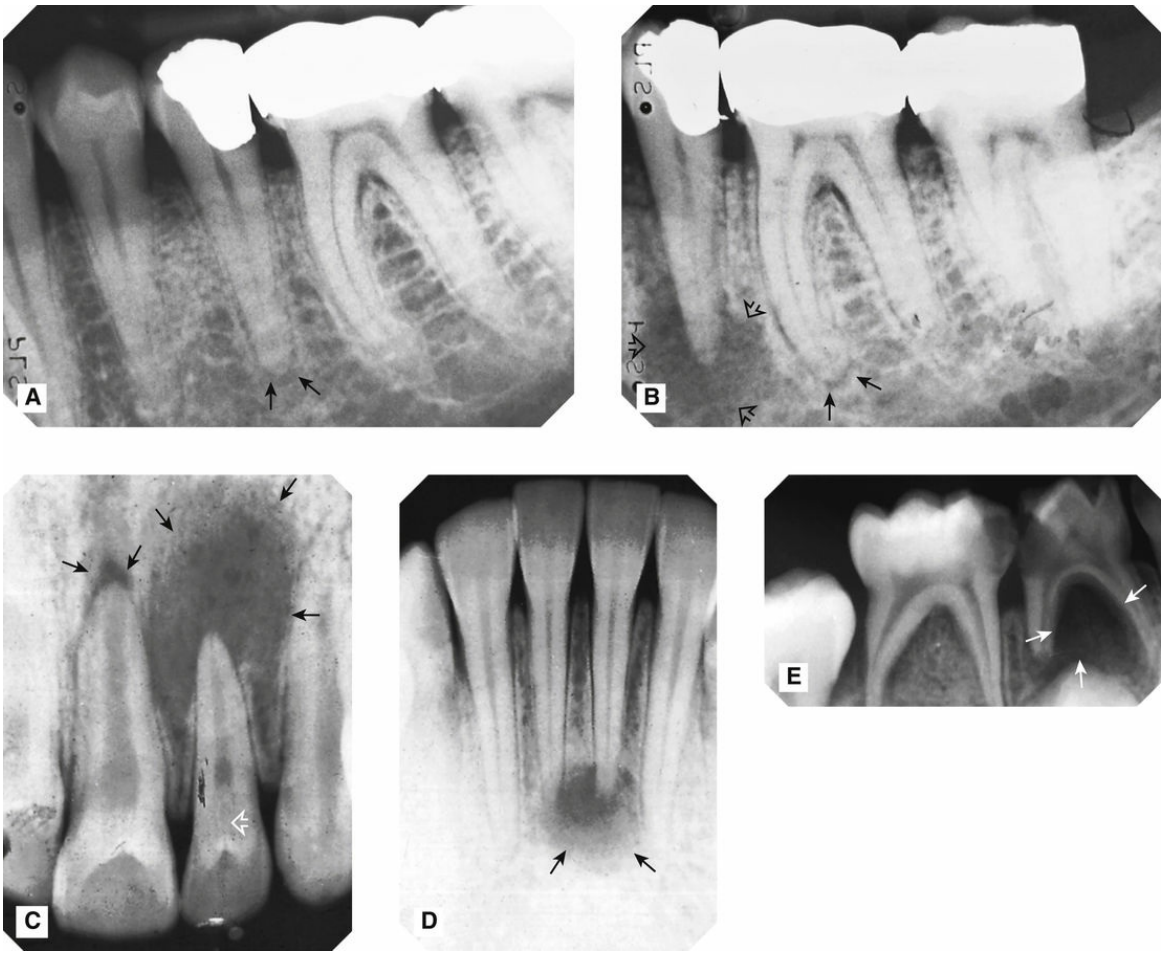


FIG. 21.9 Periapicals showing examples of inflammatory changes in the periapical tissues. (A) Early apical change on ⌊5 showing widening of the periodontal ligament space and thinning of the lamina dura (*acute apical periodontitis*) (arrowed). (B) Same patient 6 months later – the area of bone destruction at the apex ⌊5 has increased considerably (open arrows) and there is now early apical change associated with the mesial root ⌊6 (solid arrows). (C) Large, diffuse area of bone destruction associated with ⌊2 and a smaller area associated with ⌈1 (black arrows) (*periapical abscess*). ⌊2 shows evidence of a dens-in-dente (invaginated odontome) (open white arrow). (D) Reasonably well-defined area of bone destruction (arrowed) associated with ⌈1 (*periapical abscess, granuloma or cyst*). (E) Large area of bone destruction associated with ⌐D (*periapical abscess*). Note: with deciduous molars, bone destruction is typically intra-radicular (arrowed) rather than around the apices.

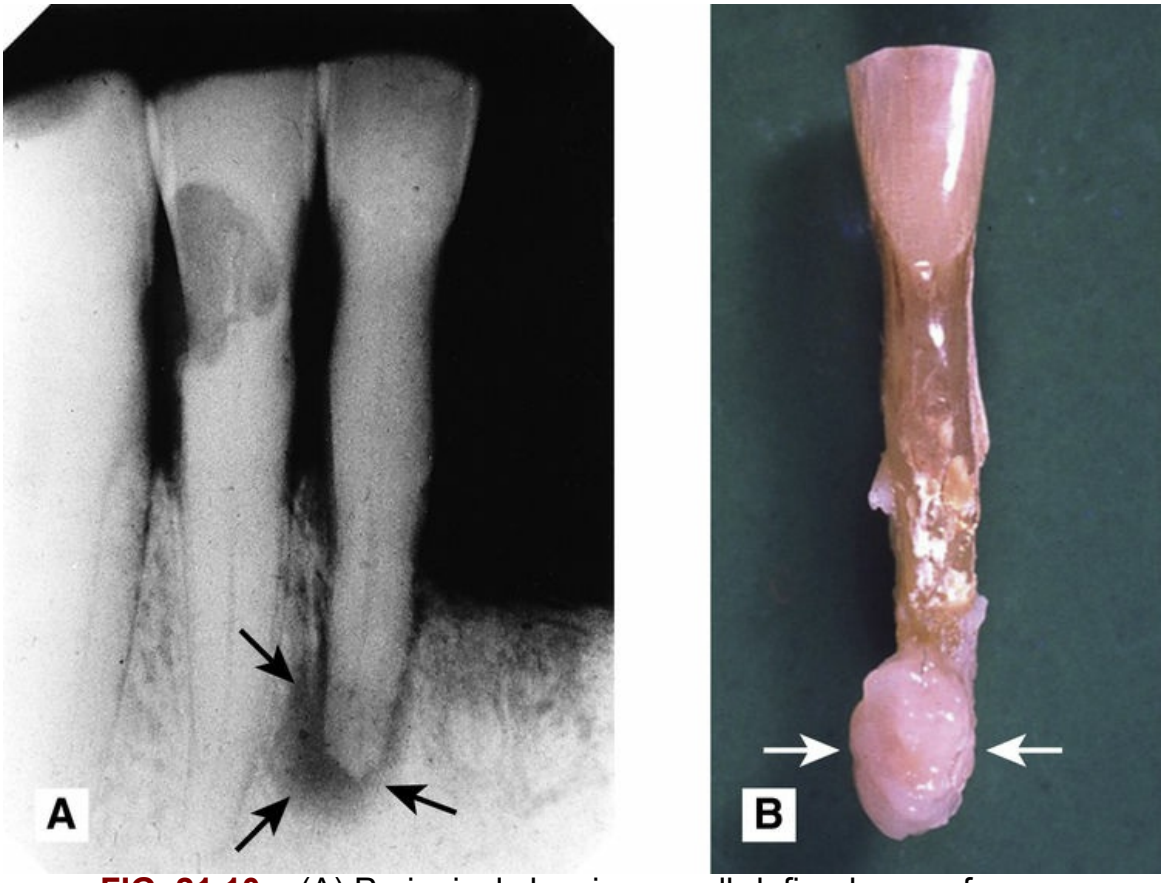


FIG. 21.10 (A) Periapical showing a well-defined area of radiolucency at the apex of ⌉| (arrowed). The surrounding bone is relatively dense and opaque, suggesting a chronic periapical granuloma or radicular cyst (B) The extracted ⌉| , showing the granuloma attached to the root apex (arrowed).

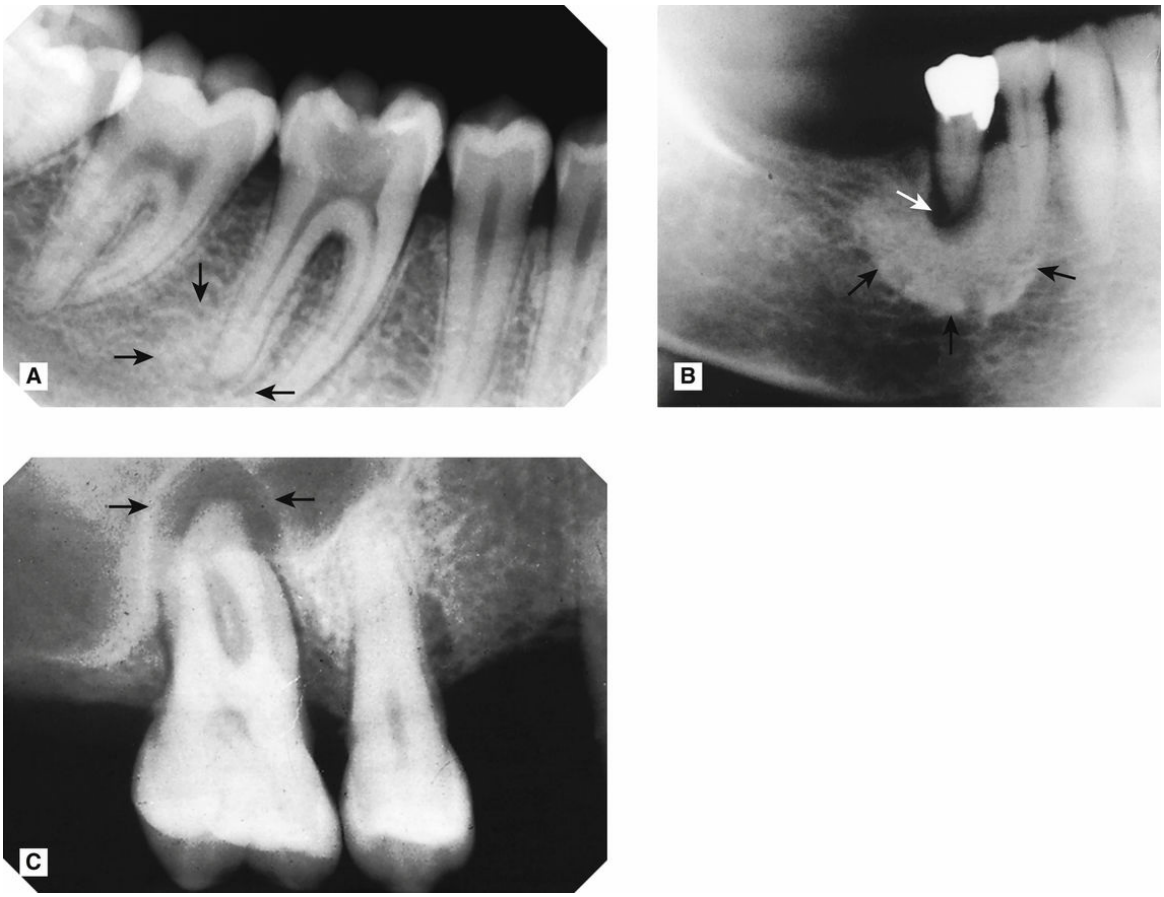


FIG. 21.11 Radiographic examples of other chronic inflammatory changes in the periapical tissues. (A) Low-grade chronic infection associated with $\overline{6}$ resulting in a predominantly radiopaque sclerotic appearance (arrowed). (B) Long-standing low-grade chronic infection associated with $\overline{5}$ resulting in a radiolucent periapical granuloma (white arrow), surrounded by dense opaque *sclerosing osteitis* (black arrow). (C) Well-defined area of bone destruction associated with $\underline{6}$, which has resulted in remodelling of the antral floor, producing the so-called *antral halo* appearance (black arrow) (see also Fig. 31.8).



FIG. 21.12 Periapicals showing (A) inflammatory radicular cyst (arrowed) associated with ⌊2 and (B) inflammatory radicular cyst (arrowed) associated with ⌊6 . The antrum has been displaced by the upper margin of the cyst, which is not evident on this radiograph.

Treatment and Imaging in Endodontics

Most inflammatory periapical lesions, and teeth damaged by minor trauma, are treated by conventional endodontic therapy. The main recommendations regarding imaging the periapical tissues in relation to endodontics from the Faculty of General Dental Practice (UK)'s *Selection Criteria in Dental Radiography* (third edition) booklet are summarised in Table 21.2 . Although these recommendations state that cone beam computed tomography (CBCT) is not indicated as a standard method for the demonstration of root canal anatomy, it may be useful if conventional radiography fails to provide the necessary information to manage the patient.

TABLE 21.2

Summary or the main recommendations for imaging the periapical tissues in relation to endodontics based on the Faculty of General Dental Practice (UK)'s (2013) *Selection Criteria for Dental Radiography* (third edition, updated in 2018).

Recommendation	Evidence-basedgrading *
A good quality preoperative paralleling technique periapical radiograph is essential for the diagnosis of endodontic problems	B
At least one good quality paralleling technique periapical radiograph is necessary to confirm working length(s)	B
If there are any doubts about the integrity of the apical constriction or resistance taper of the prepared root canal, a mid-fill periapical radiograph should be taken to confirm the position of the root filling before final compaction is carried out	C
At least one postoperative radiograph is necessary to assess the success of the obturation, and to act as a baseline for assessment of apical disease or healing	B
A further good quality follow-up paralleling technique periapical radiograph should be taken at one year after completion of treatment	B
A good quality paralleling technique periapical baseline radiograph is essential in treatment planning in vital pulp procedures	C
A good quality paralleling technique periapical baseline radiograph is essential for the management of minor dental trauma	C
Post-trauma follow-up radiographs should be taken 6 months after treatment, and then annually until root formation is complete	C
Although expert opinion supports the taking of review radiographs, there is no evidence to support any particular frequency or duration of review	C
Cone beam computed tomography is not indicated as a standard method for the demonstration of root canal anatomy, but small volume, high-resolution cone beam computed tomography may be indicated in selected cases	C

* Evidence-based grading B = based on evidence from well-conducted clinical studies but with no specific *in vitro* validation studies; C = based on evidence from expert committee reports or opinions and/or clinical experience of respected authorities and indicates an absence of directly applicable studies of good quality.



FIG. 21.13 Sagittal CBCT image of 1 showing very early apical change (arrowed), which was not readily evident on conventional radiographs.

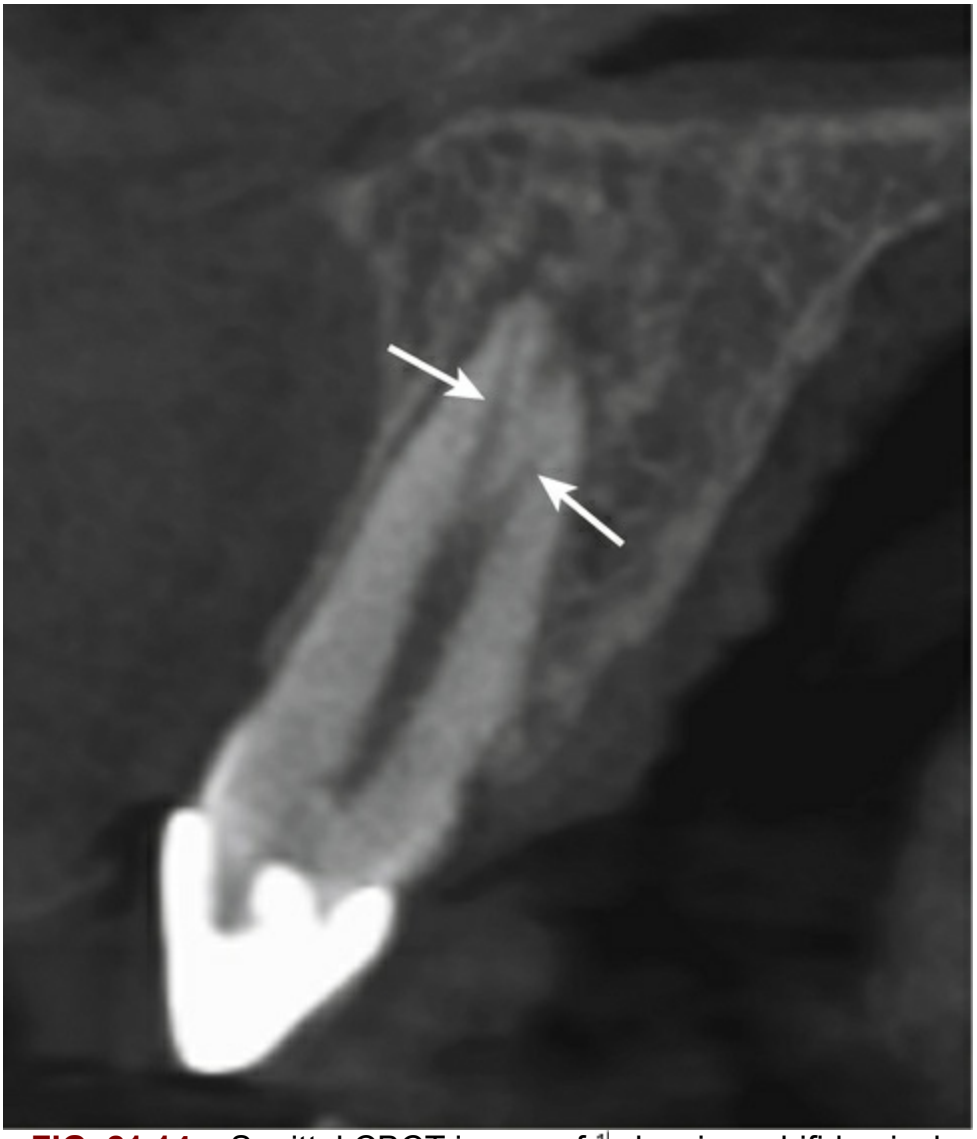


FIG. 21.14 Sagittal CBCT image of 1 showing a bifid apical root canal system (arrowed).

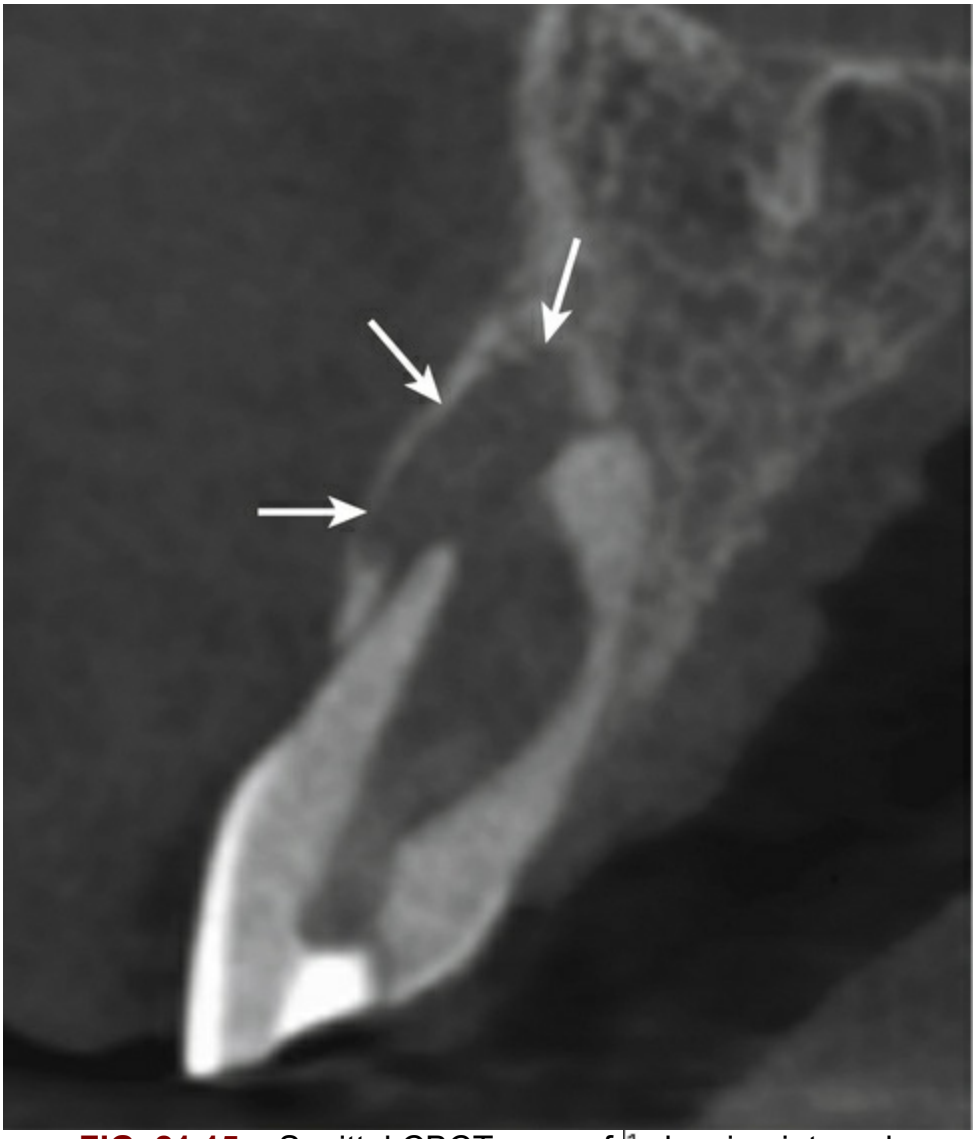


FIG. 21.15 Sagittal CBCT scan of 1 showing internal resorption, perforation and an apical radiolucency (arrowed).

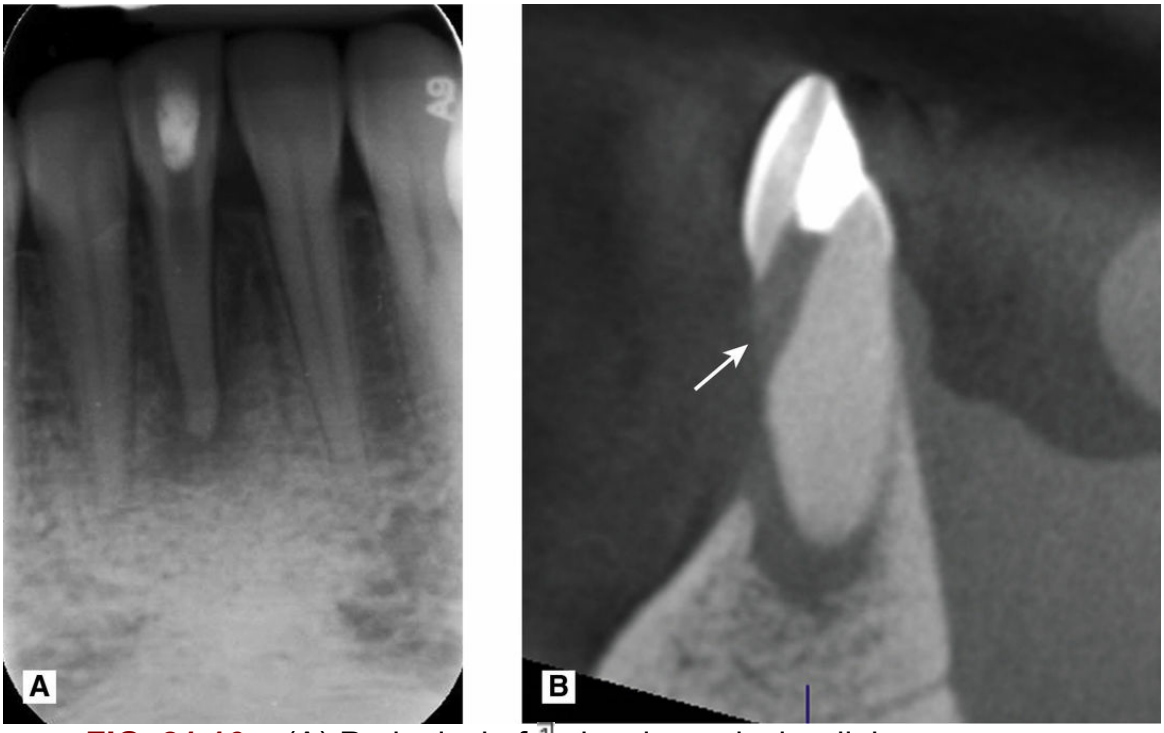


FIG. 21.16 (A) Periapical of 1| showing apical radiolucency with no evidence of a potential perforation. (B) Sagittal CBCT image of the same tooth again showing the apical radiolucency, but also clearly showing the perforation through the buccal aspect of the root (arrowed).

In 2019 the European Society of Endodontology recommended that cone beam computed tomography (CBCT) may be considered in the following circumstances:

- Detection of the radiographic signs of periapical disease when there are non-specific signs and/or symptoms (see Fig. 21.13)
- Assessment and/or management of dento-alveolar trauma
- Pre-surgical assessment prior to complex peri-radicular surgery
- Identification and location of extensively obliterated canals
- Appreciation of extremely complex root canal systems prior to endodontic management (see Fig. 21.14)
- Assessment and/or management of root resorption (see Fig. 21.15)
- Non-surgical re-treatment cases with possible untreated canals

or previous treatment complications e.g. perforations (see Fig. 21.16)
- Detection of peri-radicular bone changes indicative of root fracture.

Other Important Causes of Periapical Radiolucency

Many of the conditions described in Chapters 26 and 27 can present occasionally in the apical region of the alveolar bone. Some can simulate the simple inflammatory changes described above, including:

- Benign and malignant bone tumours including secondary metastatic deposits (see Fig. 21.17)
- Lymphoreticular tumours of bone
- Langerhans cell disease
- Cemento-osseous dysplasia (early stages).

Although it is uncommon, clinicians should still be alert to the possibility that malignant lesions can present as apparently simple localized areas of infection. The signs of concern include:

- A vital tooth with minimal caries
- *Spiking* root resorption and an irregular radiolucent apical area with a ragged, poorly defined outline
- Tooth mobility in the absence of generalized periodontal disease
- Regional nerve anaesthesia
- Failure to respond to good endodontic therapy.

Suggested Guidelines for Interpreting Periapical Images

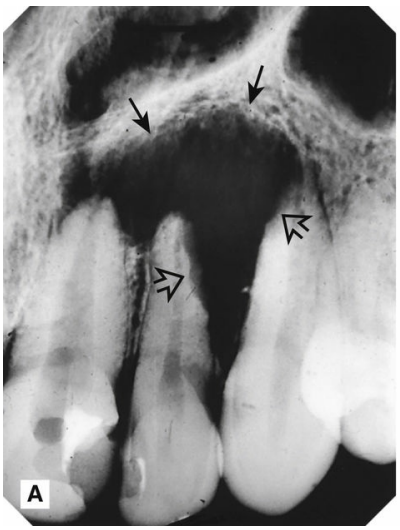
Although somewhat repetitive, this methodical approach to radiographic interpretation is so important, and so often ignored, that it is described again.

Overall Critical Assessment

A series of critical questions that should be asked about the quality of a periapical radiographic image based on the *ideal quality criteria* described in Chapter 9 include questions on technique, image processing and exposure factors. Examples of typical questions are shown below.

Technique (Digital or Film-captured Images)

- Is the required tooth shown?
- Is the apical alveolar bone shown?
- Has the image been taken using the bisected angle or paralleling technique?
- How much distortion is present?
- Is the image foreshortened or elongated?
- Are the crowns overlapped?
- Has there been any *coning off* or *cone cutting?*



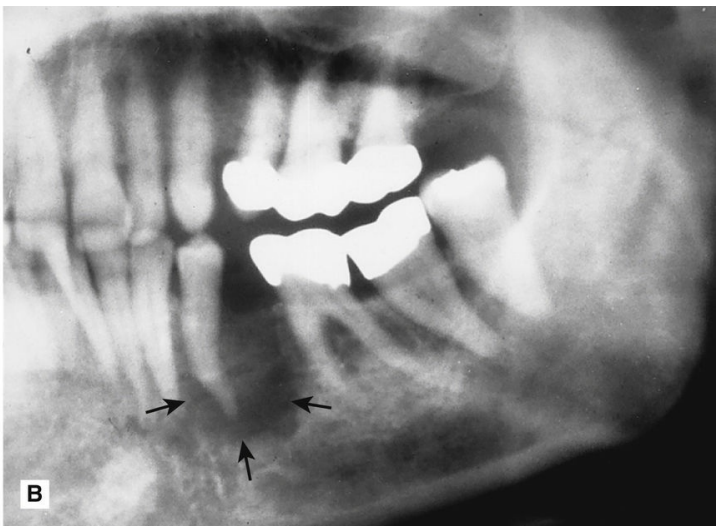


FIG. 21.17 (A) Periapical showing a poorly defined area of radiolucency in the apical region of 123 . Features of concern are the ragged bone margin (solid arrows) and the extensive resorption of 2 and 3 (open arrows). Initial treatment involved unsuccessful root treatment of 1 . Biopsy revealed an osteosarcoma. (B) Part of a panoramic radiograph showing a large poorly defined area of radiolucency in 45 region (arrowed). Both premolars were caries free and unrestored, but mobile. 5 was extracted and histopathology revealed a secondary metastatic malignant tumour from a breast primary.

Exposure Factors (Film-captured Images)

- Is the image too dark and so possibly overexposed?
- Is the image too light and so possibly underexposed?
- What effect do the exposure factors have on the appearance of the apical tissues?

Computer Processing (Digitally-captured Images)

- Is the contrast optimal?
- Is the brightness optimal?
- Is image enhancement optimal?
- Is magnification optimal?

Chemical Processing (Film-captured Images

- Is the radiograph correctly processed?
- Is it overdeveloped?
- Is it underdeveloped?
- Is it correctly fixed?
- Has it been adequately washed?

Systematic Viewing

A systematic approach to viewing periapical radiographs is shown in Fig. 21.18 . This approach ensures that all areas of the image are observed and that the important features of the tooth apex are examined.



General overview of entire radiograph

1 Note the chronological and development age of the patient

2 Note the position, outline and density of all the normal superimposed anatomical shadows including any developing teeth

Examine each tooth on the radiograph and assess

3 **The crown**
Note particularly:
- The presence of caries
- The state of existing restorations

4 **The root(s)**
Note particularly:
- The length of the root
- The number(s)
- The morphology
- The size and shape of canals
- The presence of:
  - a Pulp stones
  - b Root fillings
  - c Internal resorption
  - d External resorption
  - e Root fractures

5 **The apical tissues**
Note particularly:
- The integrity, continuity and thickness of:
  - a The radiolucent line of the periodontal ligament space
  - b The radiopaque line of the lamina dura
- Any associated radiolucent areas
- Any associated radiopaque areas
- The pattern of the trabecular bone

6 **The periodontal tissues**
Note particularly:
- The width of the periodontal ligament
- The level and quality of the crestal bone
- Any vertical or horizontal bone loss
- Any calculus deposits
- Any furcation involvements

B

FIG 21.18 (A) A periapical of 567 . (B) A suggested systematic sequence for viewing and assessing the image.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

22

The Periodontal Tissues and Periodontal Disease

Introduction

An overall assessment of the periodontal tissues is an essential component of dental patient management and is based on both the clinical examination and the radiographic examination. The initial clinical assessment includes the Basic Periodontal Examination (BPE), which is a simple and rapid screening tool that is used to indicate the level of further examination required and provide basic guidance on the treatment needed. The British Society of Periodontology's 2016 BPE guidelines represent a minimum standard of care for initial periodontal assessment. Recording the BPE includes:

- Dividing the dentition into six sextants and recording the highest score (0–4) for each sextant as shown in Table 22.1
- Examining all sites of all teeth in each sextant
- Using a World Health Organisation BPE probe, which has a 'ball end' 0.5 mm in diameter and a ***black*** band from 3.5 to 5.5 mm, with a light probing force.

TABLE 22.1

Basic Periodontal Examination (BPE) scoring codes and their interpretation based broadly on the 2016 British Society of Periodontology's BPE guidelines.

Score	Scoring code	Treatment required
0	Pockets <3.5 mm, no calculus/overhangs, no bleeding on probing (***black***	No need for periodontal treatment

	band entirely visible)	
1	Pockets <3.5 mm, no calculus/overhangs, bleeding on probing *(**black** band entirely visible)*	Oral hygiene instruction (OHI) required
2	Pockets <3.5 mm, supra or subgingival calculus/overhangs *(**black** band entirely visible)*	OHI, plus removal of plaque retentive factors, including all supra-gingival and subgingival calculus required
3	Probing depth 3.5–5.5 mm (***black*** *band partially visible, indicating a pocket of 4–5 mm*)	OHI, plus removal of plaque retentive factors, including all supra and subgingival calculus and root surface debridement (RSD) if required
4	Probing depth >5.5 mm (***black*** *band disappears, indicating a pocket of ≥6 mm*)	OHI and RSD required; assess need for more complex treatment and referral to a specialist
*	Furcation involvement	Treat according to BPE code (0–4); assess need for more complex treatment and referral to a specialist

Radiographic examination provides retrospective evidence of the periodontal disease process. However, radiographs can be used to assess the morphology of the affected teeth and the pattern and degree of alveolar bone loss that has taken place. *Bone loss* can be defined as *the difference between the present septal bone height and the assumed normal bone height for any particular patient*, taking age into account. In fact radiographs actually show the amount of alveolar bone *remaining* in relation to the length of the root. But this information is still important in the overall assessment of the severity of the disease, the prognosis of the teeth and for treatment planning. Radiographs are therefore used to:

- Assess the extent of bone loss and furcation involvement
- Determine the presence of any secondary local causative factors
- Assess root length and morphology
- Assist in treatment planning
- Evaluate treatment measures, particularly after regenerative periodontal surgical procedures.

Selection Criteria

Several radiographic projections can be used to show the periodontal tissues. Those recommended by the Faculty of General Dental Practice (UK) in 2013 are summarized in Table 22.2 .

The British Society of Periodontology's 2016 guidelines also recommend the availability of radiographs for patients with BPE scores of 3 or 4 to assess the extent of bone loss. The guidance states that *'many clinicians would regard periapical views as essential for Code 4 sextants to allow assessment of bone loss as a percentage of root length and visualisation of the periapical tissues.'*

In addition, digital radiography and image manipulation, including subtraction and densitometric image analysis (see Chapter 5), may assist in showing and measuring subtle changes in fine alveolar and crestal bone pattern. However, these techniques require the inclusion of a reference object of known density and a highly reproducible positioning technique to be helpful.

Important Points to Note

- In the interpretation of the periodontal tissues, images of excellent quality are essential – perhaps more so than in other dental specialties – because of the fine detail that is required.

TABLE 22.2

Summary of the main recommendations for imaging the periodontal tissues based on The Faculty of General Dental Practice (UK)'s 2013 *Selection Criteria for Dental Radiography* , 3rd Ed, (updated in 2018).

Recommendation	Evidence-based grading *
Horizontal bitewings if a patient has generalised pocketing <6 mm (BPE scores of code 3) and little or no recession.	C
Vertical bitewings if a patient has pocketing of ≥6 mm (BPE scores of code 4), supplemented by paralleling technique periapicals at sites	C

where the alveolar bone is not shown on the bitewings.	
Bitewings (horizontal or vertical depending on pocket depth), supplemented by paralleling technique periapicals if necessary if a patient has localised pocketing	C
A paralleling technique periapical if a periodontal/endodontic lesion is suspected	C
CBCT is not indicated as a routine method of imaging periodontal bone support	C
Small volume, high resolution CBCT may be indicated in selected cases of infra-bony defects and furcation lesions, where clinical and conventional radiographic examination do not provide the information needed for patient management	C

* Evidence-based grading: C = based on evidence from expert committee reports or opinions and/or clinical experience of respected authorities and indicates an absence of directly applicable studies of good quality.

- Exposure factors should be reduced when using film-based techniques to avoid *burn-out* of the interdental crestal bone.

Radiographic Features of Healthy Periodontium

A *healthy* periodontium can be regarded as *periodontal tissue exhibiting no evidence of disease.* Unfortunately, *health* cannot be ascertained from radiographs alone; clinical information is also required.

However, to be able to interpret radiographs successfully, clinicians need to know the usual radiographic features of healthy tissues where there has been no bone loss. The only reliable radiographic feature is the relationship between the crestal bone margin and the cemento-enamel junction (CEJ). If this distance is within normal limits (2–3 mm) and there are no clinical signs of loss of attachment, then it can be said that there has been no periodontitis.

The usual radiographic features of *healthy* alveolar bone are shown in Figs. 22.1 and 22.2 and include:

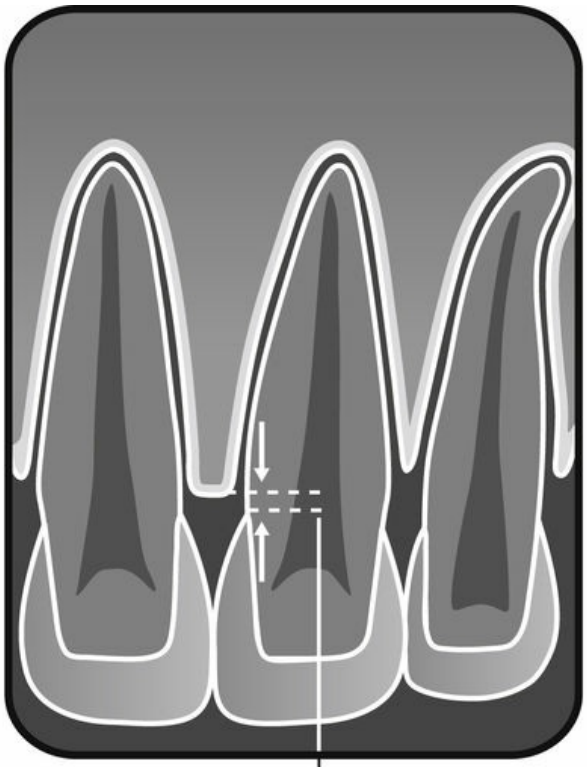
- Thin, smooth, evenly corticated margins to the interdental

crestal bone in the posterior regions

- Thin, even, pointed margins to the interdental crestal bone in the anterior regions - cortication at the top of the crest is not always evident, owing mainly to the small amount of bone between the teeth anteriorly
- The interdental crestal bone is continuous with the lamina dura of the adjacent teeth. The junction of the two forms a sharp angle
- Thin even width to the mesial and distal periodontal ligament spaces

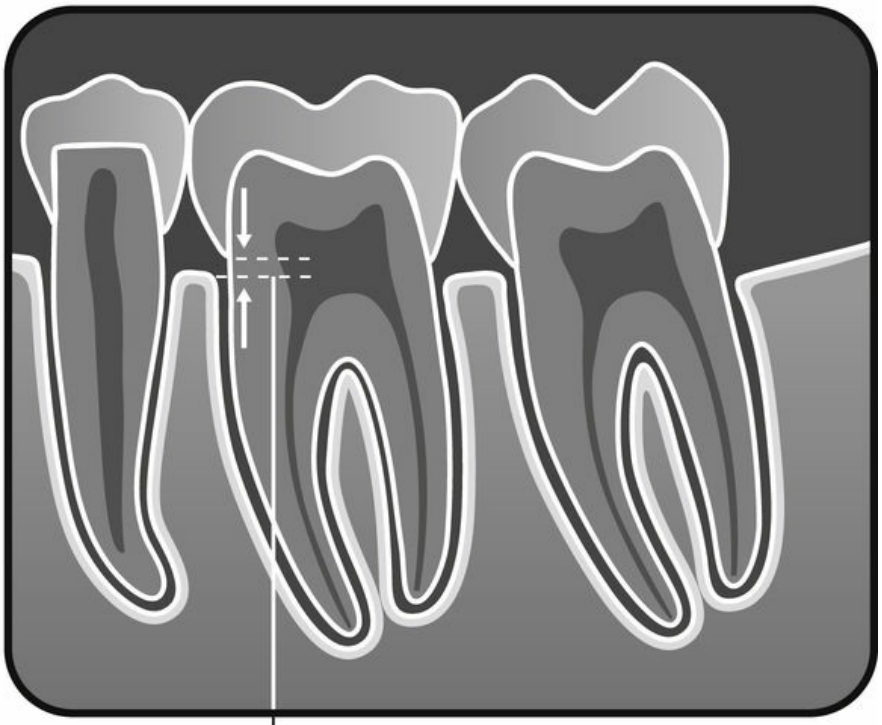
Important Points to Note

- Although these are the usual features of a healthy periodontium, they are not always evident.
- Their absence from radiographs does not necessarily mean that periodontal disease is present.
- Failure to see these features may be due to:
  - Technique error
  - Overexposure
  - Normal anatomical variation in alveolar bone shape and density.
- Following successful treatment, the periodontal tissues may seem to be healthy clinically, but radiographs may show evidence of earlier bone loss when the disease was active. Bone loss observed on radiographs is therefore not an indicator of the presence of inflammation.



A

2–3 mm



B

2–3 mm

FIG. 22.1 Diagrams showing the radiographic appearance of a healthy periodontium. (A) The upper incisor region. (B) The lower molar region. The normal distance of 2–3 mm from the crestal bone to the cemento-enamel junction is indicated.

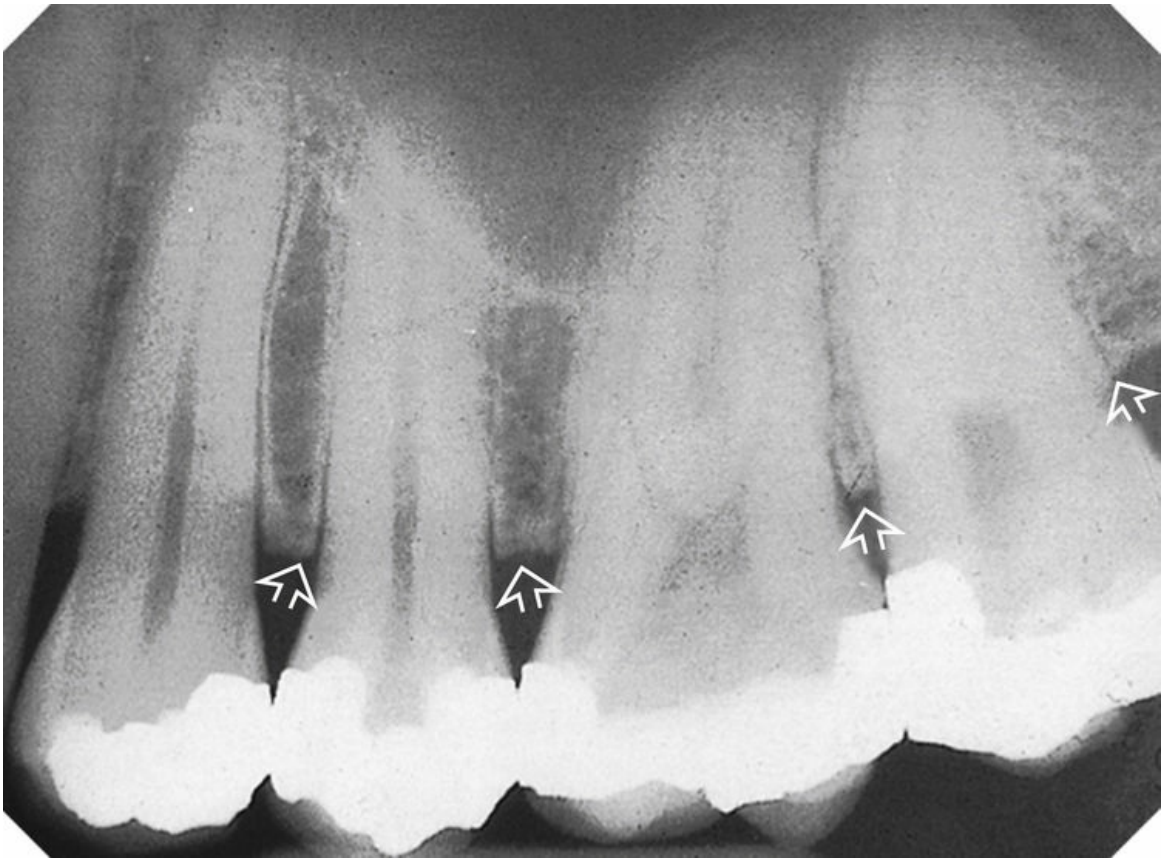


FIG. 22.2 Paralleling technique periapical radiograph of 4567 (slightly reduced exposure) showing the radiographic features of a healthy periodontium (arrowed).

Classification of Periodontal Diseases

The classification of periodontal diseases and other conditions affecting the periodontal tissues is based on the outcomes of the World Workshop on *Classification of Periodontal and Peri-Implant Diseases and Conditions,* held in 2017. A summary of this classification

is shown in Table 22.3 . This current classification differs from classification systems that were previously used, in a number of important ways.

Firstly, it defines periodontal health, including the recognition that health, and gingivitis, may exist even where previous bone loss has occurred. Secondly, and most importantly, it abolishes the term *aggressive periodontitis* (previously denoting severe periodontitis that undergoes rapid progressive breakdown), and instead recognises periodontitis as a continuous entity of severity based on stage and grade of disease and its distribution pattern.

TABLE 22.3

Summary of the classification of periodontal diseases and conditions based broadly on the outcomes of the 2017 World workshop on the *Classification of Periodontal and Peri-implant Diseases and Conditions*

1. **Health:**

    Intact periodontium
    Reduced periodontium

2. **Plaque-induced gingivitis** : (localised / generalised gingivitis)

3. **Non plaque-induced gingival diseases and conditions:**

    Intact periodontium
    Reduced periodontium

4. **Periodontitis:**

    Localised (≤30% teeth)
    Generalised (>30% teeth)
    Molar–incisor pattern

5. **Necrotising periodontal diseases**

6. **Periodontitis as a manifestation of systemic disease**

7. **Systemic diseases or conditions affecting the periodontal tissues:**

Disorders that influence periodontal inflammation
e.g. *Down's syndrome*
Papillon-Lefevre syndrome
Congenital neutropenia
Disorders that influence the pathogenesis of periodontal diseases
e.g. Smoking [nicotine dependence]
Disorders that can result in loss of periodontal tissue independent of periodontitis
e.g. Primary neoplasms of periodontal tissue
Langerhans cell histiocytosis

8. **Periodontal abscesses**

9. **Periodontal-endodontic lesions**

10. **Mucogingival deformities and conditions**

Staging and Grading of Periodontitis

The 2018 British Society of Periodontology Guidelines to enable implementation of the 2017 Classification of Periodontitis proposed a system of staging and grading periodontitis. *Staging* is an assessment of disease severity (from I - IV) based on the estimated amount of interproximal attachment loss (on the worst affected tooth) as shown in Table 22.4 . *Grading* is an assessment of patient susceptibility (A, B or C) based on the *rate* of attachment loss, estimated by dividing the percentage of interproximal bone loss by the patient's age as shown in Table 22.5 . Thus, periodontitis is described by stage and grade and distribution of lesions (e.g. *III/B generalised periodontitis*).

TABLE 22.4

Staging of periodontitis based broadly on the British Society of Periodontology's guidelines to enable implementation of the 2017 classification of periodontitis.

	Stage I (mild)	Stage II (moderate)	Stage III (severe)	Stage IV (very severe)
% inter-proximal bone loss	<15%	15–33% (coronal third of root)	33–66% (mid third of root)	≥66% (apical third of root)

TABLE 22.5

Grading of periodontitis based broadly on the British Society of Periodontology's guidelines to enable implementation of the 2017 classification of periodontitis.

	Grade A (slowly progressing)	Grade B (moderate)	Grade C (rapid)
% bone loss/age	<0.5	0.5–1.0	>1.0

Radiographic Features of Periodontal Disease and the Assessment of Bone Loss and Furcation Involvement

It is beyond the scope of this book to describe the features of all the periodontal diseases and conditions shown in the classification in Table 22.3 . This discussion is restricted to:

- Gingivitis
- Periodontitis
- Periodontal abscesses and periodontal-endodontic lesions.

Gingivitis

Radiographs cannot provide direct evidence of soft tissue inflammation, which is the key feature of gingivitis. Furthermore, as noted, the classification recognises that where there has been previous loss of attachment and bone loss detectable by radiograph, it is still quite possible to have gingival health or gingivitis only. Thus, gingival disease can only be diagnosed by the clinical observation of inflammation without deep pocketing.

Periodontitis

Periodontitis is the name given to periodontal disease when *the superficial inflammation in the gingival tissues extends into the underlying alveolar bone and there has been loss of attachment.* The destruction of the bone can be either *localized,* affecting a few areas of the mouth, or *generalized* affecting all areas.

Terminology

The terms used to describe the various appearances of bone destruction include:

- Horizontal bone loss
- Vertical bone loss
- Furcation involvements.

The terms *horizontal* and *vertical* have been used traditionally to describe the direction or pattern of bone loss using the line joining two adjacent teeth at their cemento-enamel junctions as a line of reference. Thus, horizontal bone loss is associated with the clinical finding of a *supra-bony* pocket, whereas vertical bone loss is associated with *infra-bony* pockets. The amount of bone loss is assessed as mild, moderate, severe or very severe according to the amount of interproximal bone loss, using the criteria described in Tables 22.4 and 22.5 , and shown diagrammatically in Fig. 22.3 .

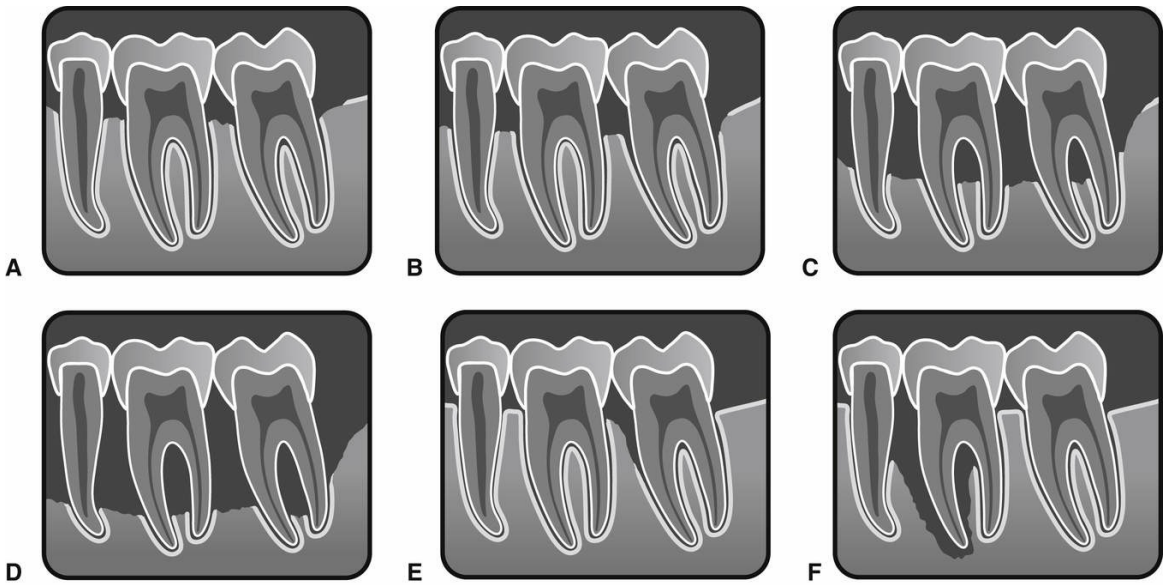


FIG. 22.3 Diagrams illustrating the various radiographic appearances of periodontitis. (A) **Stage I (mild)** bone loss of less than 15% of the root length. Early loss of the corticated crestal bone and loss of the normally sharp angle between the crestal bone and lamina dura. (B) **Stage II (moderate)** horizontal bone loss of 15%–33% of root length. (C) **Stage III (severe)** horizontal bone loss of 33%–66% of the root length. (D) **Stage IV (very severe)** horizontal bone loss of more than 66% of the root length. (E) Moderate localised vertical bone affecting 7 (stage II). (F) Localised bone loss involving the apex of 6 – a *perio-endo* lesion.

Severe vertical bone loss, extending from the alveolar crest and involving the tooth apex, in which necrosis of pulp tissue is also believed to be a contributory factor, is classified as a *periodontal-endodontic lesion*, often abbreviated to a *perio-endo lesion* (see Figs. 22.3F and 22.13).

The term *furcation involvement* describes the radiographic appearance of bone loss in the furcation area of the roots, which is evidence of advanced disease in this zone, as shown diagrammatically in Fig. 22.4 . Although central furcation involvements are seen more readily in mandibular molars, they can also be seen in maxillary molars despite the superimposed shadow of the overlying palatal root. In addition, early maxillary molar furcation involvement between the mesiobuccal or distobuccal roots and the palatal root

produces a characteristic triangular-shaped radiolucency at the edge of the tooth. Radiographic examples of horizontal and vertical patterns of bone loss and furcation involvements are shown in Figs. 22.5 –22.9 .

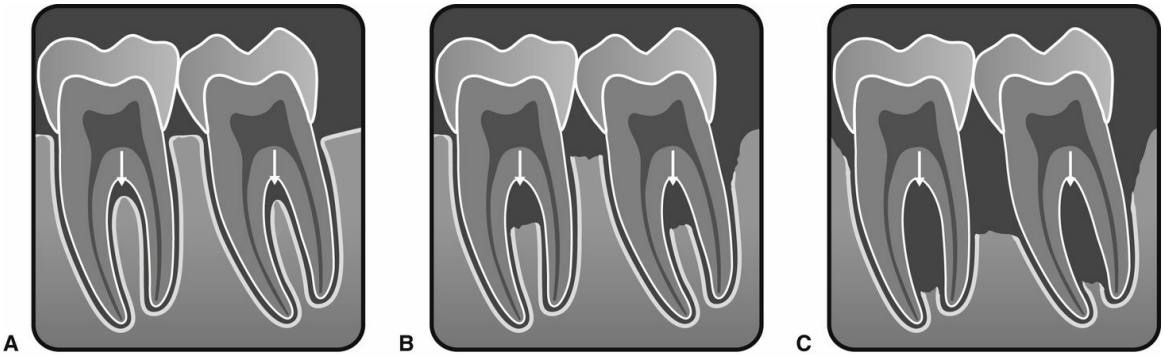


FIG. 22.4 Diagrams illustrating the radiographic appearances of varying degrees of furcation involvement in lower molars (arrowed). (A) Very early involvement showing widening of the furcation periodontal ligament shadow. (B) Moderate involvement. (C) Severe involvement.

Main pathological features of periodontitis

These include:

- Inflammation (usually a progression from chronic gingivitis)
- Destruction of periodontal ligament fibres
- Resorption of the alveolar bone
- Loss of epithelial attachment
- Formation of pockets around the teeth
- Gingival recession.

It is the resorption of the alveolar bone that provides the main radiographic features of periodontitis. These include:

- Loss of the corticated interdental crestal margin; the bone edge becomes irregular or blunted

- Widening of the periodontal ligament space at the crestal margin
- Loss of the normally sharp angle between the crestal bone and the lamina dura – the bone angle becomes rounded and irregular
- Localized or generalized loss of the alveolar supporting bone
- Patterns of bone loss – *horizontal* and/or *vertical* – resulting in an even loss of bone or the formation of complex intra-bony defects
- Loss of bone in the furcation areas of multirooted teeth – this can vary from widening of the furcation periodontal ligament to large zones of bone destruction
- Widening of the interdental periodontal ligament spaces
- Associated complicating *secondary local factors* – although the primary cause of periodontal disease is bacterial plaque, many complicating secondary local factors may also be involved. Some of these factors can be detected on radiographs (see Figs. 22.10 and 22.11) and include:
    - – Calculus deposits
    - – Caries cavities
    - – Root resorption
    - – Overhanging filling ledges
    - – Poor restoration margins
    - – Lack of contact points
    - – Poor restoration contour, including pontic design
    - – Perforations by pins or posts
    - – Endodontic status in relation to perio-endo lesions
    - – Over-erupted opposing teeth
    - – Tilted teeth
    - – Root approximation
    - – Gingivally fitting partial dentures
    - – Developmental grooves
    - – Dens-in-dente.

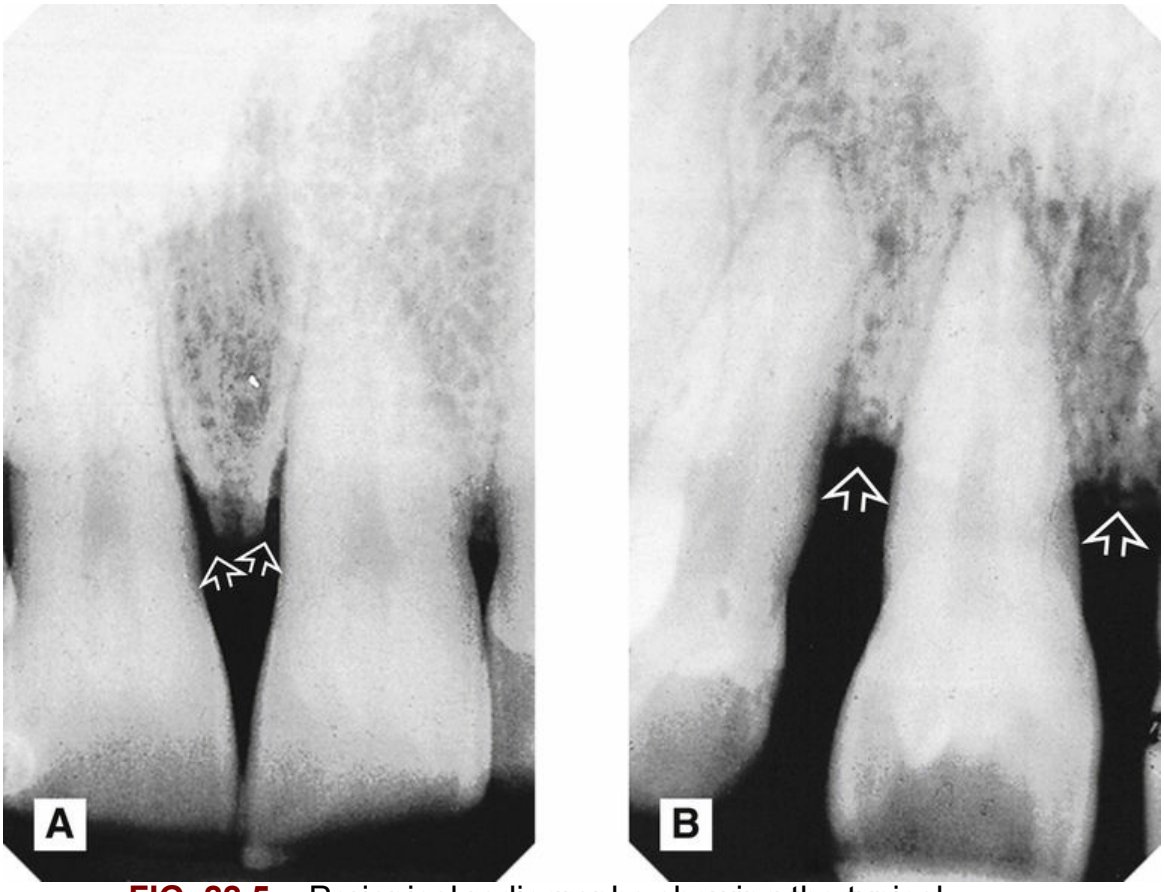


FIG. 22.5 Periapical radiographs showing the typical radiographic features of horizontal bone loss (arrowed) in periodontitis affecting maxillary incisors. (A) Moderate bone loss. (B) Severe bone loss.

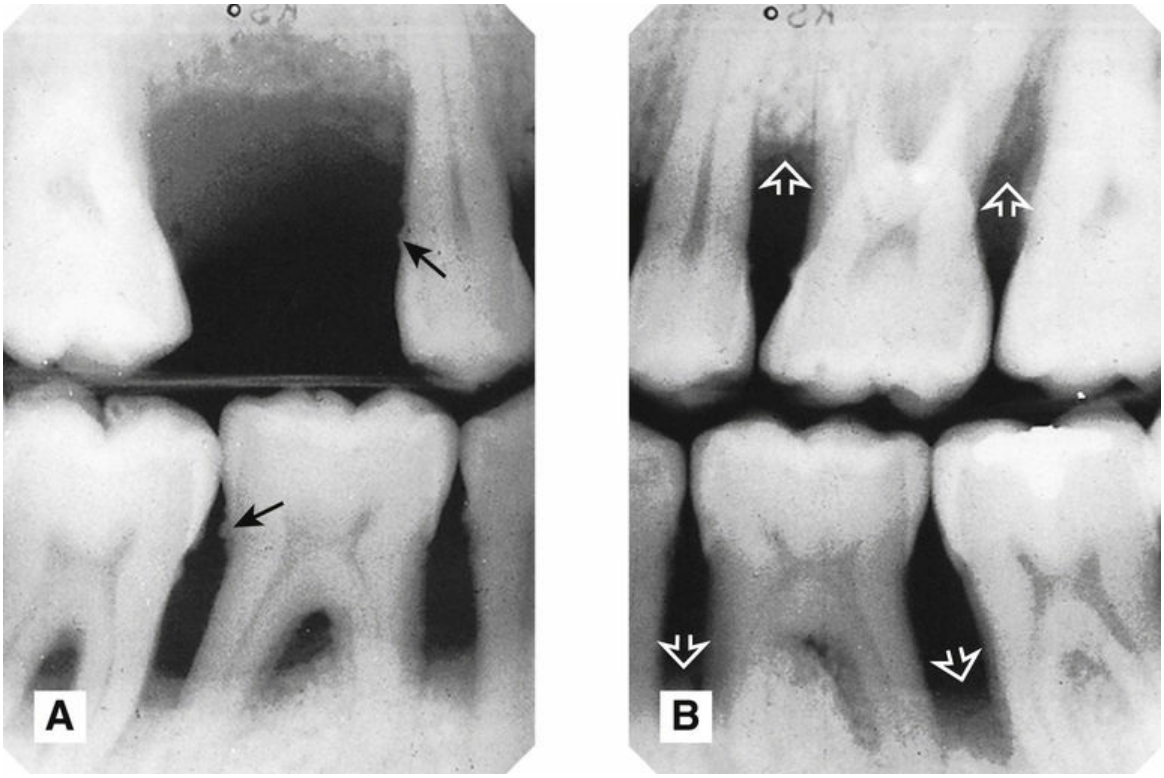


FIG. 22.6 (A) RIGHT and (B) LEFT vertical bitewings showing severe bone loss (open arrows) typical of periodontitis. The black arrows indicate calculus deposits.

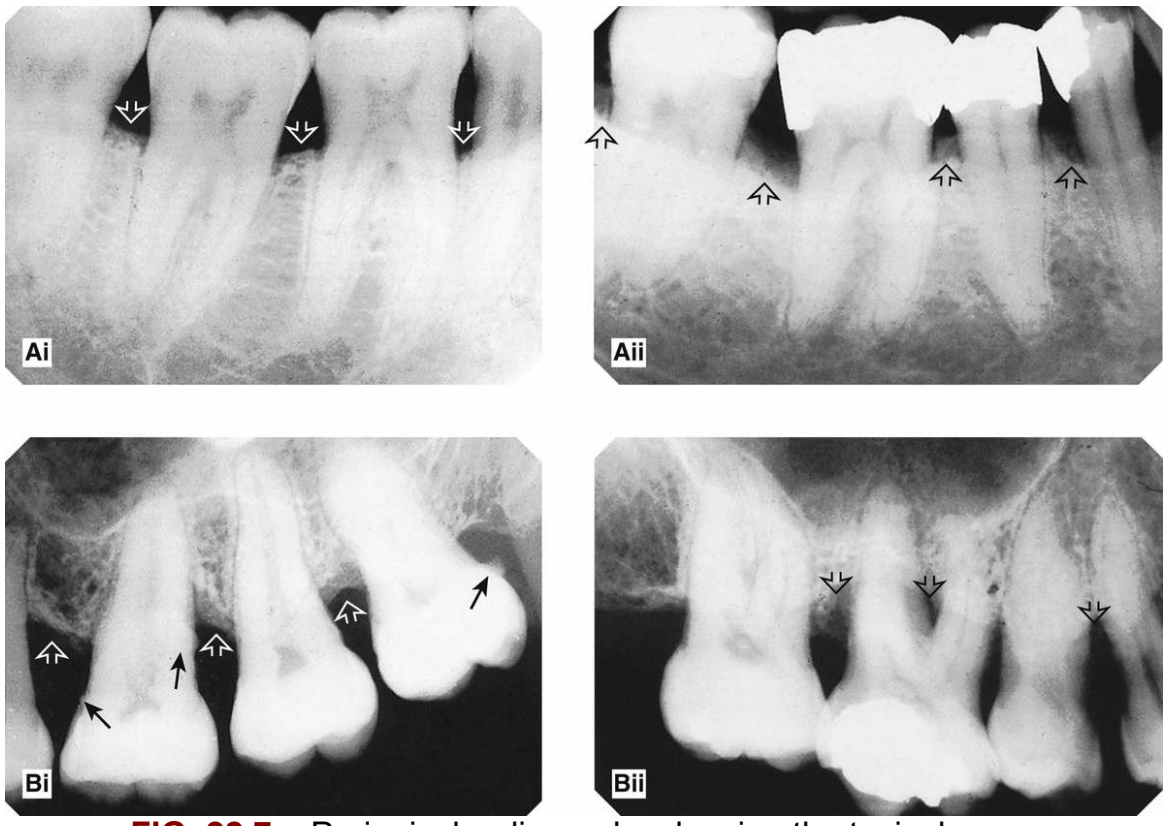


FIG. 22.7 Periapical radiographs showing the typical radiographic features of horizontal bone loss in periodontitis affecting posterior teeth. **(A) (i)** Early or mild and **(ii)** moderate bone loss (arrowed) affecting mandibular molars. **(B) (i)** Moderate and **(ii)** severe bone loss (open arrows) affecting maxillary molars. The black arrows indicate calculus deposits.

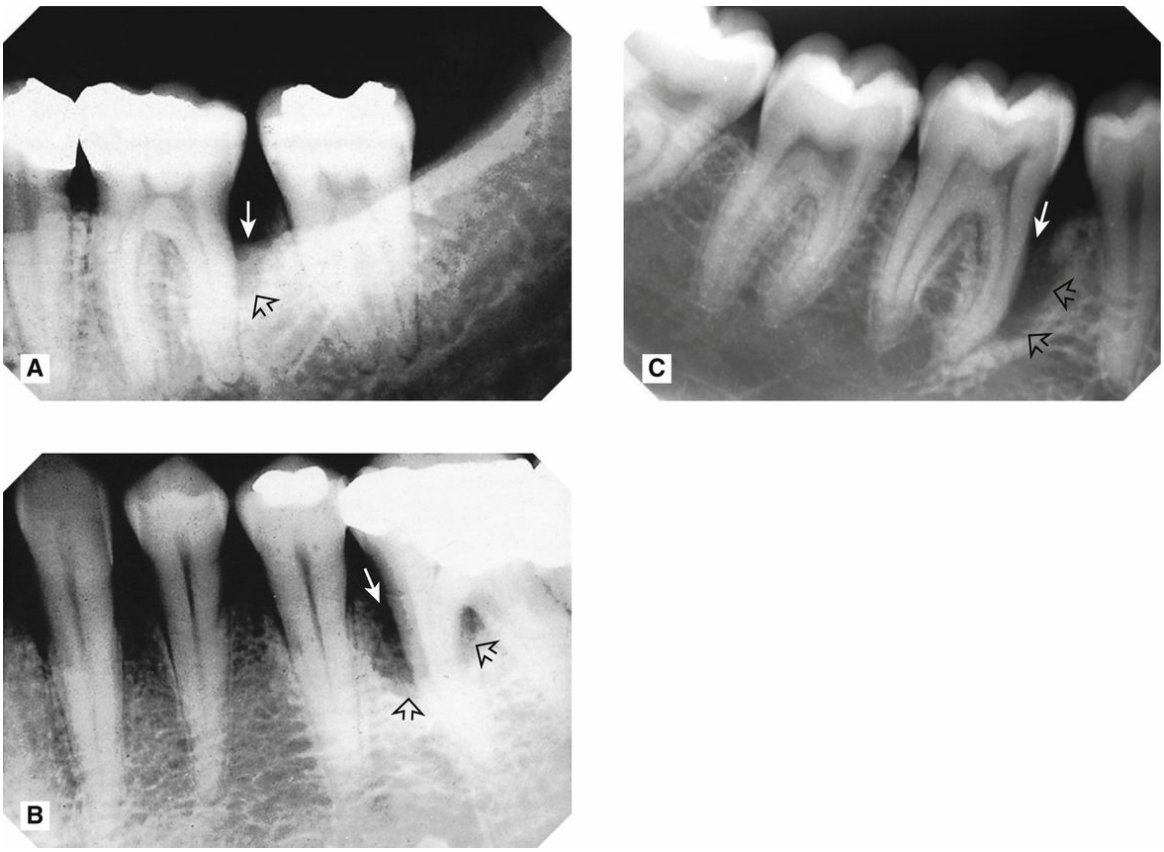


FIG. 22.8 **(A-C)** Periapical radiographs showing examples of vertical bone loss of increasing severity in periodontitis (arrowed).



FIG. 22.9 (A) Periapical showing moderate and severe degrees of furcation bone loss (arrowed) in mandibular molars. (B) Periapical showing moderate furcation involvement (arrowed) in maxillary molars. Note the characteristic mesial and distal cervical triangular radiolucent shadows indicating furcation involvement between the mesiobuccal and palatal roots and the distobuccal and palatal roots. **(C) (i)** Sagittal and **(ii)** axial CBCT scans showing severe bone loss between 7 and 8 (open arrows) and the involvement of the furcation of 7 (solid arrows).

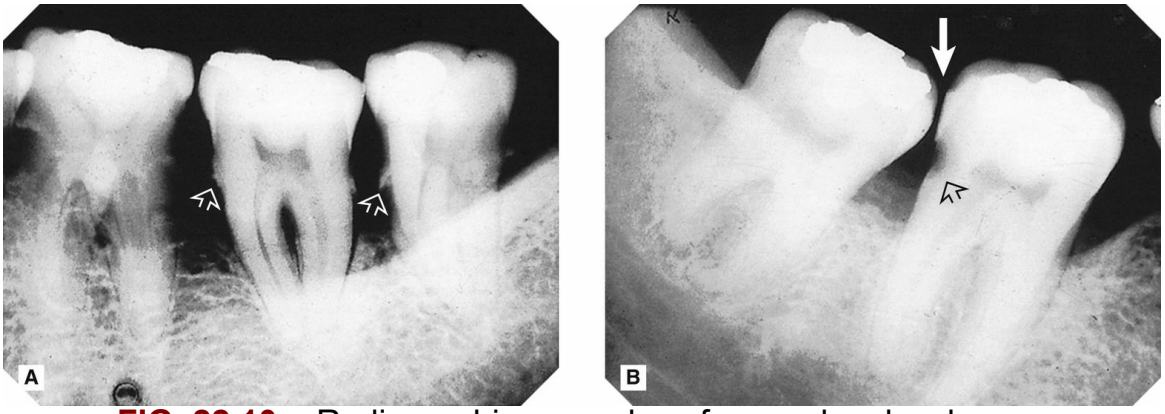


FIG. 22.10 Radiographic examples of secondary local causative factors (arrowed) associated with periodontitis. (A) Small calculus deposits. (B) Defective contact point (white solid arrow) and root caries (black open arrow).

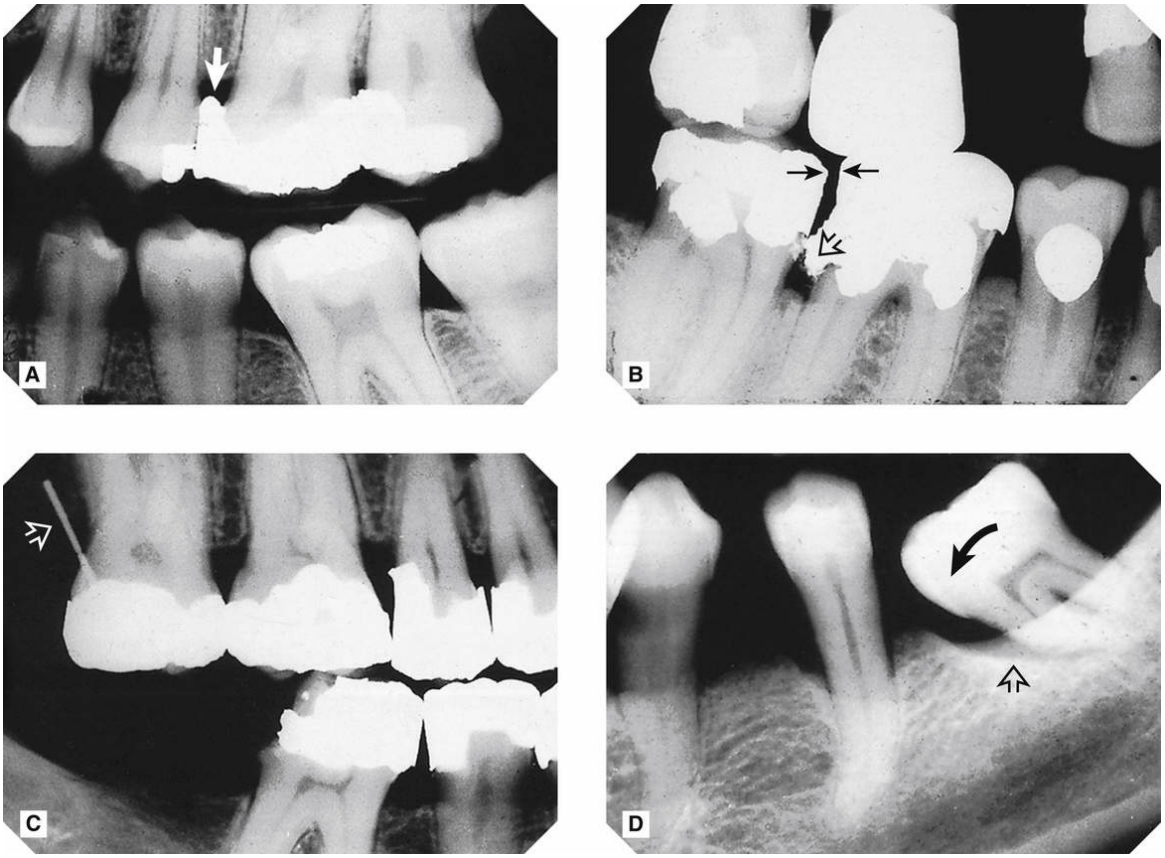


FIG. 22.11 Further radiographic examples of secondary local factors (arrowed). (A) Overhanging filling ledge. (B) Defective contact point and overhanging filling ledge. (C) Pin

perforated into the periodontal tissues. (D) Tilted tooth.

Distribution Patterns of Periodontitis

As noted previously and shown in Table 22.2 , periodontitis is classified as being generalized, localised or exhibiting a specific *molar–incisor pattern* of distribution. When localised to a few teeth only, periodontitis typically results in vertical bone loss. The *molar–incisor pattern* of lesions is sometimes seen where periodontitis is confined to the incisors and first molar teeth. This specific distribution is unusual, but is typically seen in young adults and is indicative of a high susceptibility to rapid localised periodontal breakdown. In previous classification systems, this condition was referred to as *localised aggressive periodontitis.* The radiographic features of the *molar–incisor pattern* of periodontitis are shown in Fig. 22.12 and include:

- Severe vertical bone defects affecting the first molars and/or incisors
- Arch or saucer-shaped defects
- Migration of the incisors with diastema formation
- Rapid rate of bone loss.

Periodontal Abscesses and Periodontal-endodontic Lesions

Lateral periodontal abscesses are a localised exacerbation of underlying periodontitis and are diagnosed clinically by the presence of suppuration from a pocket, sometimes accompanied by pain and swelling. The radiographic appearance of a periodontal abscess is typically indistinguishable from other forms of periodontal breakdown.

Periodontal-endodontic (perio-endo) lesions are where there is direct communication between a periodontal pocket and the pulpal tissues. These lesions may also often present clinically with suppuration from a pocket and may be the result of the extension of a periodontal lesion

to the apex of the tooth, or alternatively may be the result of pulpal disease extending to a periodontal pocket. Vitality testing and radiographic features are the principle methods for diagnosis of a perio-endo lesion (see Fig. 22.13).

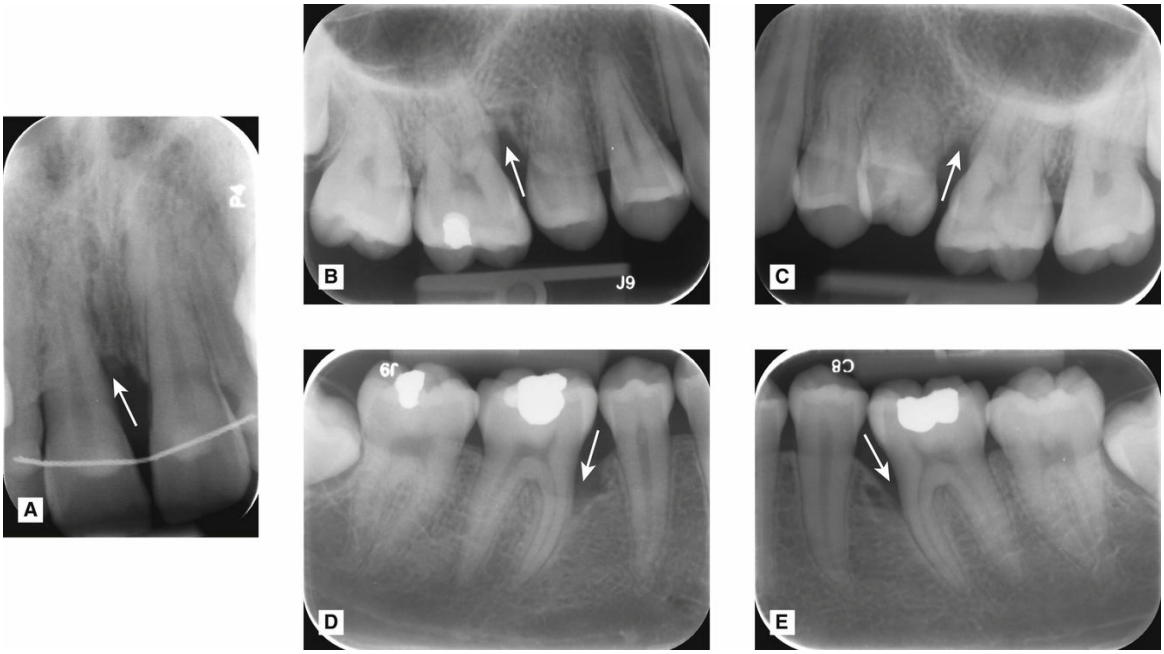


FIG. 22.12 **(A–E)** Anterior and posterior periapicals of the same patient showing the typical localized bone defects (arrowed) of molar–incisor pattern periodontitis affecting the upper incisors and the mesial aspect of the first molars in all four quadrants.



FIG. 22.13 Periapical radiograph showing an extensive area of bone loss (arrowed) associated with $\underline{4}$ – a *perio-endo* lesion. The patient had presented clinically with a periodontal abscess.

Evaluation of Treatment Measures

Conventional treatment of periodontal disease involves improving oral hygiene, supra-gingival and subgingival calculus removal, root surface debridement (RSD) and the removal of any other secondary local causative factors in an attempt to slow down or arrest the disease process. Thus, successful periodontal treatment results in very little or no change to the radiographic appearance of periodontal lesions. The exception to this is where the periodontal defects are treated by periodontal regenerative surgical procedures, which include the use of barrier membranes (guided tissue regeneration), bone graft materials or the use of biologically active factors in an attempt to stimulate tissue regeneration. All of these procedures are really only

applicable to deep vertical bony defects and their outcomes may be quite variable.

The success or otherwise of these treatment measures can be assessed by a combination of clinical examination, including probing and attachment loss measurements, and periodic radiographic investigation, as shown in Figs. 22.14 and 22.15 .

NOTE : To provide useful information, sequential radiographs ideally should be comparable in both technique and exposure factors.

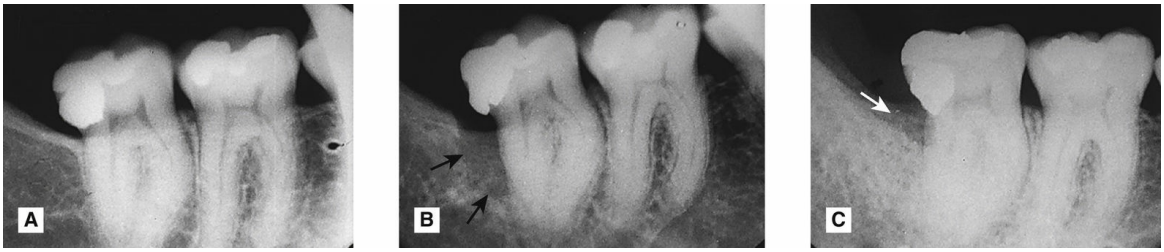


FIG. 22.14 Periapicals showing evaluation of treatment. (A) Initial image. (B) Nine years later, showing overhanging filling margin and severe distal bony defect on 7| (arrowed). (C) Follow-up image 3 years later after guided tissue regeneration showing the reduced defect (arrowed) and the bone in-fill.
Courtesy of Dr A. Sidi.

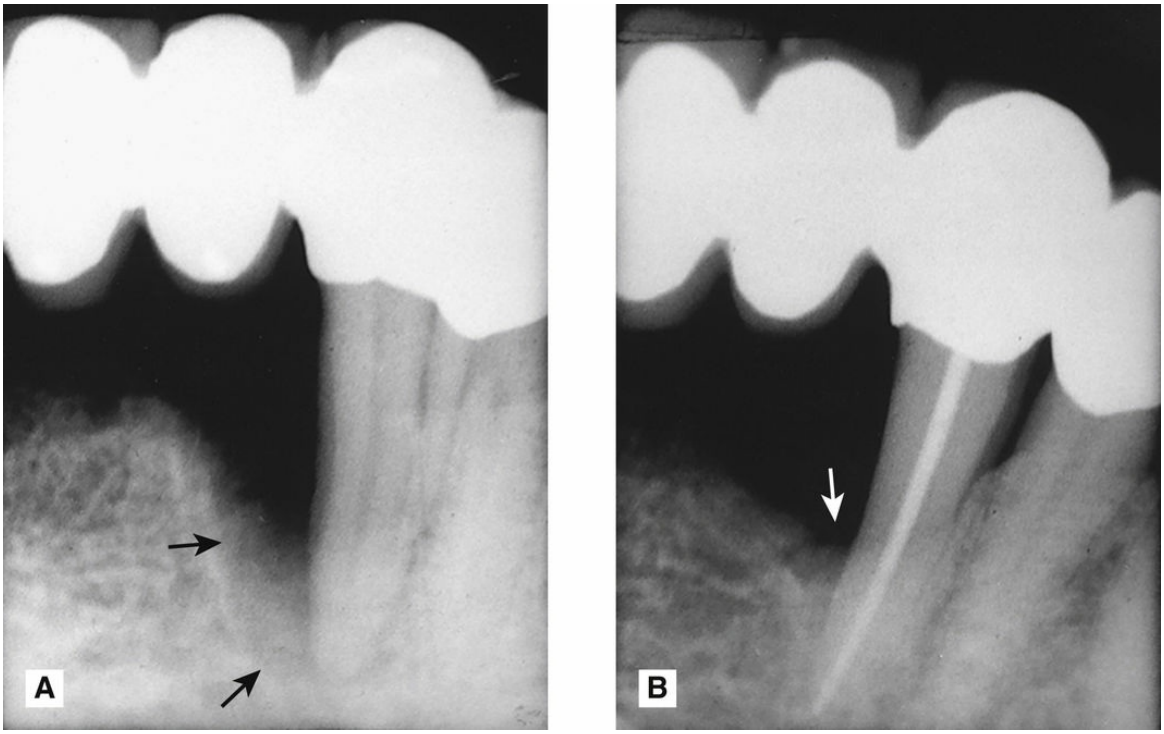


FIG. 22.15 Periapicals showing evaluation of treatment. (A) Preoperative image showing a *perio-endo* lesion affecting 3 with a very severe bony defect on the mesial aspect of the root (arrowed). (B) Follow-up image 2 years later after successful endodontic therapy and guided tissue regeneration. Note the reduced bony defect (arrowed).
Courtesy of Dr A. Sidi.

Limitations of Radiographic Diagnosis

The radiographic evaluation of the periodontal tissues is somewhat limited. The main limitations include:

- Superimposition and a two-dimensional image bringing about the following problems:
  - Difficulty in differentiating between the buccal and lingual crestal bone levels
  - Only part of a complex bony defect is shown
  - One wall of a bone defect may obscure the rest of the defect

  - Dense tooth or restoration shadows may obscure buccal or lingual bone defects, and buccal or lingual calculus deposits
  - Bone resorption in the furcation area may be obscured by an overlying root or bone shadow.
- Information is provided only on the hard tissues of the periodontium, because the soft tissue gingival defects are not normally detectable.
- Bone loss is detectable only when sufficient calcified tissue has been resorbed to alter the attenuation of the X-ray beam. As a result, the histological front of the disease process cannot be determined by the radiographic appearance.
- Technique variations in image receptor and X-ray beam positions can considerably affect the appearance of the periodontal tissues; hence the need for accurate, reproducible techniques as described in Chapter 10 .
- Exposure factors can have a marked effect on the apparent crestal bone height – overexposure causing *burn-out* when using film-based imaging.
- Complete reliance cannot be placed on the inherently inferior images of panoramic radiographs although they do provide a reasonable overview of the periodontal status (see Fig. 22.16 and Chapter 15).
- Some of the limitations of two-dimensional conventional radiography, in visualizing three-dimensional periodontal bone defects, can be overcome by high resolution cone beam computed tomography (see Chapter 16).

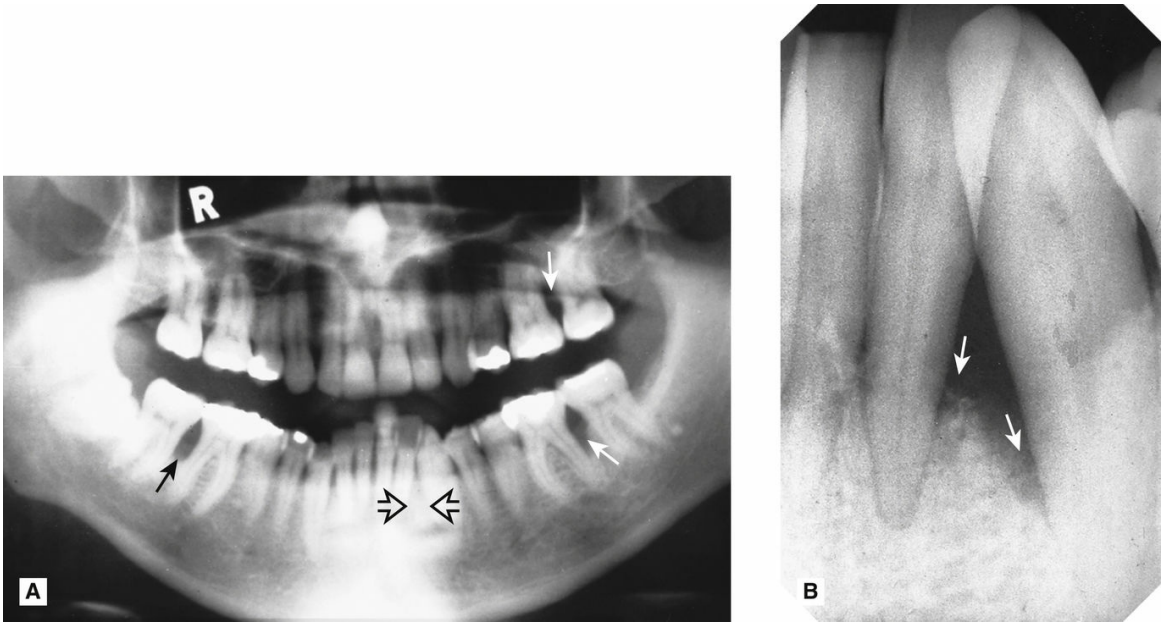


FIG. 22.16 (A) Panoramic radiograph showing bony defects in the molar regions (arrowed), but no evidence of a similar defect in the 23 region (open arrows) owing to superimposition of the radiopaque ghost shadow of the cervical vertebrae. (B) Periapical of 23 region taken at the same time showing the severe bony defect (arrowed) that was actually present.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

23

Implant Assessment

Introduction

The restoration of edentulous and partially dentate jaws using a variety of implant-retained prostheses has become a common clinical procedure in recent years. The implants are usually made of titanium and are described as either:

- Endosteal – placed in the bone. These are manufactured in a variety of shapes – screw, smooth sided or plate form, and essentially replace the roots of one or more teeth
- Subperiosteal – placed on the bone, under the periosteum and secured in place with screws.

This chapter provides a basic introduction to the commonly used endosteal dental implants. There are many different implant systems available and it is beyond the scope of this book to discuss all the systems and their various advantages and disadvantages.

However, whatever the system used, radiology plays an essential role in preoperative treatment planning, postoperative follow-up and long-term success evaluation.

Basic Endosseous Dental Implant Design

Modern implants consist of a number of different components as shown in Fig. 23.1 . Most commonly these include:

- A roughened, threaded, titanium osseous component that interacts, and osseointegrates, with the bone. These

components are manufactured in different lengths and diameters and geometrically are either:

- Cylindrical or parallel-sided
- Root form or tapering

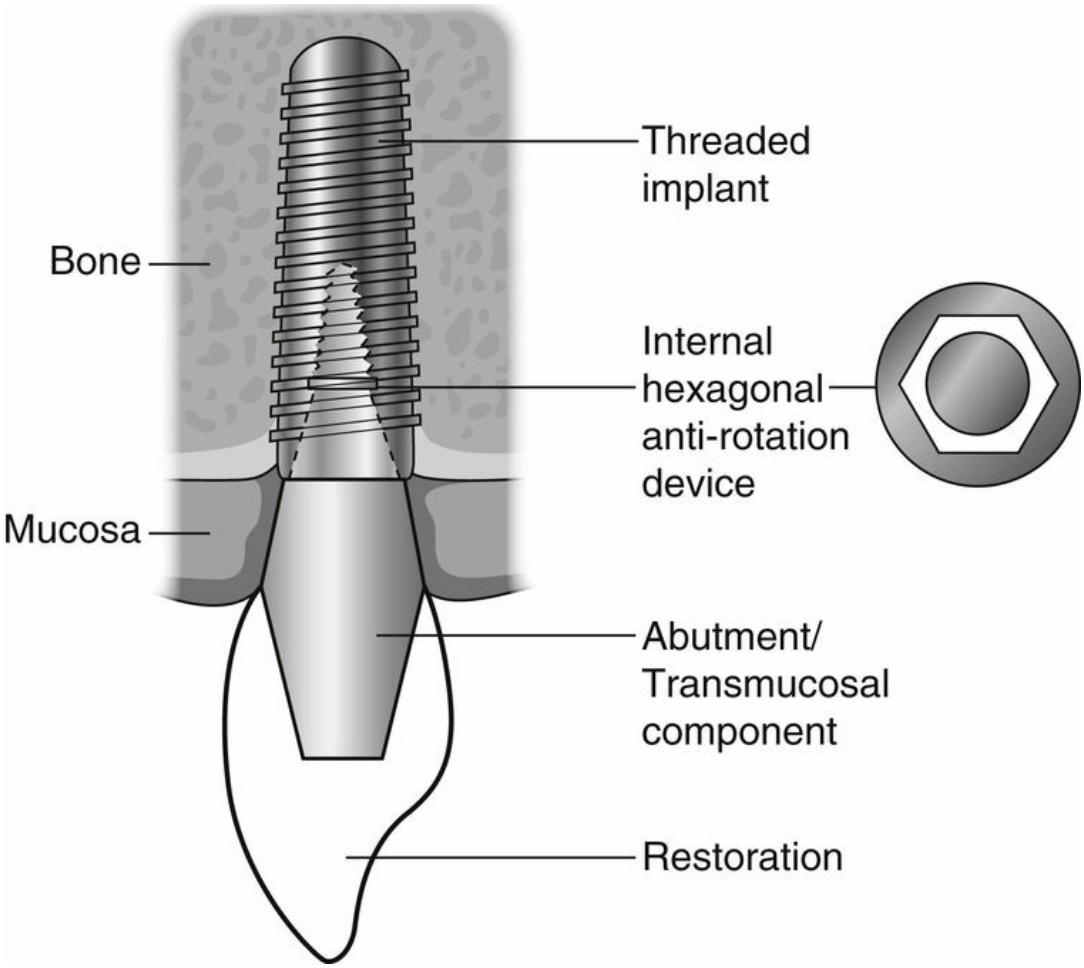


FIG. 23.1 Diagram showing the basic components of a typical endosseous dental implant.

- A smooth transmucosal component that interacts with the mucosa
- Together these components comprise either:
  - A *bone-level* implant that is inserted into bone at crestal or subcrestal-level plus a separate screw-in transmucosal component

  - An all-in-one *tissue-level* implant incorporating its own polished collar that protrudes above the crestal bone into the soft tissues (see Fig. 23.2)
- The abutment
- The final restoration which is typically either:
  - A crown
  - A bridge abutment
  - A denture abutment (ball, locator or bar).

Main Indications

Replacement of missing teeth in patients with:

- Healthy dentitions that have suffered tooth loss because of trauma
- Free-end saddles
- Developmentally missing teeth
- Loss of a single tooth as a result of root fracture, subcrestal/subgingival caries, failed endodontic treatment
- Remaining teeth not suitable as bridge abutments
- Severe ridge resorption making the wearing of dentures difficult
- Severe gag reflex
- Cleft palate and insufficient remaining teeth to support a denture/obturator
- Reconstruction after radical ablative jaw surgery
- A desire to avoid wearing a removable prosthesis
- The social stigma of being edentulous or wearing a removable denture.

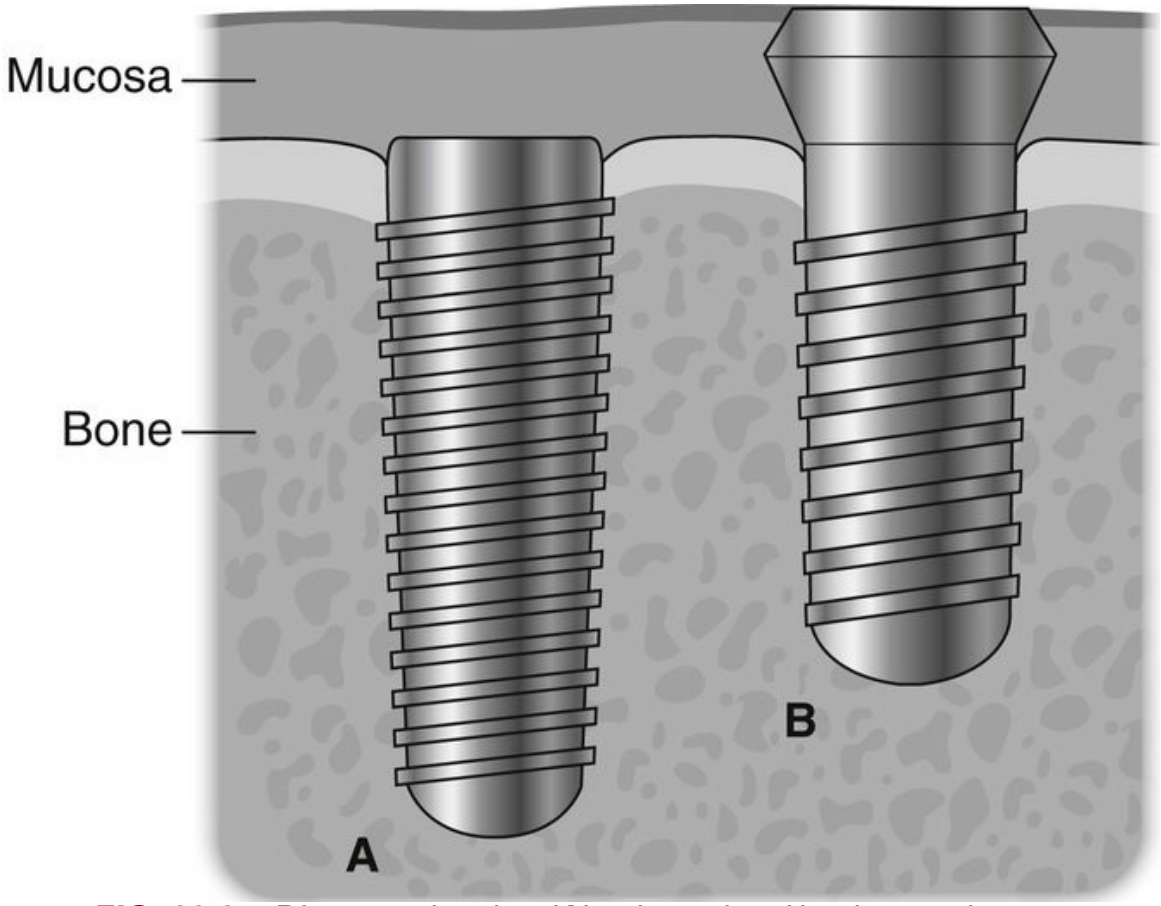


FIG. 23.2 Diagram showing **(A)** a *bone-level* implant and **(B)** a *tissue-level* implant.

Main Contraindications

These can include:

- Age – dental implants are effectively ankylosed to the bone, so they are generally not placed until the facial skeleton and jaws have stopped growing – usually at about 18 years of age
- Uncontrolled or untreated periodontal disease
- Poor plaque control
- Smoking
- Previous radiotherapy to the jaws
- Previous antiresorptive or antiangiogenic agents
- Untreated intraoral disease or malignancy

- Drug or alcohol abuse
- Poor medical history – e.g. recent heart attack or stroke
- Immunosuppression – e.g. after organ transplantation.

Treatment Planning Considerations

Clinical Examination

A thorough clinical examination using study casts and an overall evaluation of the patient are essential, because good case selection is imperative for the long-term success of implants. A multidisciplinary approach involving surgeons, prosthodontists and dental technicians is often adopted because of the many important factors that need to be taken into account, including:

- General factors about the patient, including:
  - Age
  - Medical history and general health
  - Dental and social history
  - Motivation, desires and expectations
- Extraoral factors including lip and smile lines
- Intraoral factors, including:
  - The condition and position of the remaining teeth (if present) and their occlusion
  - The status of the periodontal tissues
  - The level of oral hygiene and plaque control
  - The size and condition of any edentulous mandibular or maxillary alveolar ridges
  - The condition of the soft tissues.

Important Points to Note

- Final aesthetics – the ultimate position of the replacement teeth after restoration needs to be agreed with the patient before implant placement – *implant surgery should always be*

prosthodontically driven.

- If the required restorative result cannot be readily obtained, then implant site development using bone grafting and regenerative procedures should be considered.

Radiographic Examination

In recent years, various guidelines have been published in both the United States and in Europe recommending the most appropriate radiographic examination(s) to use in preoperative treatment planning. However, the reliable evidence on which to base recommendations remains limited. In addition, other variables contribute to disagreement on selection criteria in individual clinical situations. Examples of these include:

- The experience of the operator
- The thoroughness of the clinical examination, including the use of ridge-mapping techniques
- The proposed anatomical site.

There are a range of investigations that are suitable in different clinical situations. Clinical choice may well depend on availability of facilities. Investigations include:

- Periapical radiography
- Panoramic radiography (see Fig. 23.3A)
- Lower 90° occlusal radiography (see Fig. 23.3B)
- Lateral cephalometric radiography (see Fig. 23.3C)
- Cone beam computed tomography (CBCT)
- Computed tomography (CT)
- Magnetic resonance imaging (MRI).

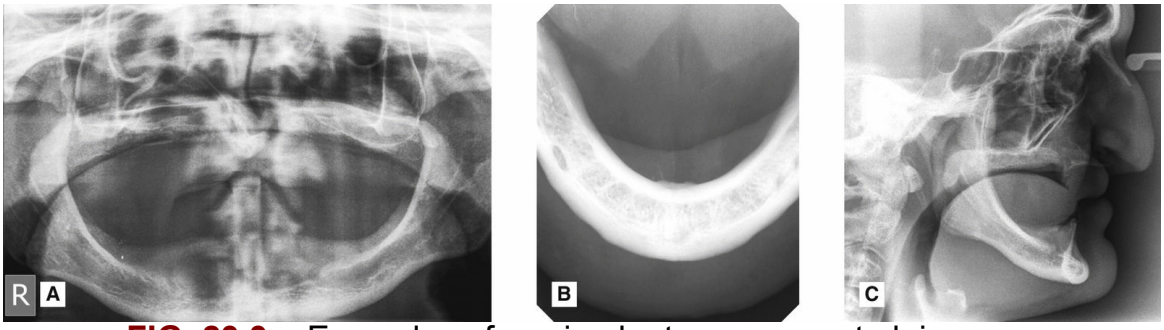


FIG. 23.3 Examples of pre-implant assessment plain images. **(A)** Panoramic radiograph. **(B)** Lower 90° occlusal radiograph. **(C)** Cephalometric radiograph (this view only supplies information on the morphology of the ridges in the anterior region).

Cone Beam Computed Tomography (CBCT)

CBCT is ideal for pre-implant assessment and treatment planning. Computer manipulation enables the production of panoramic and cross-sectional images (transaxial) (Figs. 23.4A and Fig. 23.5A). CBCT data can be imported into specially designed implant planning software programs such as Simplant® or Nobleguide®, to create three-dimensional reconstructions of the jaws and to plan implant placement in three dimensions. The software can be used to design drill guides so that implants can be placed accurately at the proposed sites (see Figs. 23.4B –C and 23.5B).

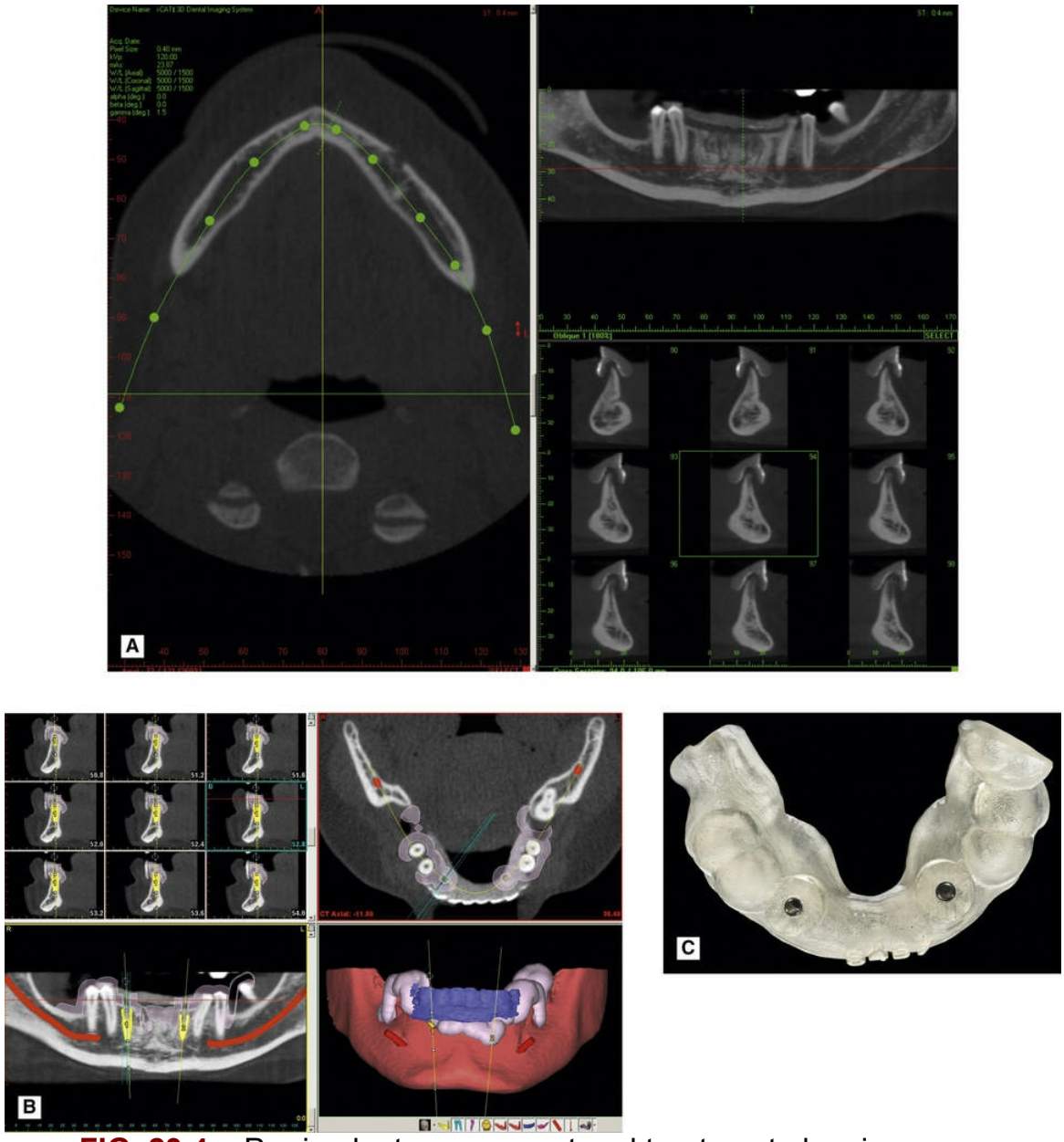


FIG. 23.4 Pre-implant assessment and treatment planning CBCT images of the mandible. **(A)** Axial, panoramic and transaxial images. **(B)** Using implant planning software to determine the ideal implant position in three-dimensions (DentsplySirona – Simplant®Pro). **(C)** The tooth borne drill guide to facilitate implant placement.
Courtesy of Dr M. Thomas.

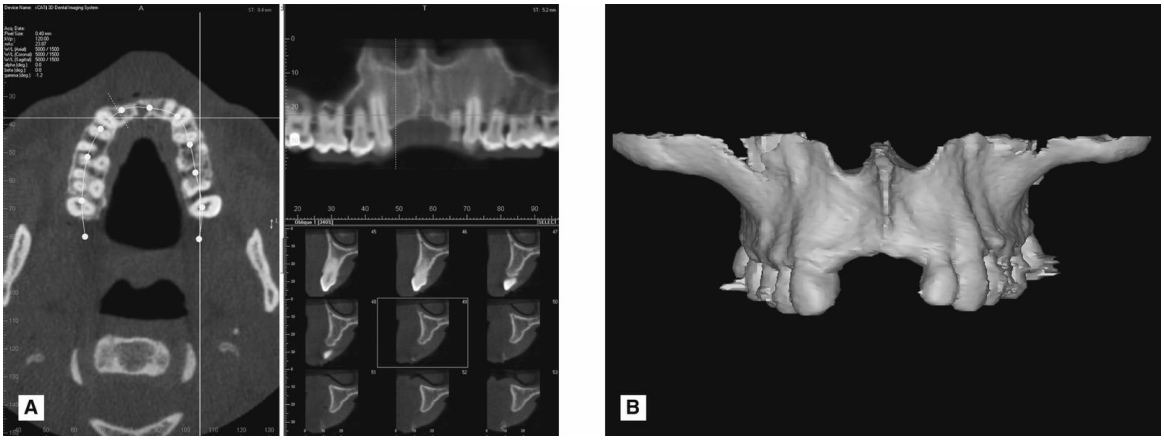


FIG. 23.5 Examples of pre-implant assessment CBCT images of the maxilla. **(A)** Axial, panoramic and a series of cross-sectional images (or transaxial) images. **(B)** 3-D surface-rendered reconstruction.
©DentsplySirona – Simplant®Pro.

Computed Tomography (CT)

Before the widespread use of CBCT, medical CT was used for pre-implant assessment using specifically written dental computer programs. These enabled reformatted cross-sectional, panoramic and three-dimensional images to be created.

Magnetic Resonance Imaging (MRI)

MRI offers the advantages of not using ionizing radiation and producing sectional images in any desired plane without reformatting as shown in Fig. 23.6 . However, facilities are not widely available and its use is restricted to certain specialized units.

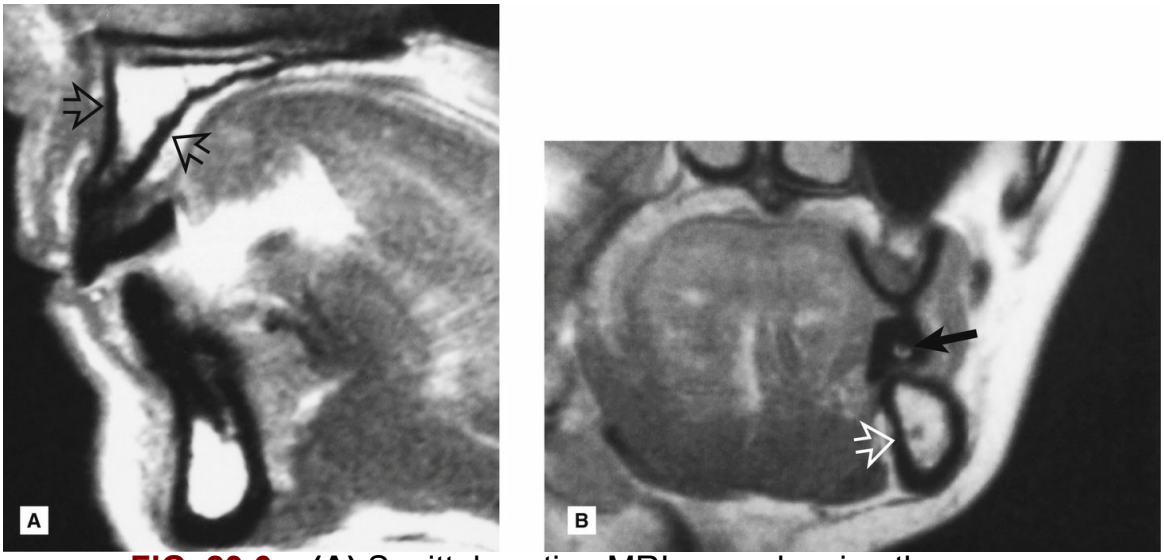


FIG. 23.6 **(A)** Sagittal section MRI scan showing the buccopalatal width and height of the edentulous anterior maxilla (arrowed). **(B)** Cross-sectional MRI showing an edentulous left mandible (open arrow) and the stent containing the gadolinium marker (black arrow). The inferior dental canal is clearly evident.
Courtesy of Mr C. Gray.

Radiographic Information Provided

These various radiographic investigations are used to show:

- The position and size of relevant normal anatomical structures, including the:
  - inferior dental canals
  - mental foramina
  - submandibular fossae
  - nasopalatine or incisive foramen and canal
  - nasal floor
- The shape and size of the antra, including the position of the antral floor and its relationship to adjacent teeth
- The presence of any underlying disease
- The presence of any retained roots or buried teeth
- The quantity of alveolar crest and basal bone, allowing direct

measurements of its height, width and shape
- The quality (density) of the bone, noting:
  – the amount of cortical bone present
  – the density of the cancellous bone
  – the size of the trabecular spaces.

Overall, preoperative imaging needs to allow the clinician the ability to assess the position and direction of implant placement to avoid damaging important adjacent structures.

Important Points to Note

- Cross-sectional imaging is important to provide information on the width and quality of the alveolar bone and the location of anatomical structures. The choice of imaging modality will obviously depend on the availability of facilities. The more complex the clinical case, the more comprehensive the radiographic assessment needs to be.
- The European Association for Osseointegration's Guidelines for the use of imaging in implant dentistry suggest cross-sectional imaging may be of benefit in the following situations:

– When clinical examination and conventional two-dimensional radiography have failed to adequately demonstrate relevant anatomy and absence of underlying disease
– To minimize the risk of damage to important anatomical structures
– In borderline cases where there is limited bone available for implant placement
– To improve implant positioning for biomechanical, functional and aesthetic reasons.

Their specific indications for cross-sectional imaging include:

  - When there is an extensive bony defect at the proposed implant site requiring augmentation, so that the size and extent of the defect can be determined
  - Before sinus augmentation (lift) surgery
  - To assess bone donor sites
  - Before special techniques such as zygomatic implants
  - In cases requiring computed assisted planning implant placement guides.
- Information from traditional two-dimensional radiographs can be enhanced by using plastic stents containing radiopaque makers, e.g. ball bearings of known size for calibration and markers to show the position of the planned restorations. Gadolinium markers are used with magnetic resonance imaging (see Fig. 23.6).
- Digitally constructed, or physically created, mock-ups of the proposed final prosthodontic/restorative result can provide precise planning information.

Peri-operative Imaging

Peri-operative imaging using a simple traditional two-dimensional periapical can be very useful to confirm implant alignment, especially when placing a single tooth implant between two adjacent teeth. This image can ensure a minimum safe distance is maintained from adjacent teeth so they are not inadvertently damaged (see Fig. 23.7).



FIG. 23.7 Peri-operative periapical showing the radiopaque implant drill in situ confirming the alignment of the proposed implant ensuring a minimum safe distance is maintained from the adjacent teeth.
Courtesy of Dr G. Paolinelis

Post-operative Evaluation and Follow-Up

Post-operative evaluation can be carried out immediately after surgery and usually after the initial 4 to 6-month healing period. Further clinical evaluation of the success or otherwise of the implant, including radiographic assessment, should be carried out on an annual basis for the first few years and then biannually. Geometrically accurate paralleling technique periapicals (either digital or film-based) are most commonly used.

NOTE : The accuracy can be checked by examining the geometric thread pattern of the fixture.

Criteria for Success

Ideally, implants should be evaluated against standardized success criteria and not simply assessed for their survival. Several *criteria for success* have been put forward over the years for the different implant systems. Those favoured by the author, and cited frequently in the literature, are those proposed by Albrektsson in 1986. These include:

1. That an individual, unattached implant is immobile when tested clinically.
2. That a radiograph does not demonstrate any evidence of peri-implant radiolucency.
3. That vertical bone loss be less than 0.2 mm annually after the implant's first year of service.
4. That individual implant performance be characterized by an absence of signs and symptoms such as pain, infection, neuropathies, paraesthesia or violation of the inferior dental canal.
5. That, in the context of the above, a success rate of 85% at the end of a 10-year period be the minimum criteria for success.

Radiographic Evaluation

Radiographs allow evaluation of criteria 2 and 3, as shown in Figs. 23.8 –23.9 , but also are used to assess:

- The position of the fixture in the bone and its relation to nearby anatomical structures
- Healing and integration of the fixture in the bone
- The peri-implant bone level and any subsequent vertical bone loss – threaded fixtures allow easy measurement if radiographs are geometrically accurate
- Development of any associated disease, e.g. *peri-implantitis*

- The fit of the impression components and abutment to the fixture
- The fit of the abutment to the crown or prosthesis
- Possible fracture of the implant or prosthesis.

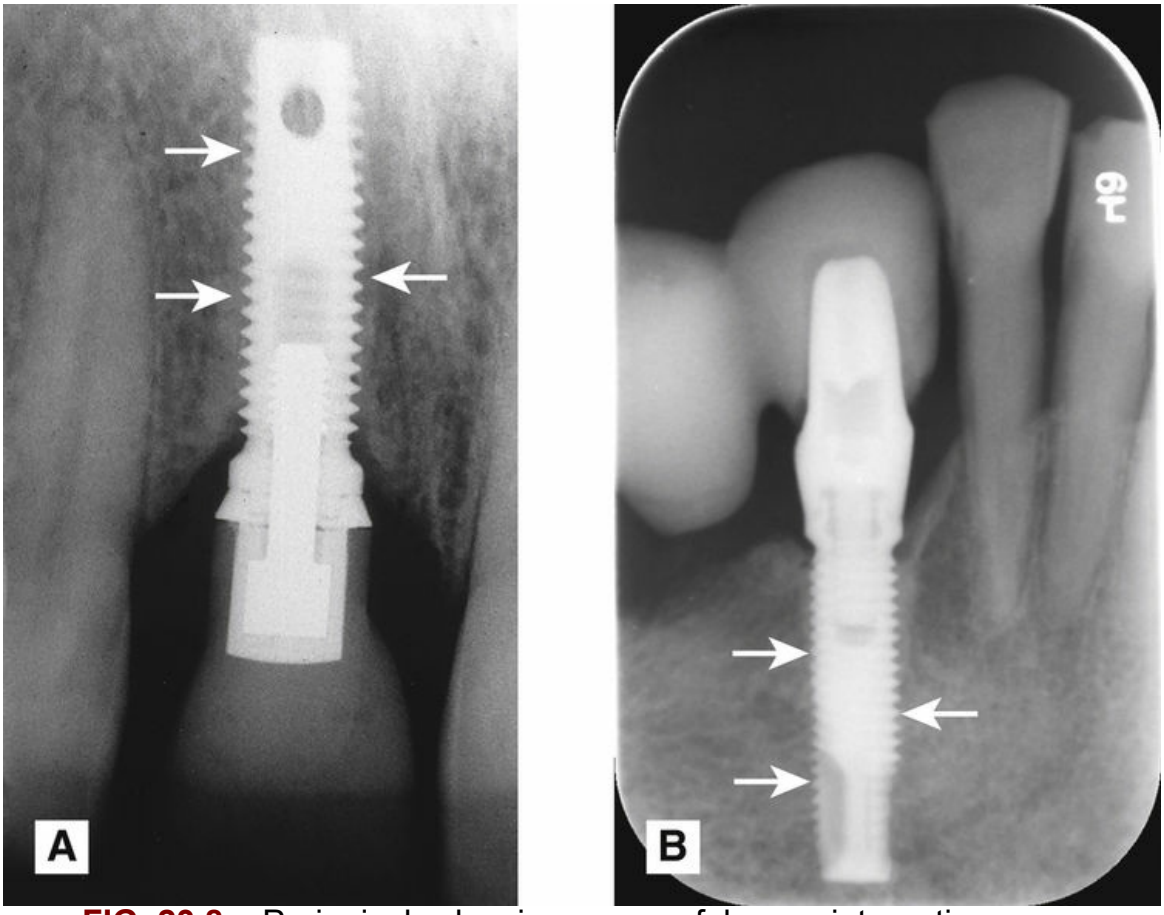


FIG. 23.8 Periapicals showing successful osseointegration of implants with bone. **(A)** Upper right central incisor region. **(B)** Lower right canine region. Note the bone–implant interface (arrowed); there is no radiolucency in between.

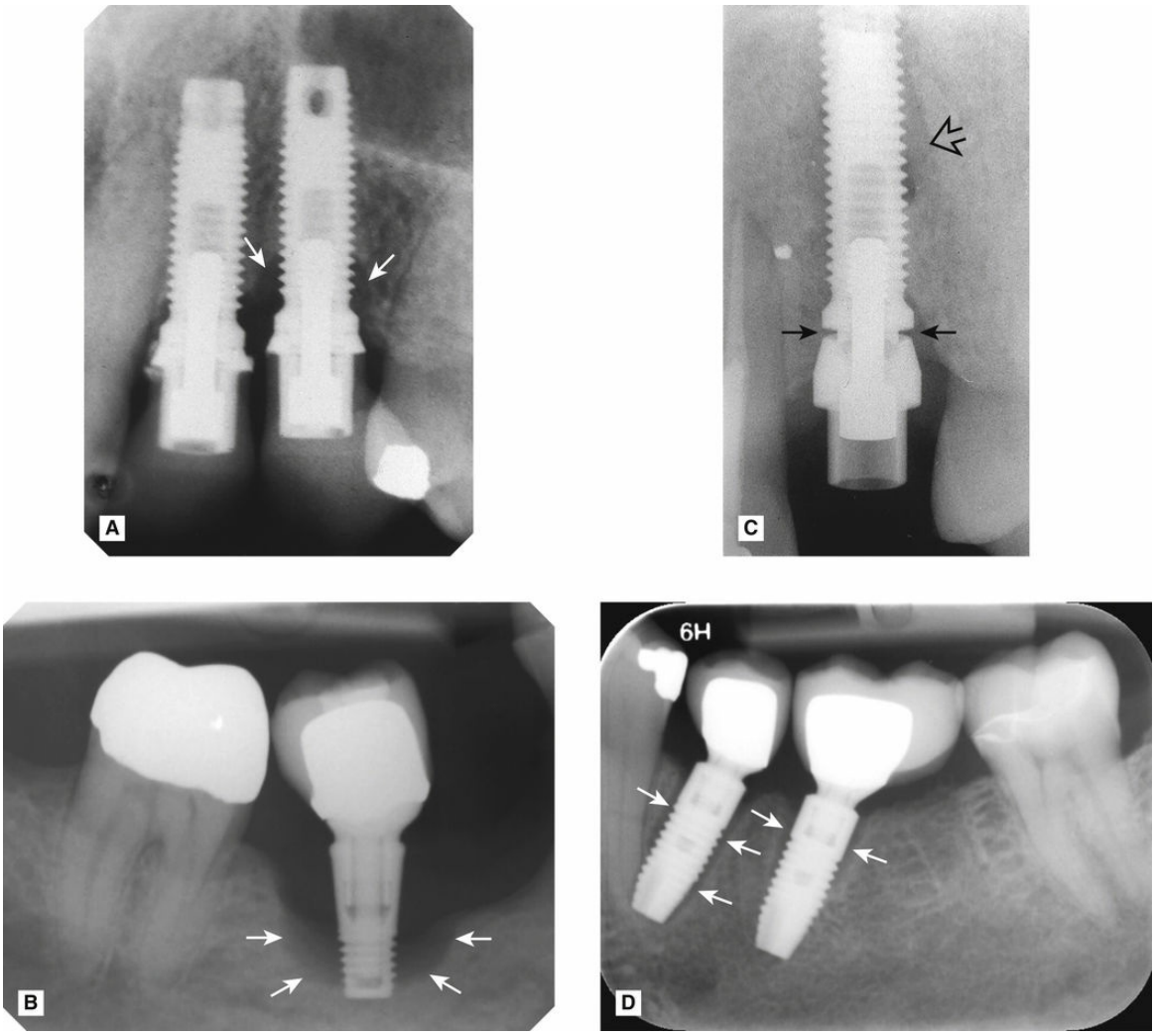


FIG. 23.9 Periapicals showing failing implants, **(A)** in the left anterior maxilla showing vertical bone loss (arrowed) around the thread of the implant, **(B)** in the right mandibular premolar region showing a large radiolucency surrounding the implant (arrowed), **(C)** in the left maxillary canine region showing incorrect seating of the abutment on the fixture (solid arrows) and residual radiolucency from the previous periapical area (open arrow) and **(D)** in the left mandibular molar region showing radiolucent lines between the bone and the metallic implant (arrowed).

Examples courtesy of Prof R. Palmer, Mr L. Howe and Mr W. McLaughlin.

Footnote

The limited nature of the information provided by conventional two-dimensional radiographs on the width or thickness of the alveolar bone cannot be overemphasized. Inadequate clinical and radiographic assessment of possible implant sites, before surgery, may lead to implant failure and more seriously, to temporary or permanent nerve damage and possible litigation.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

24

Developmental Abnormalities

Introduction

There are many developmental abnormalities that can affect the teeth and facial skeleton. In most cases, clinicians need little more than to be able to recognize these abnormalities – this recognition being based on both the clinical and radiographic findings. Therefore, the bulk of this chapter is designed like an atlas to show examples of some of the more common and important abnormalities that have characteristic radiographic features. A broad classification of the main conditions is also included.

Two important developmental anomalies are often encountered: unerupted mandibular wisdom teeth and malpositioned maxillary canines. These two topics are described in more detail.

Classification of Developmental Abnormalities

Developmental anomalies of the maxillofacial region are usually classified into:

- Anomalies of the teeth
- Skeletal anomalies.

Anomalies of the Teeth

These include abnormalities in:

- Number
- Structure
- Size
- Shape
- Position.

Abnormalities in Number

Missing teeth

- Localized anodontia or hypodontia – usually third molars, upper lateral incisors or second premolars
- Anodontia or hypodontia associated with systemic disease – e.g. Down's syndrome, ectodermal dysplasia.

Additional teeth

- Localized hyperdontia
  - Supernumerary teeth
  - Supplemental teeth
- Hyperdontia associated with specific syndromes, e.g. cleidocranial dysplasia, Gardner's syndrome.

Abnormalities in Structure

Genetic defects

- Amelogenesis imperfecta
  - Hypoplastic type
  - Hypocalcified type
  - Hypomature type
- Dentinogenesis imperfecta
- Shell teeth
- Regional odontodysplasia (ghost teeth)
- Dentinal dysplasia (radicular and coronal types).

Acquired defects

- Turner teeth – enamel defects caused by infection from overlying deciduous predecessor
- Congenital syphilis – enamel hypoplastic and altered in shape
- Severe childhood fevers, e.g. measles – linear enamel defects
- Fluorosis – discoloration or pitting of the enamel
- Discoloration – e.g. tetracycline staining.

Abnormalities in Size

- Macrodontia – large teeth
- Microdontia – small teeth, including rudimentary teeth.

Abnormalities in Shape

Anomalies affecting whole teeth

- Fusion – two teeth joined together from the fusion of adjacent tooth germs
- Gemination (twinning) – two teeth joined together but arising from a single tooth germ
- Concrescence – two teeth joined together by cementum
- Dens-in-dente (invaginated odontome) – infolding of the outer surface of a tooth into the interior usually in the cingulum pit region of maxillary lateral incisors.

Anomalies affecting the crowns

- Extra cusps
- Congenital syphilis
  - *Hutchinson's incisors* – crowns small, screwdriver or barrel-shaped, and often notched
  - *Moon's/mulberry molars* – dome-shaped or modular
- Tapering pointed incisors – ectodermal dysplasia.

Anomalies affecting roots and/or pulp canals

- Number – additional roots, e.g. two-rooted incisors, three-rooted premolars or four-rooted molars
- Morphology, including:
  - Bifid roots
  - Excessively curved roots
  - *Dilaceration* – sharp bend in the root direction
  - *Taurodontism* – short, stumpy roots and longitudinally enlarged pulp chambers
- Pulp stones – localized or associated with specific syndromes, e.g. Ehlers-Danlos syndrome
- Cementoma (see odontogenic tumours in Chapter 27).

Odontomes

- Compound odontome – made up of one or more small tooth-like denticles (see Chapter 27)
- Complex odontome – complex mass of disorganized dental tissue (see Chapter 27)
- Enameloma/enamel pearl.

Abnormalities in Position

Delayed eruption

- Local causes
  - Loss of space
  - Abnormal crypt position – especially $\overline{8}|\overline{8}$ and $\underline{3}|\underline{3}$
  - Overcrowding
  - Additional teeth
  - Retention of deciduous predecessor
  - Dentigerous and eruption cysts
- Systemic causes
  - Metabolic diseases, e.g. cretinism and rickets
  - Developmental disturbances, e.g. cleidocranial

dysplasia
– Hereditary conditions, e.g. gingival fibromatosis and cherubism.

Other positional anomalies

- Transposition, two teeth occupying exchanged positions
- Wandering teeth, movement of unerupted teeth for no apparent reason (distal drift)
- Infraocclusion, second deciduous molars apparently descend into the jaws. These teeth in fact remain in their original position while the adjacent alveolar bone grows normally. Because these teeth seem to *submerge,* the original term for this positional anomaly was *submersion.*

Skeletal Anomalies

These include:

- Abnormalities of the mandible and/or maxilla
- Other rare developmental diseases and syndromes.

Abnormalities of the Mandible and/or Maxilla

Micrognathia

- True micrognathia – usually caused by bilateral hypoplasia of the jaw or agenesis of the condyles
- Acquired micrognathia – usually caused by unilateral early ankylosis of the temporomandibular joint.

Macrognathia (prognathism)

- Genetic
- Relative prognathism – mandibular/maxillary disparity

- Acquired, e.g. acromegaly owing to excessive growth hormone from a pituitary tumour.

Other mandibular anomalies

- Condylar hypoplasia
- Condylar hyperplasia
- Bifid condyle
- Coronoid hyperplasia.

Cleft lip and palate

- Cleft lip
  - Unilateral, with or without alveolar ridge
  - Bilateral, with or without alveolar ridge
- Cleft palate
  - Bifid uvula
  - Soft palate only
  - Soft and hard palate
- Clefts of lip and palate (combined defects)
  - Unilateral (left or right)
  - Cleft palate with bilateral cleft lip.

Localized bone defects

- Exostoses (see Chapter 27)
  - Torus palatinus
  - Torus mandibularis
- Idiopathic bone cavities (see Chapter 26)
  - Stafne's bone cavity.

Other Rare Developmental Diseases and Syndromes

- Cleidocranial dysplasia (see Chapter 28)
- Gorlin's syndrome (nevoid basal cell carcinoma syndrome) (see Chapter 26)
- Eagle's syndrome
- Crouzon's syndrome (craniofacial dysostosis)
- Apert's syndrome
- Mandibular facial dysostosis (Treacher–Collins syndrome).

Typical Radiographic Appearances of The More Common and Important Developmental Abnormalities

Examples of the more common and important developmental abnormalities of both the teeth and the maxillofacial skeleton are shown in Figs. 24.1 –24.35 .



FIG. 24.1 Panoramic radiograph showing hypodontia in a patient with ectodermal dysplasia. Numerous teeth are missing.

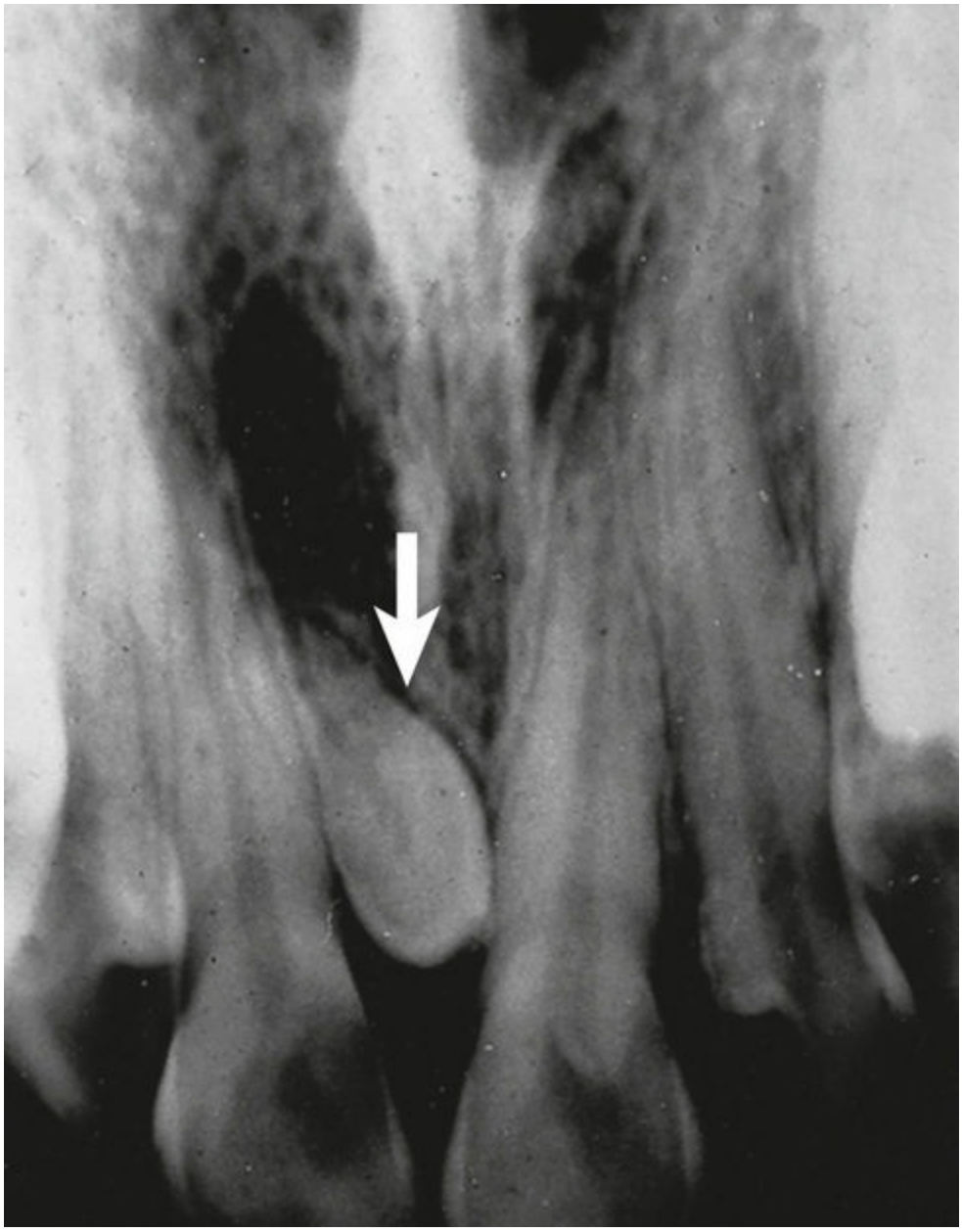


FIG. 24.2 Periapical showing a supernumerary or mesiodens (arrowed) between $\underline{1}\underline{1}$.

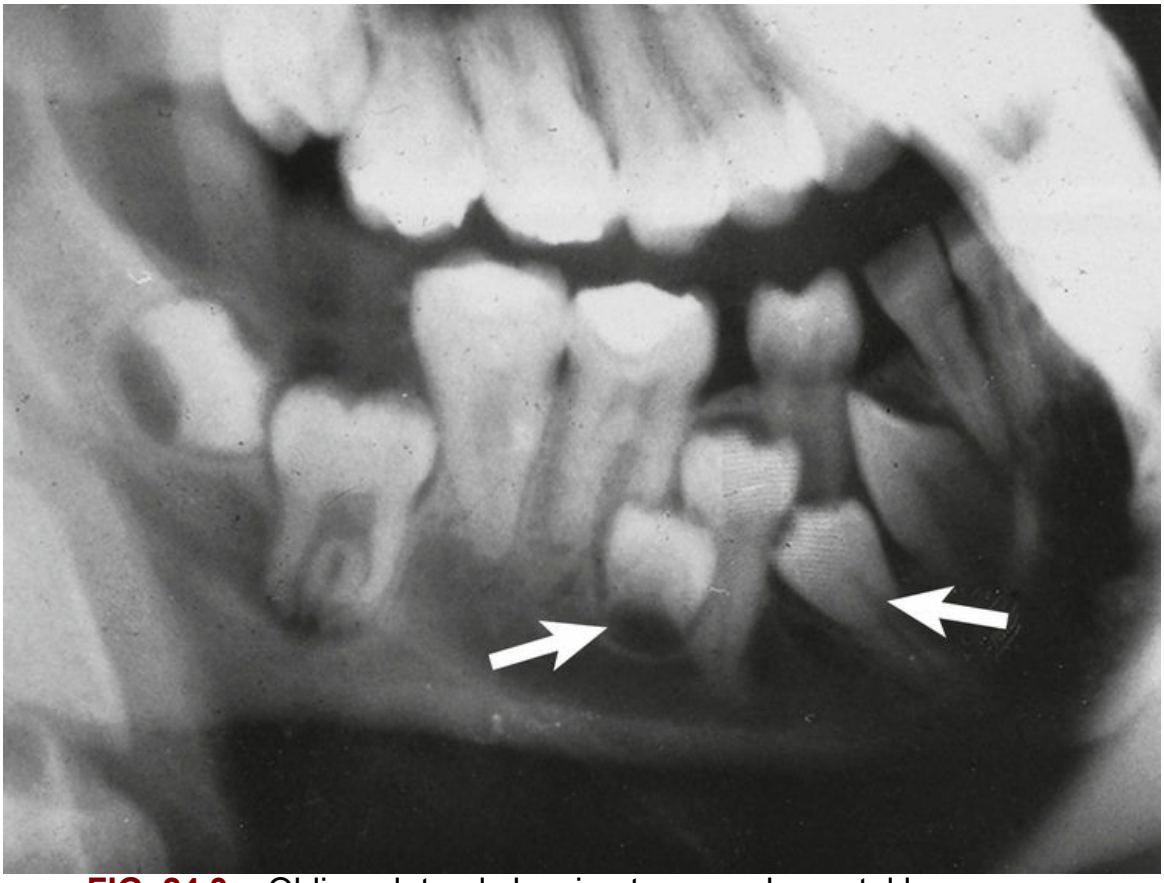


FIG. 24.3 Oblique lateral showing two supplemental lower premolars (arrowed) and a developing $\overline{9}$|.

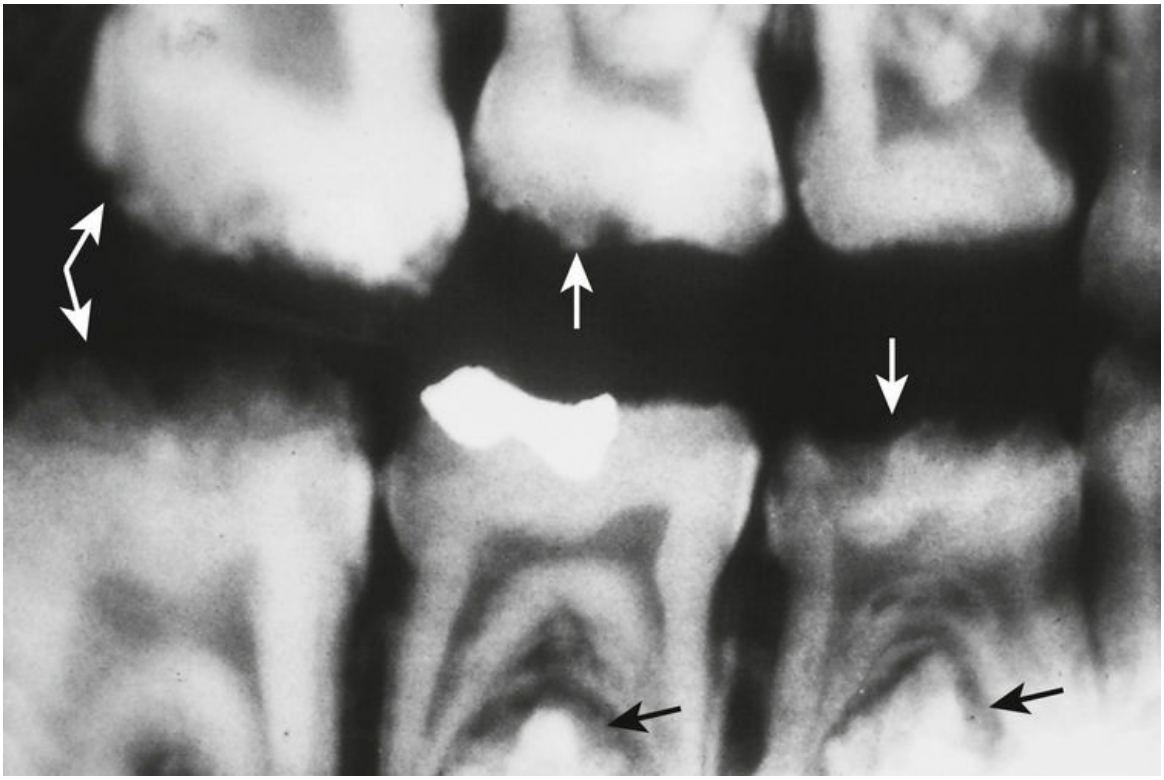


FIG. 24.4 Right bitewing showing the enamel defects of amelogenesis imperfecta (arrowed) in both the deciduous and permanent dentitions.

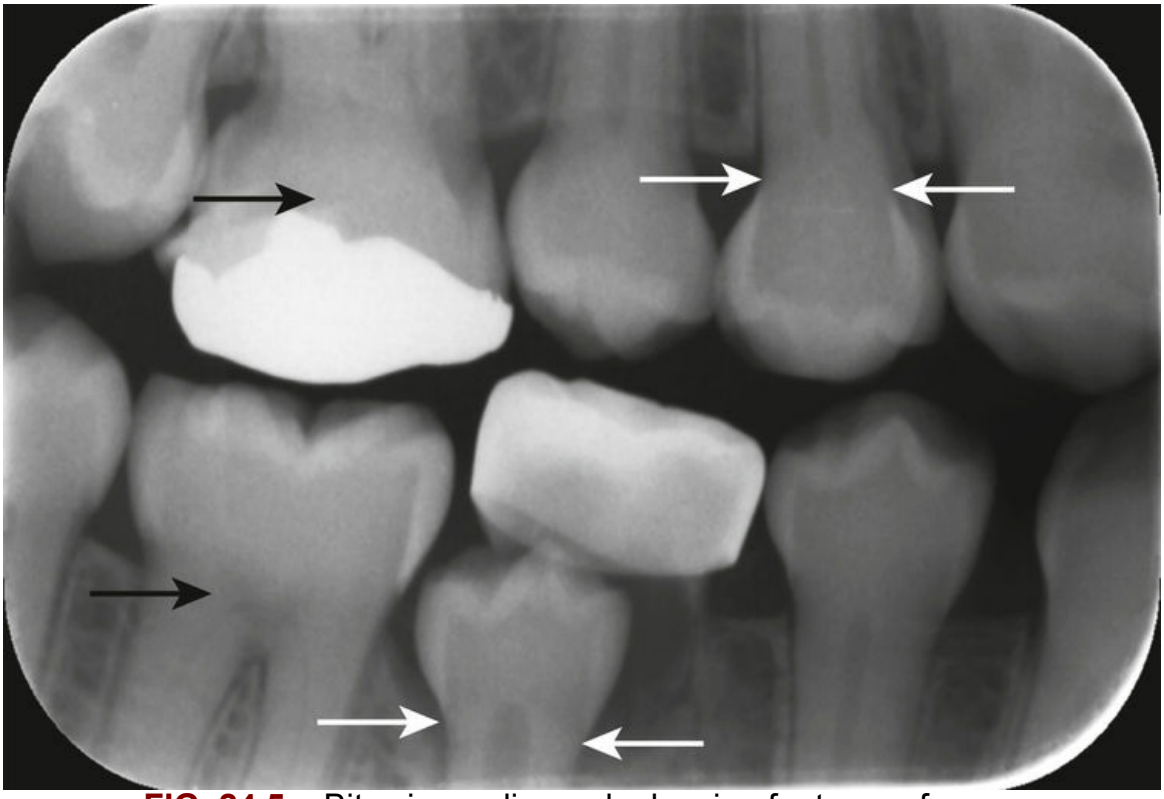


FIG. 24.5 Bitewing radiograph showing features of dentinogenesis imperfecta. Note the partial obliteration of the pulp chambers (black arrows), bulbous crowns and constriction at the cervical margin of the teeth (white arrows).

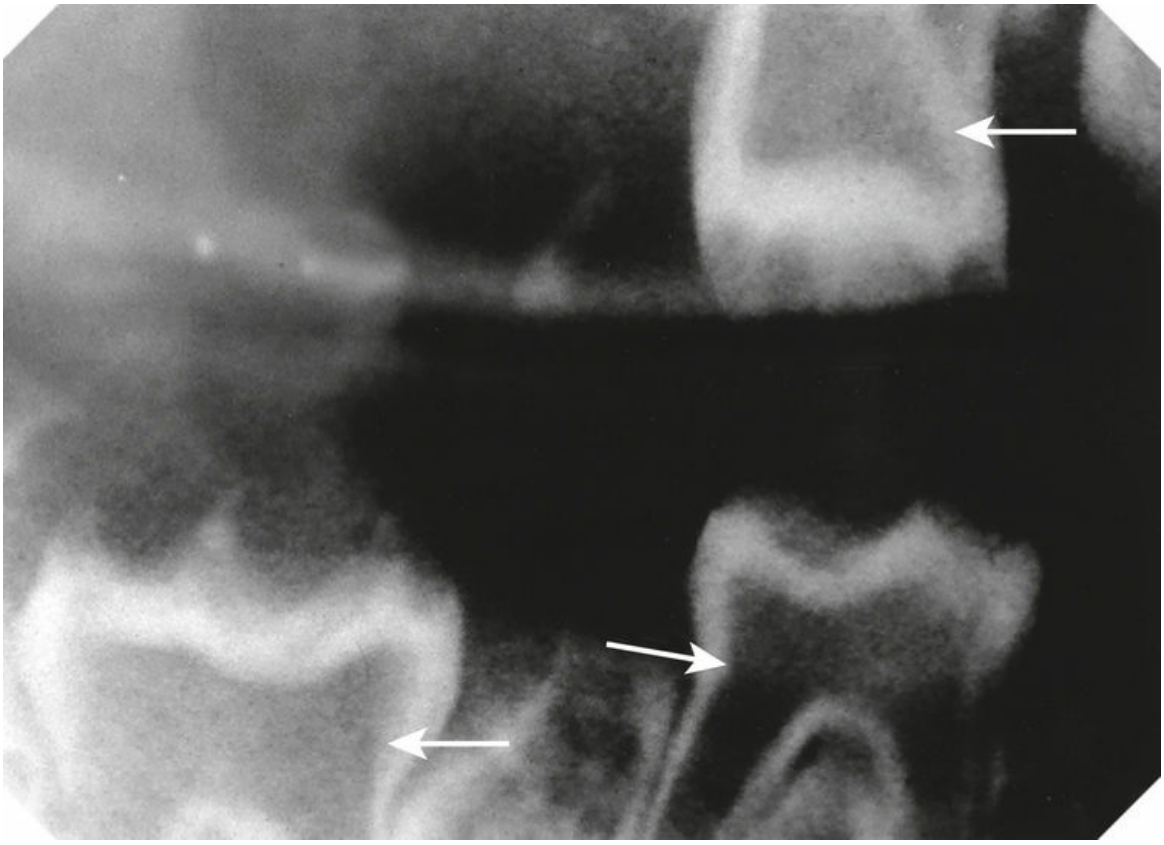


FIG. 24.6 Bitewing showing so-called *shell teeth* – a type of dentinogenesis imperfecta. The enamel is essentially normal but there is almost no dentine and the pulp chambers are very large (arrowed).



FIG. 24.7 Periapical showing a microdont ⊠ (arrowed).

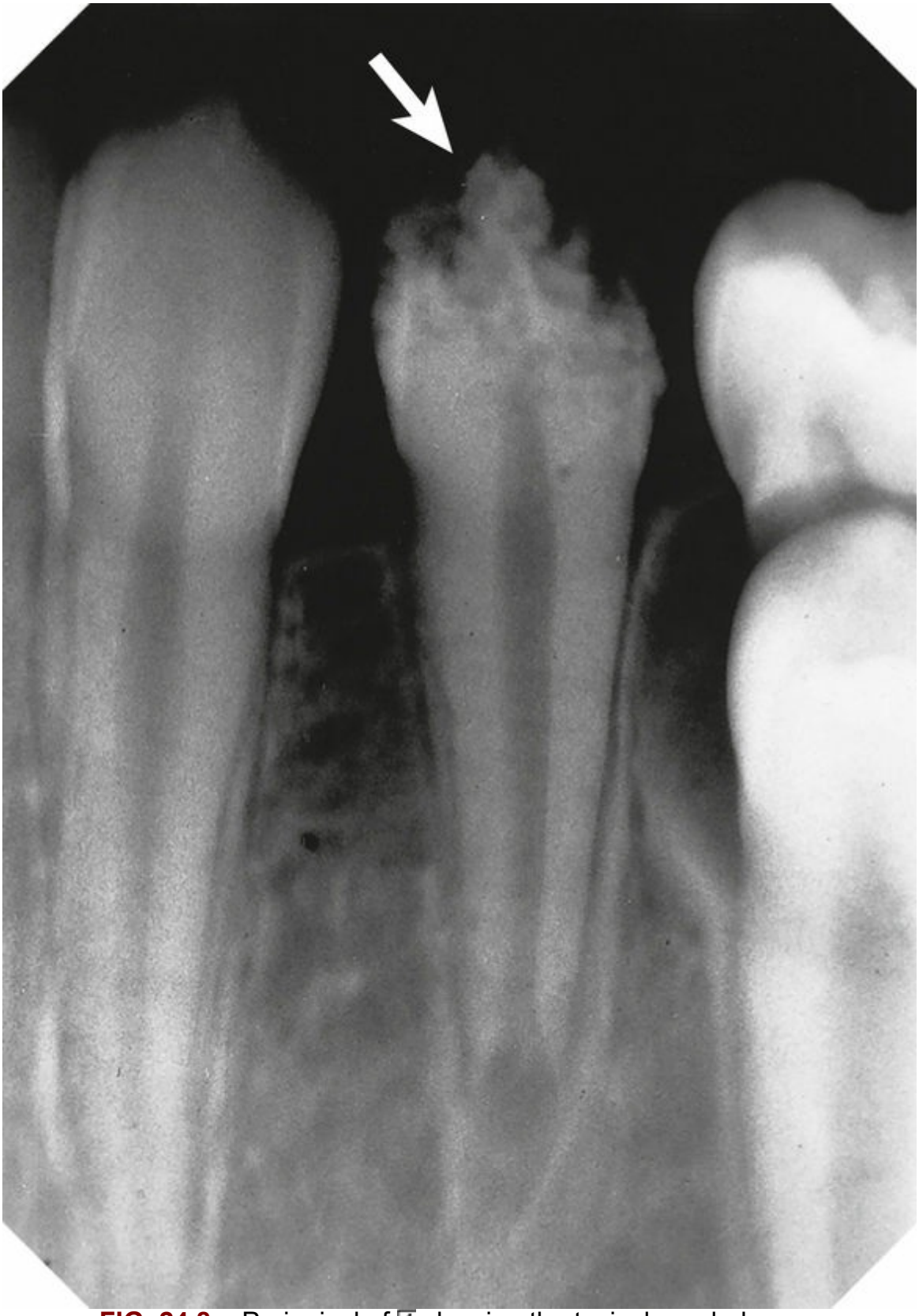


FIG. 24.8 Periapical of 4 showing the typical gnarled

enamel defects of a Turner tooth (arrowed), caused by previous infection of the deciduous predecessor.

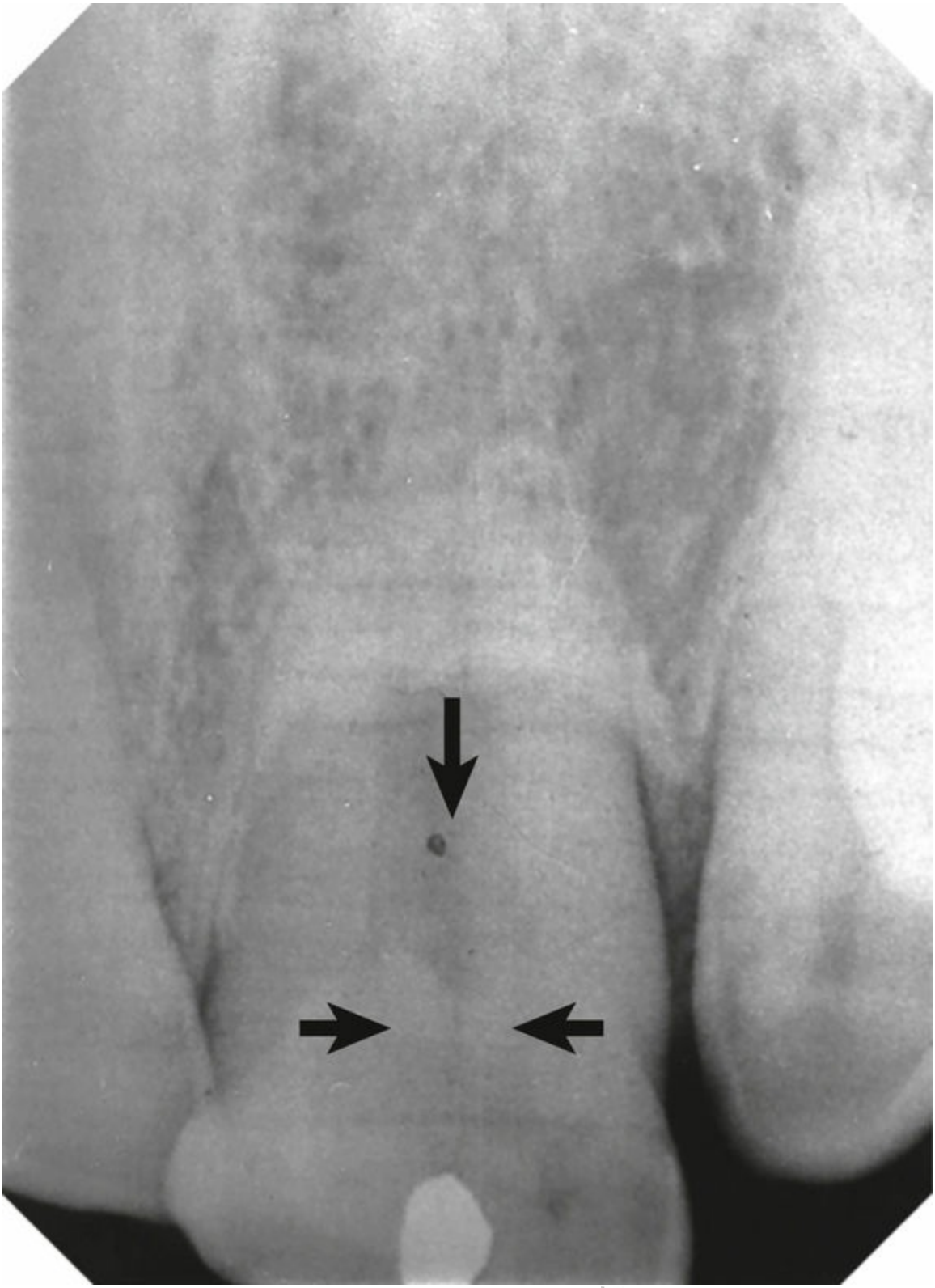


FIG. 24.9 Periapical showing fusion of 12 (arrowed).

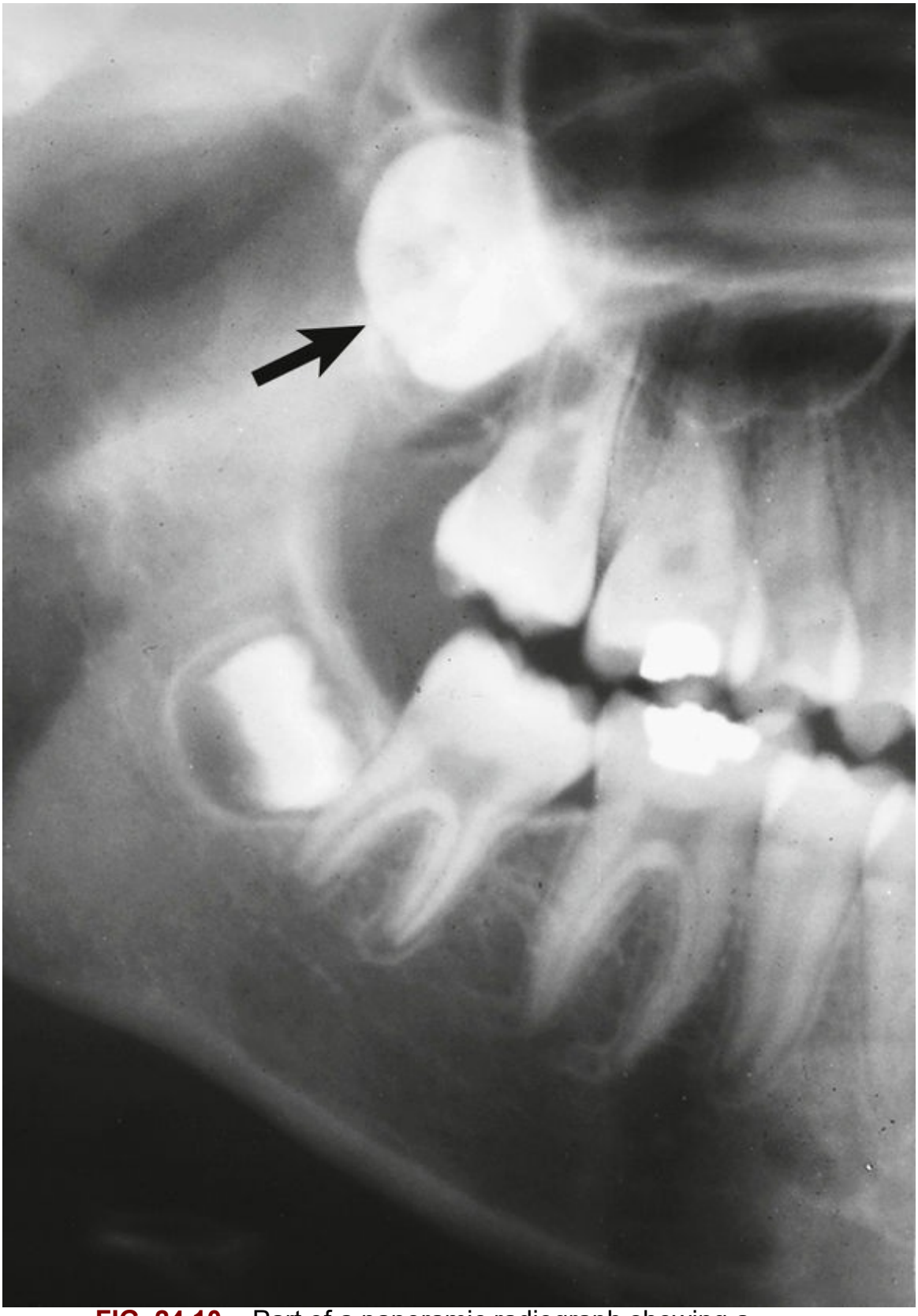


FIG. 24.10 Part of a panoramic radiograph showing a

macrodont 8 (arrowed).

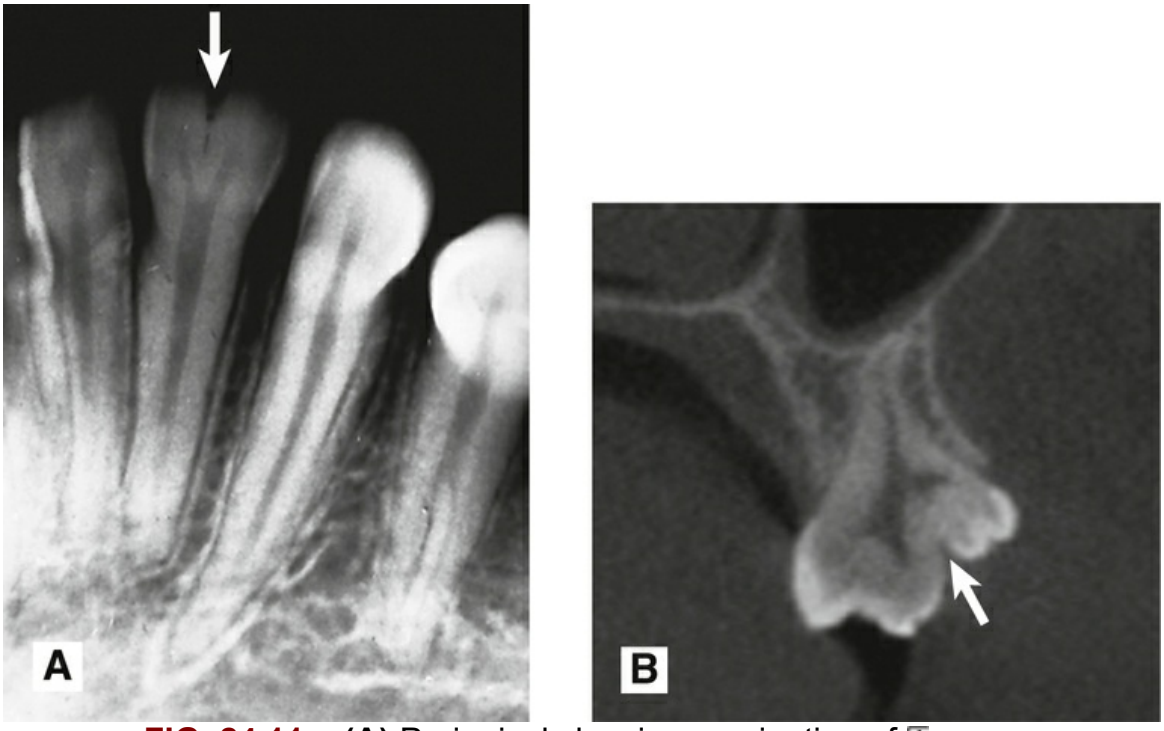


FIG. 24.11 **(A)** Periapical showing gemination of 1 (arrowed). **(B)** Cross-sectional CBCT image showing gemination of 5 (arrowed).

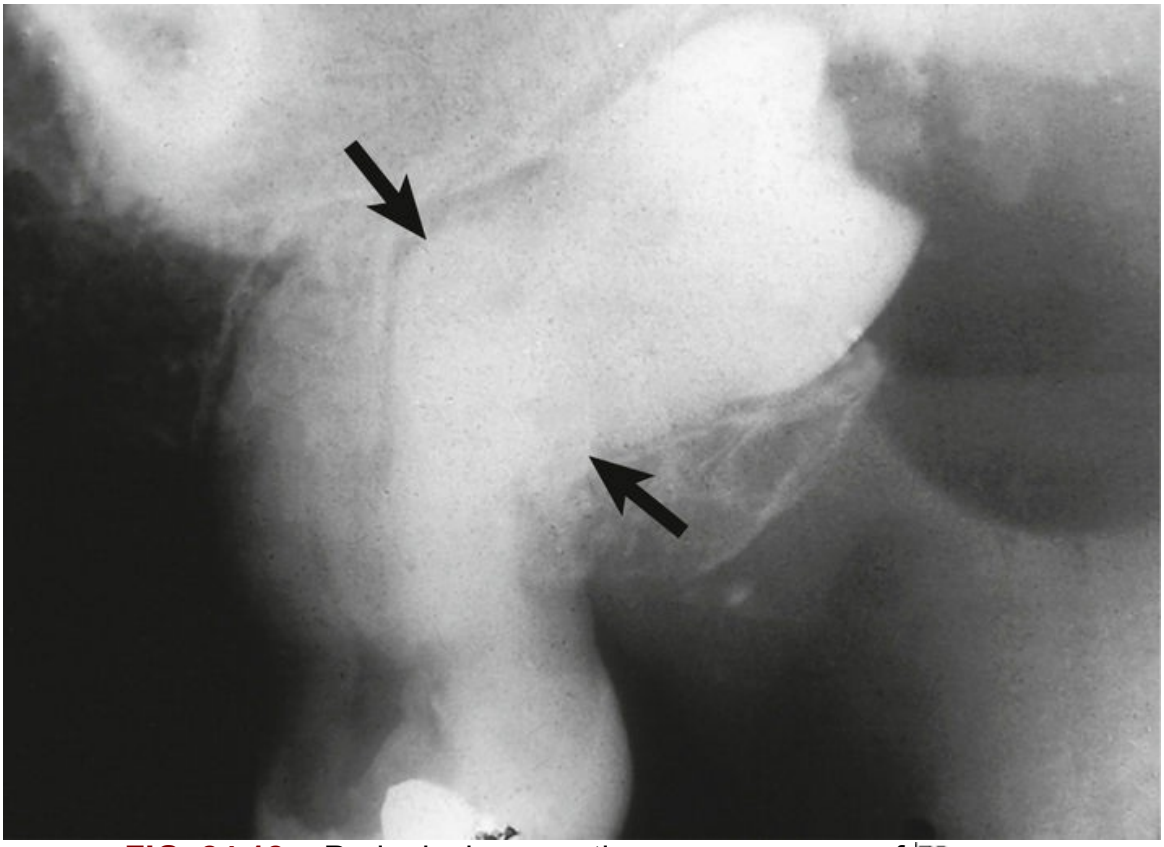


FIG. 24.12 Periapical suggesting concrescence of 78 (arrowed). Note it is not possible to be certain simply from the radiograph that 78 are joined together with cementum.

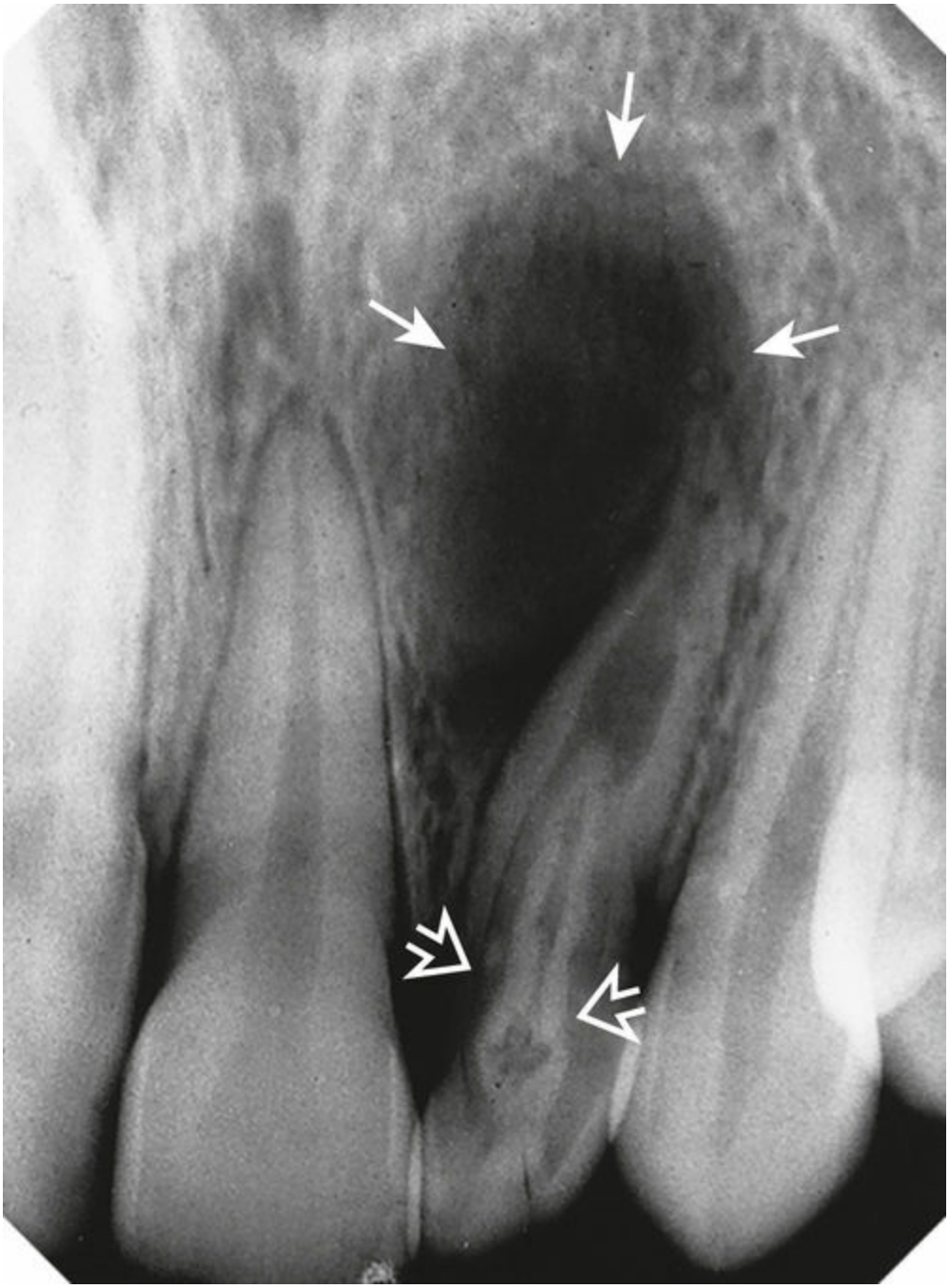
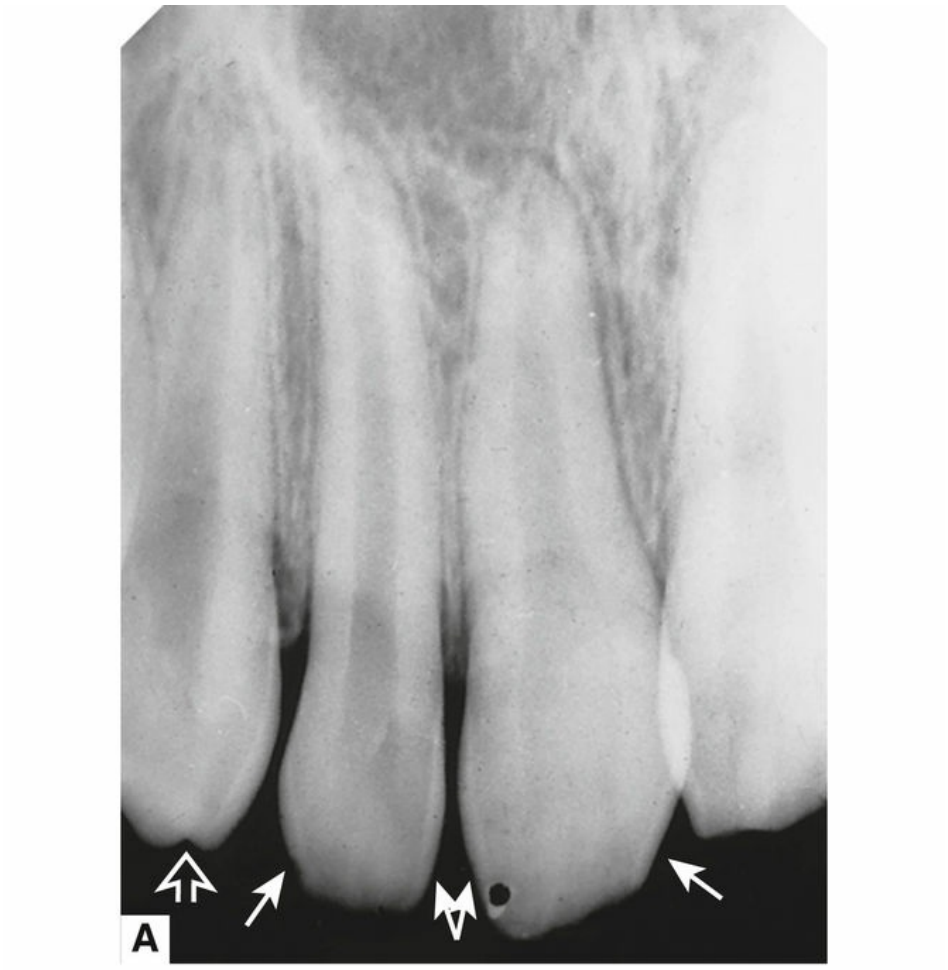


FIG. 24.13 Periapical, showing a dens-in-dente or invaginated odontome involving $\underline{2}$ (open arrows). There is an associated periapical area of infection (solid arrows) – a common occurrence with dens-in-dente.


A

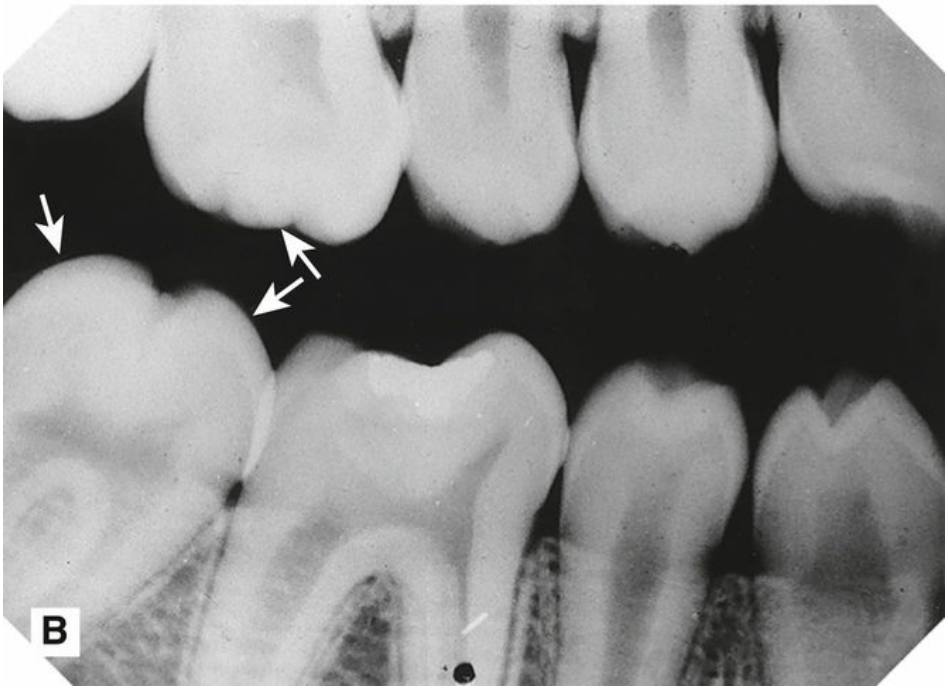

B

FIG. 24.14 Congenital syphilis. **(A)** Periapical of maxillary incisors and canine showing Hutchinson's teeth. Note the tapering screwdriver-shaped crowns (solid arrows) and the incisal edge notching (open arrow). **(B)** Bitewing showing Moon's/mulberry molars. Note the dome-shaped, nodular appearance of the molars (arrowed).

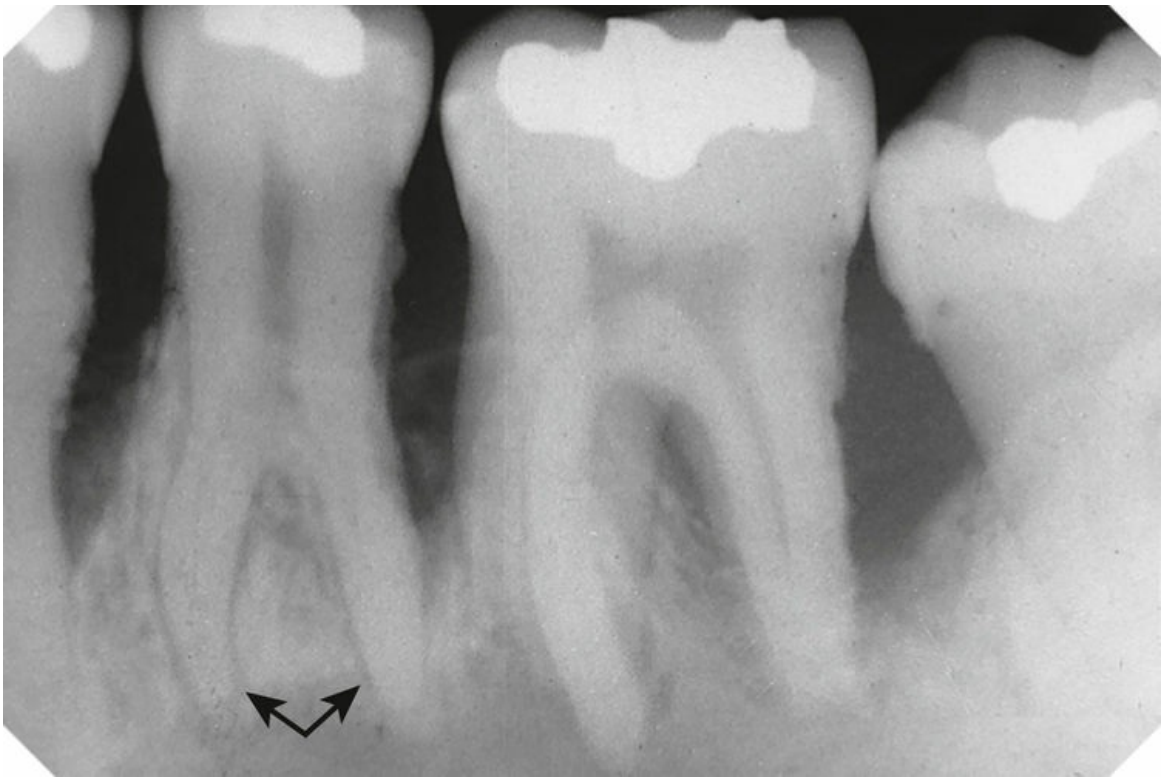


FIG. 24.15 Periapical showing a bifid lower premolar root (arrowed).

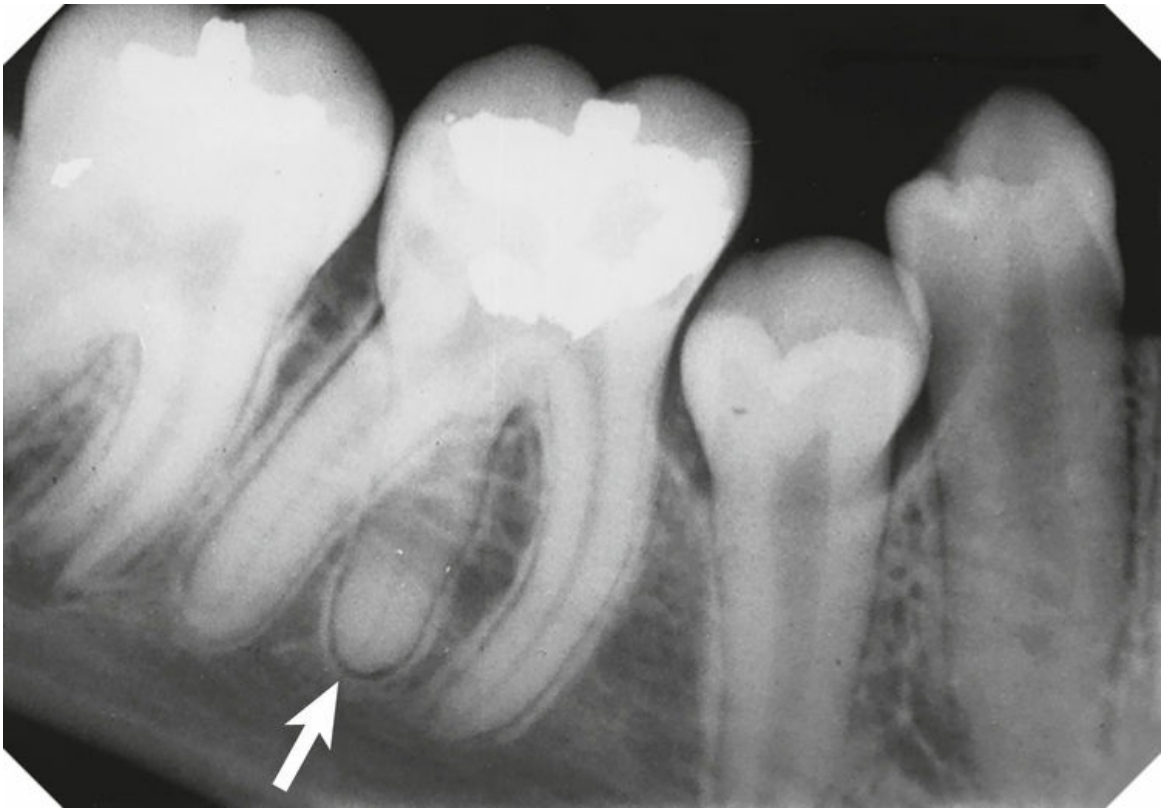


FIG. 24.16 Periapical showing a three-rooted lower first molar (arrowed).

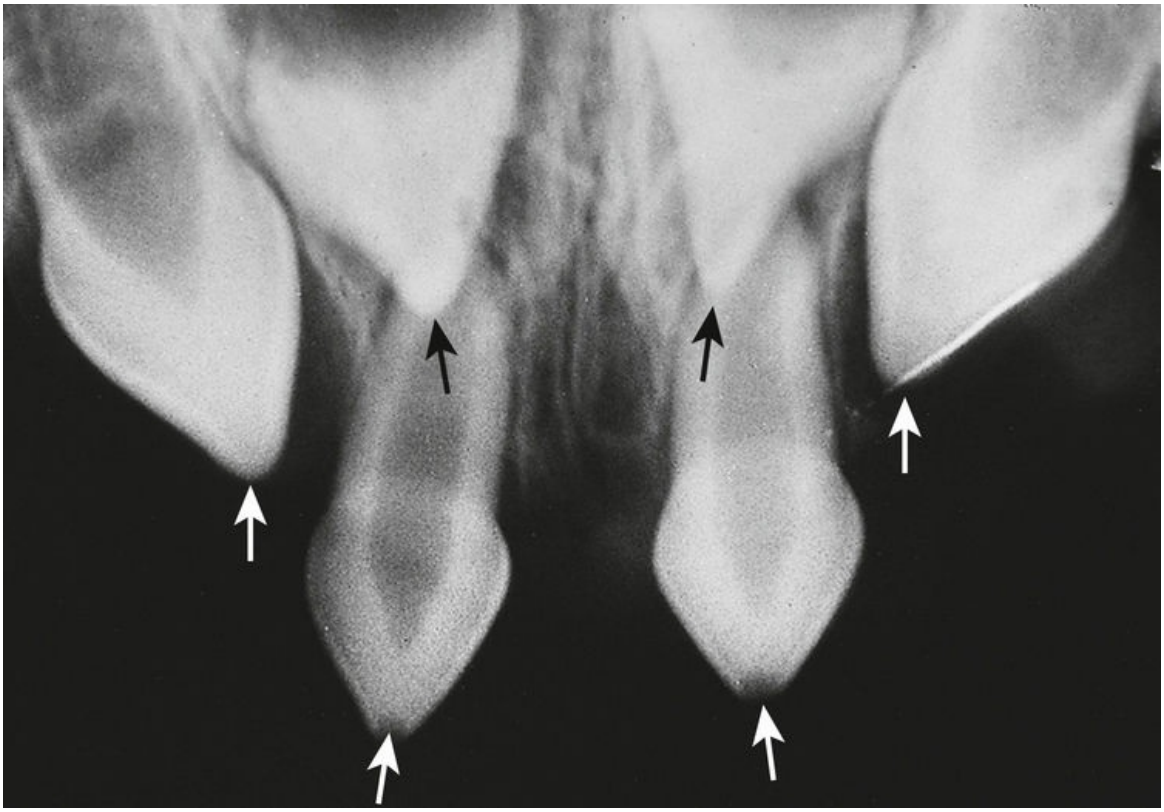


FIG. 24.17 Periapical showing the typical tapering pointed incisor teeth (arrowed) of ectodermal dysplasia.

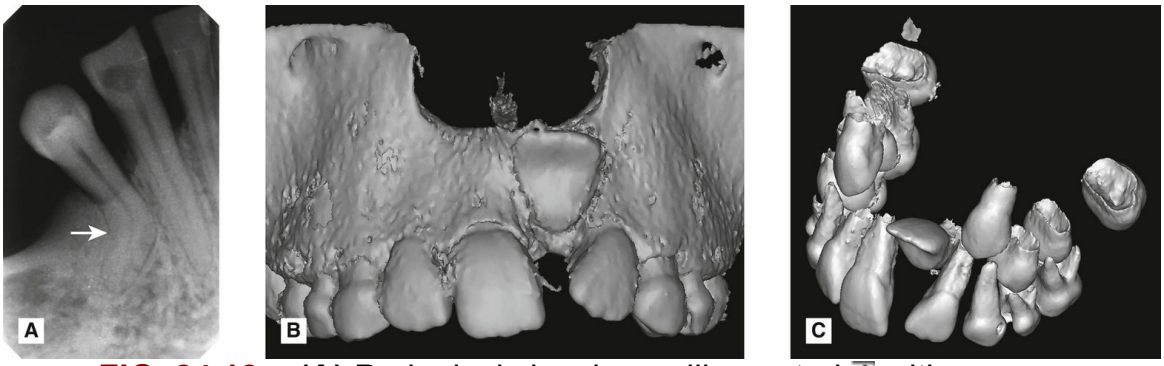


FIG. 24.18 **(A)** Periapical showing a dilacerated 4 with a near right angle bend in the root (arrowed). **(B)** *Surface rendered* 3-D CBCT image showing a dilacerated 1 . **(C)** Segmented *surface rendered* view showing only the teeth and the same dilacerated 1 . (©DentsplySirona – Simplant® Pro.)

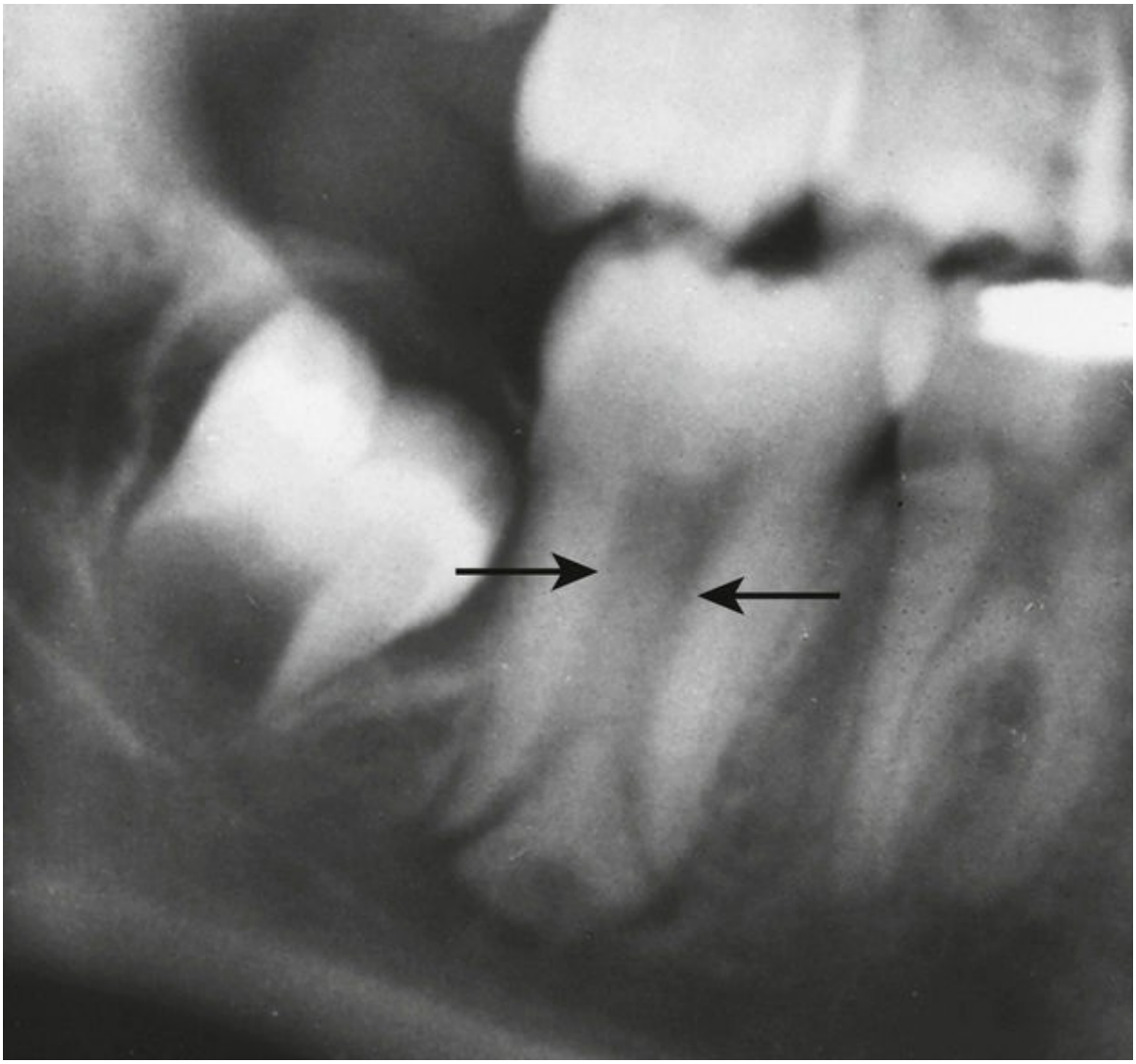


FIG. 24.19 Part of a panoramic radiograph showing a taurodont lower second molar with the typical large pulp chamber (arrowed).

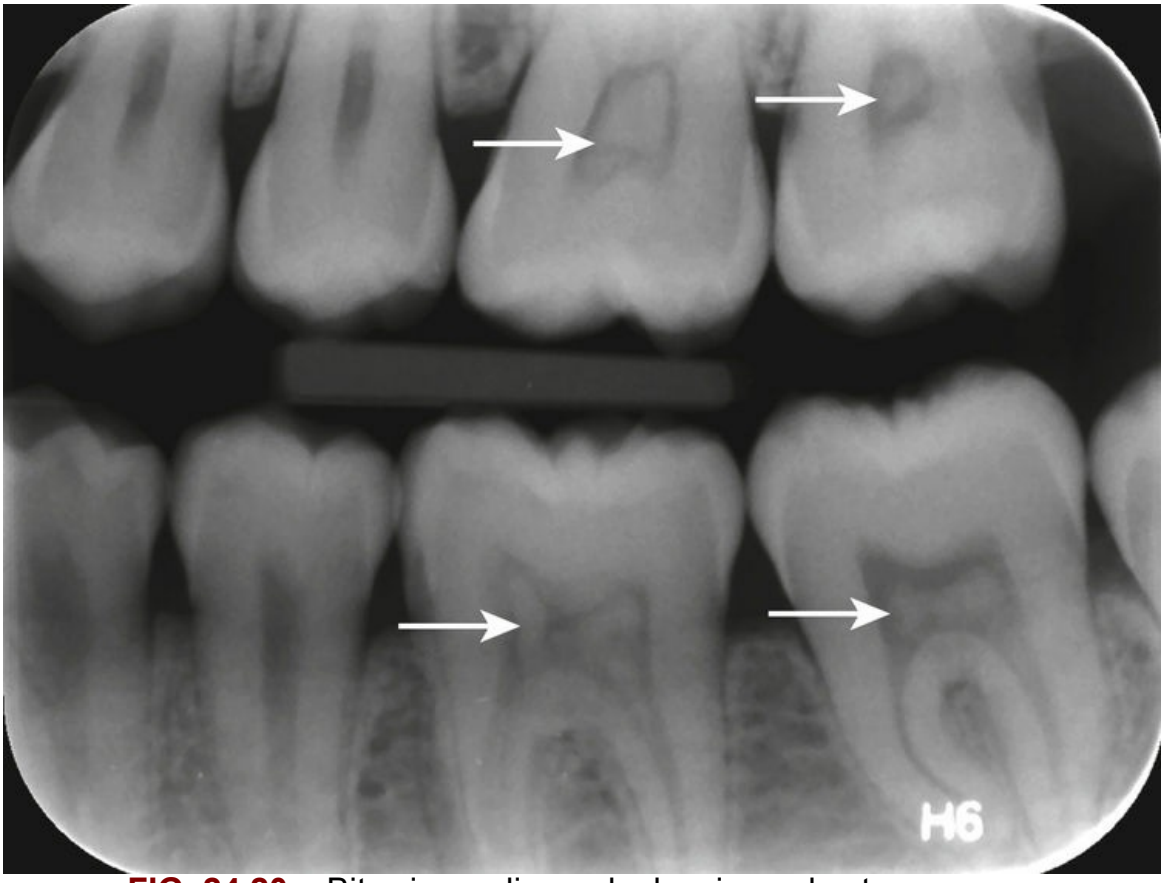


FIG. 24.20 Bitewing radiograph showing pulp stones (arrowed) in the pulp chambers of $\overline{67}$ and $\underline{67}$.

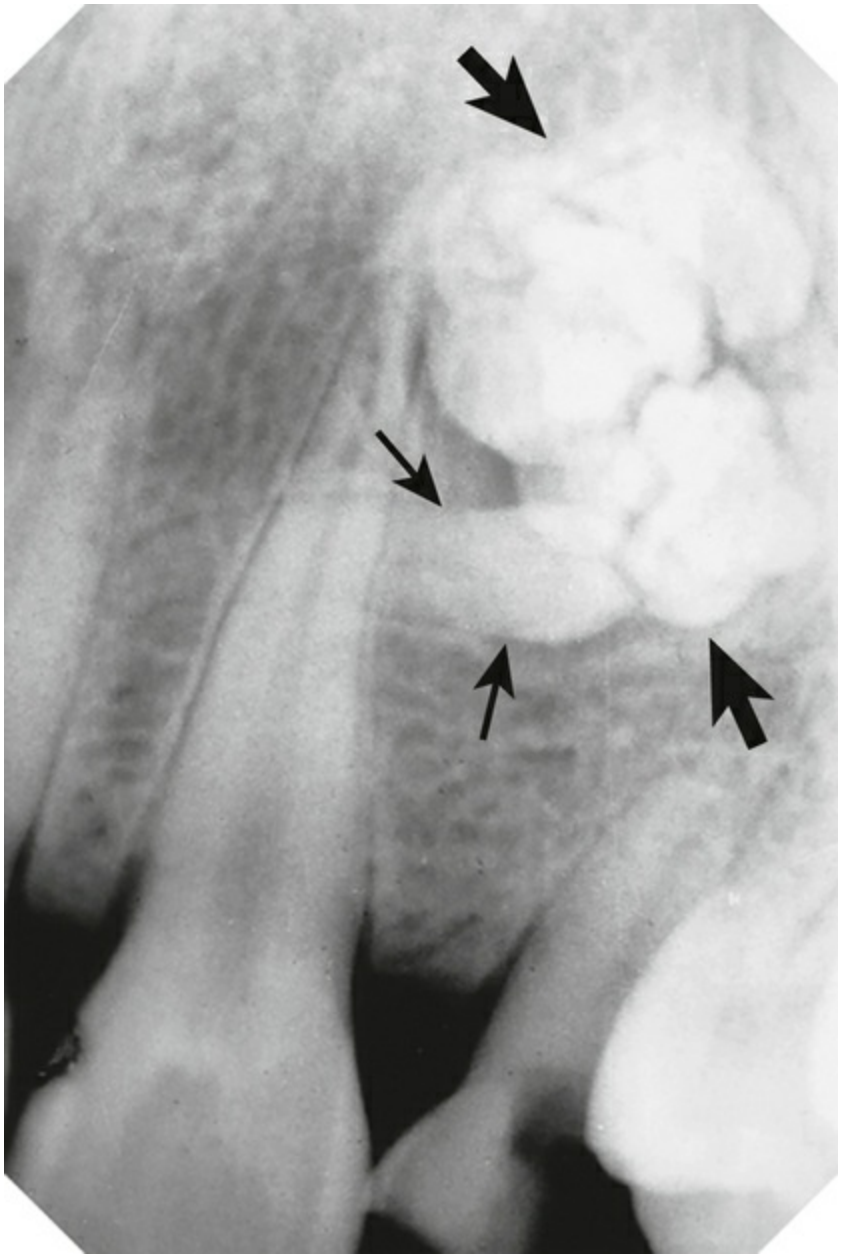


FIG. 24.21 Periapical showing a compound odontome in the anterior maxilla – several small discrete denticles are evident (arrowed).

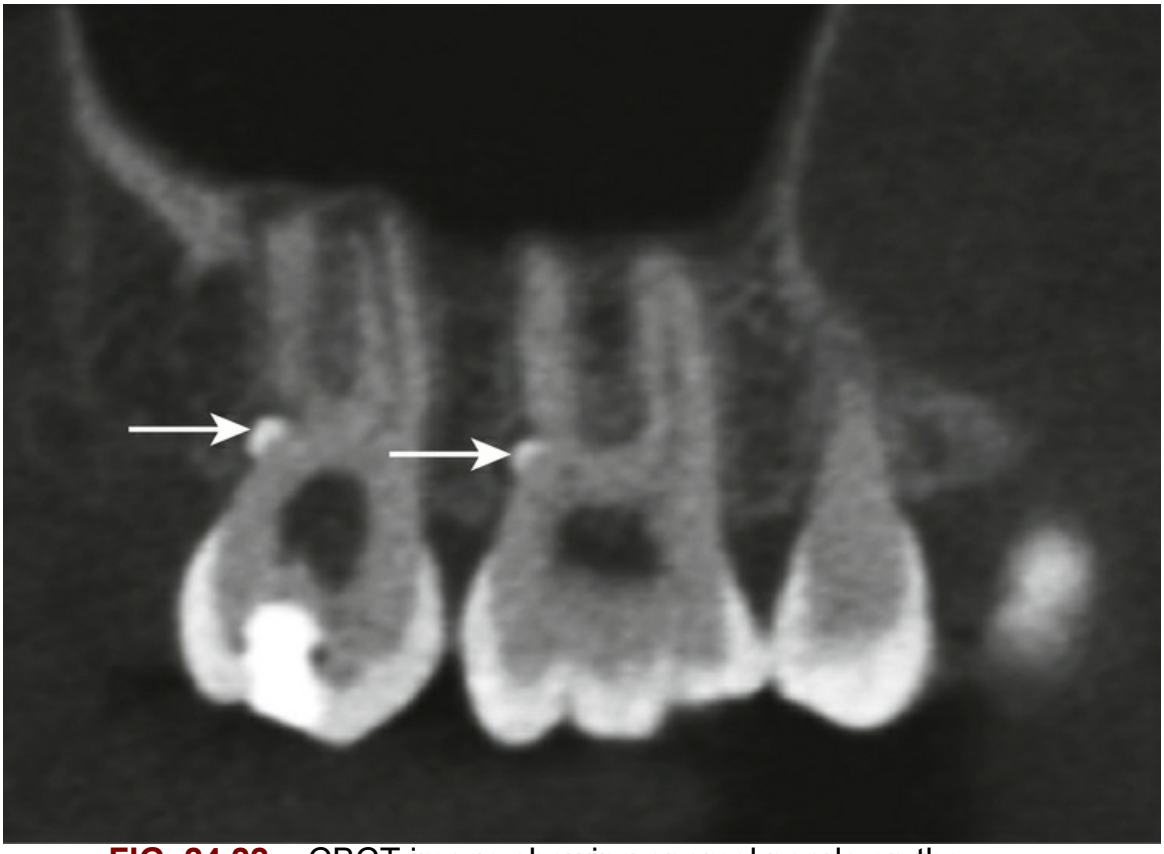


FIG. 24.22 CBCT image showing enamel pearls on the distal aspects of 76 (arrowed).

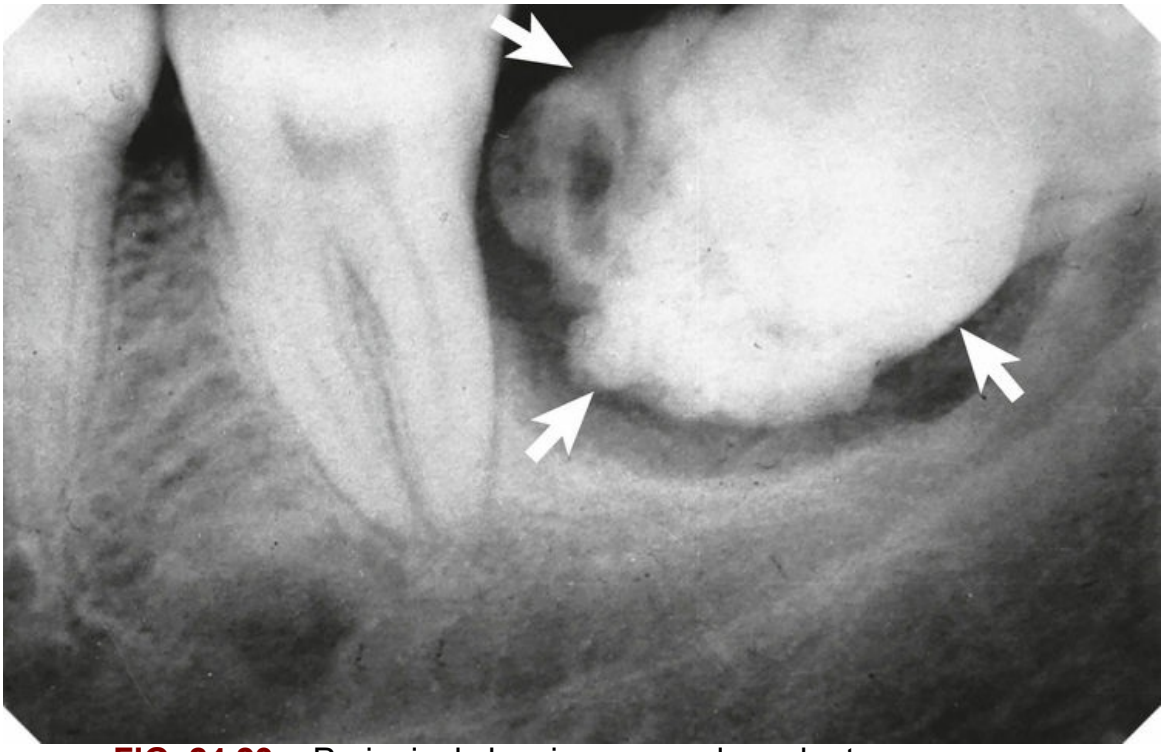


FIG. 24.23 Periapical showing a complex odontome, a disorganized mass of dental tissues in ⌈7 region (arrowed).

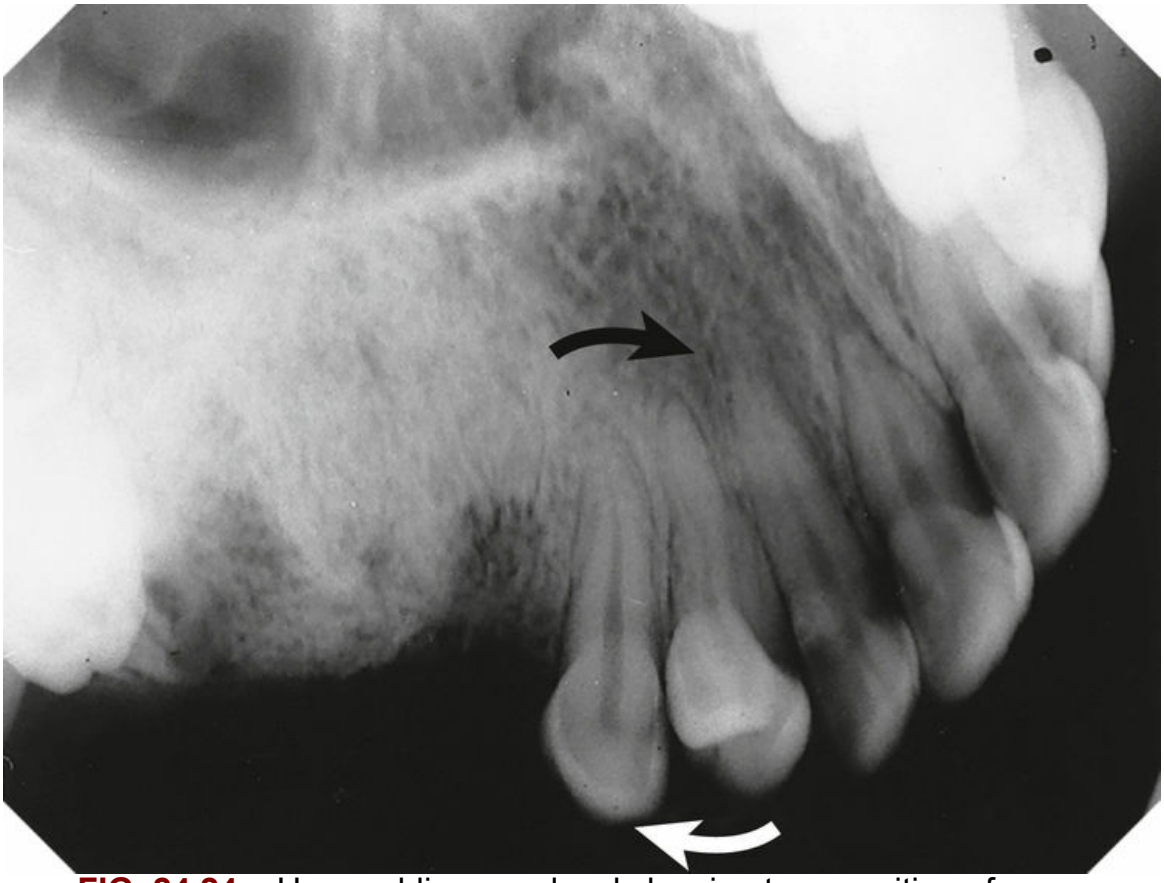


FIG. 24.24 Upper oblique occlusal showing transposition of 43| to give 34| (arrowed).

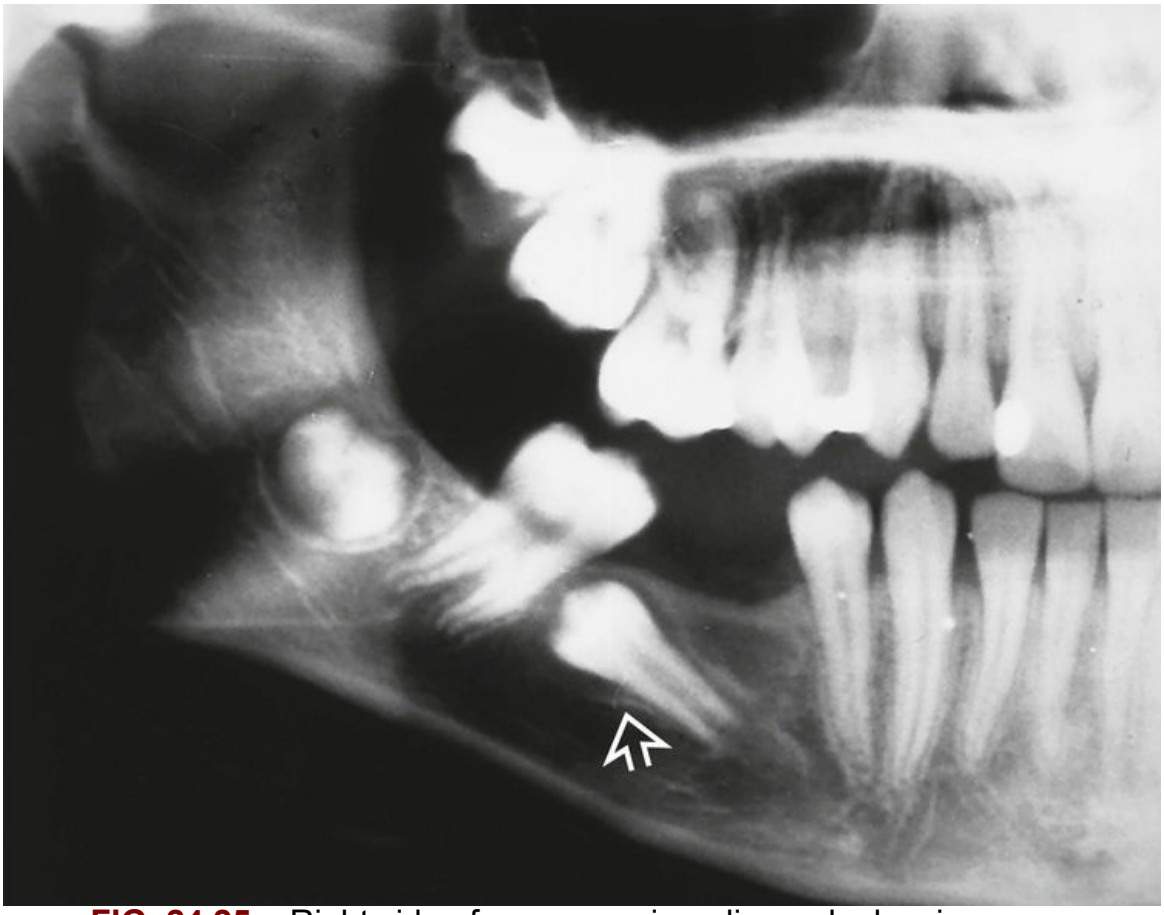


FIG. 24.25 Right side of a panoramic radiograph showing distal drift of a wandering $\overline{5}|$ (arrowed).

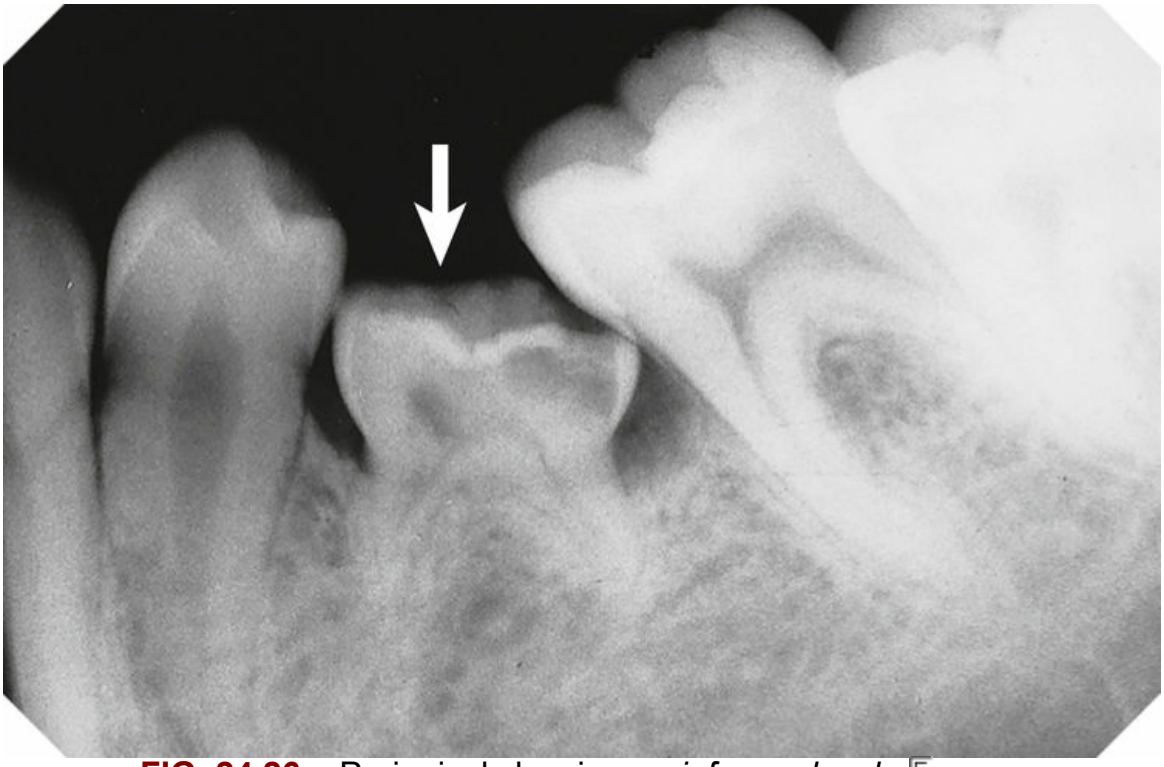


FIG. 24.26 Periapical showing an *infra-occlusal* (arrowed). Note there is no underlying second premolar.

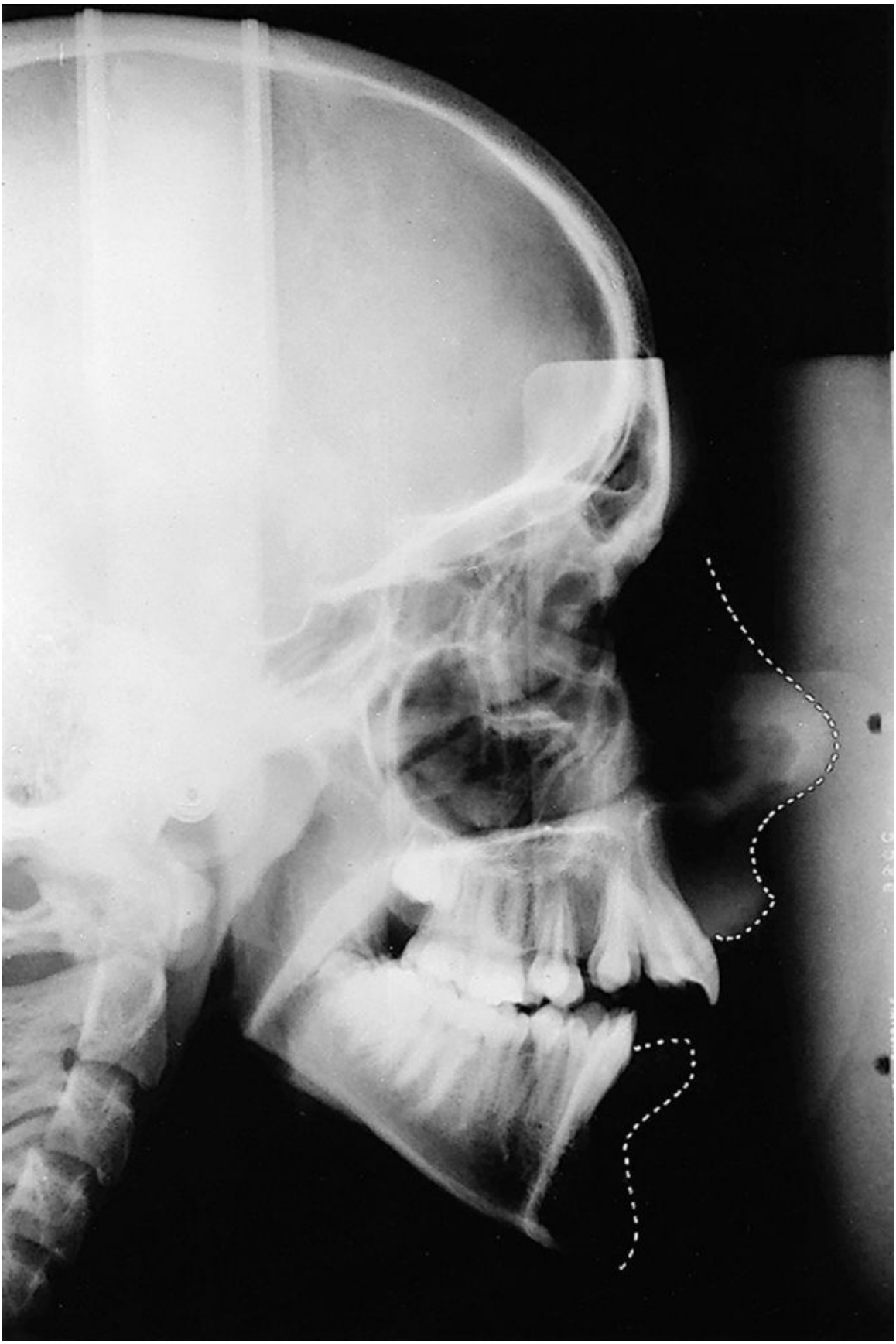


FIG. 24.27 True cephalometric lateral skull showing micrognathia (underdeveloped mandible) in skeletal class II. The soft tissue profile has been drawn in.



FIG. 24.28 True cephalometric lateral skull showing macrognathia (overgrowth of the mandible) in skeletal class III. The soft tissue profile has been drawn in.

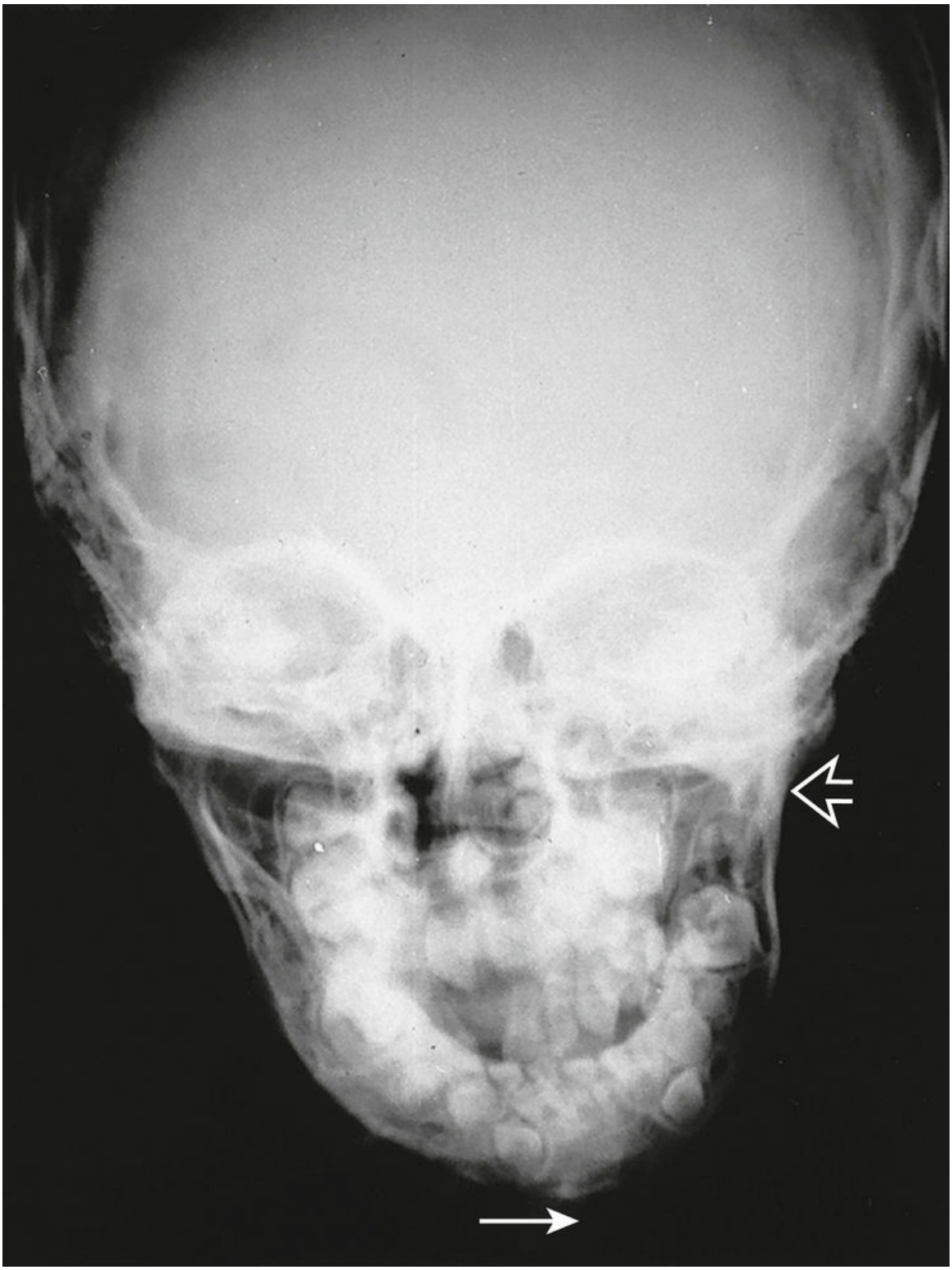


FIG. 24.29 Posteroanterior skull showing condylar hypoplasia on the left side (open arrow), with a marked deviation of the midline of the mandible to that side (closed arrow).

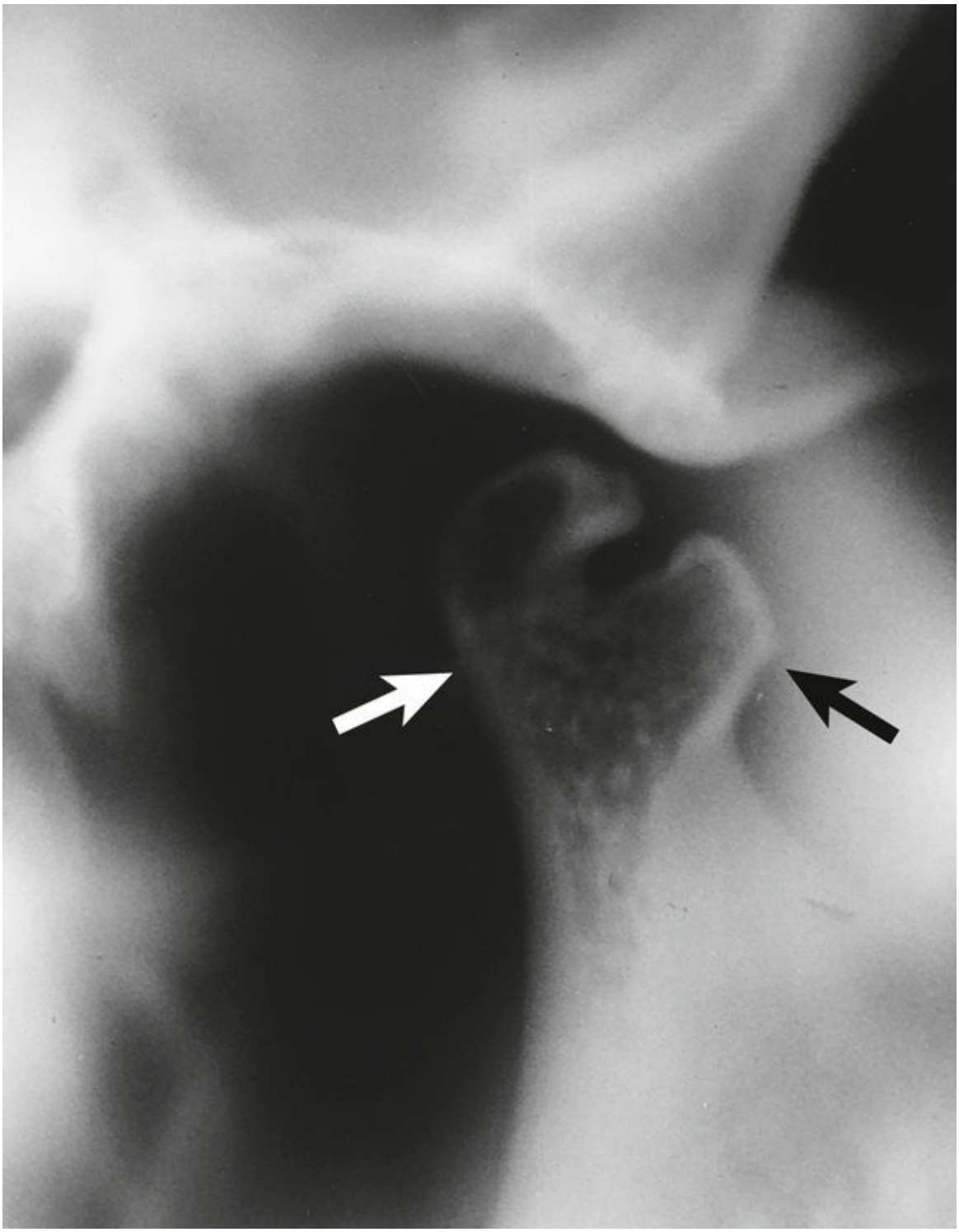


FIG. 24.30 Sagittal tomograph showing a bifid right condyle (arrowed).



FIG. 24.31 Periapical showing a unilateral cleft palate (arrowed). Note $\underline{2}$ is absent.

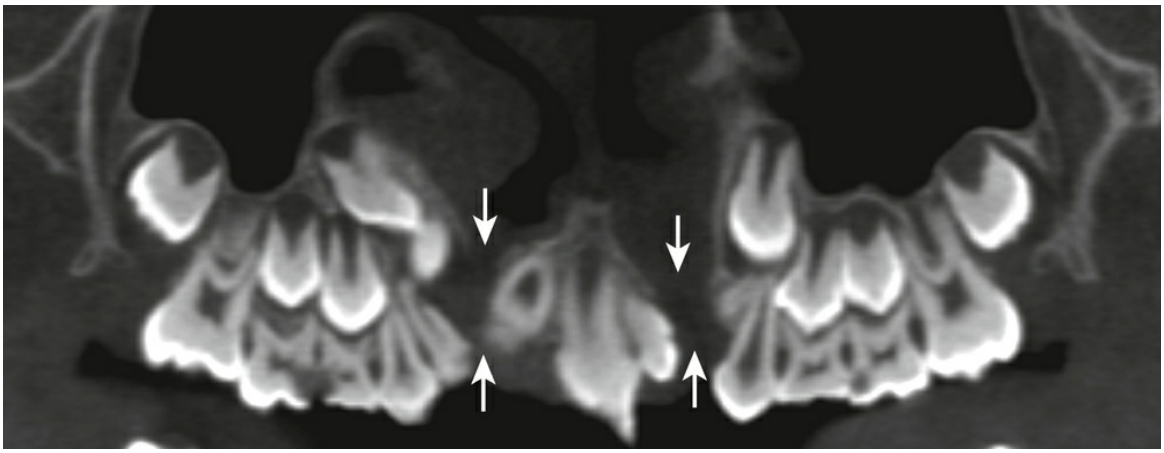


FIG. 24.32 CBCT reconstructed panoramic type image showing a bilateral cleft palate (arrowed).

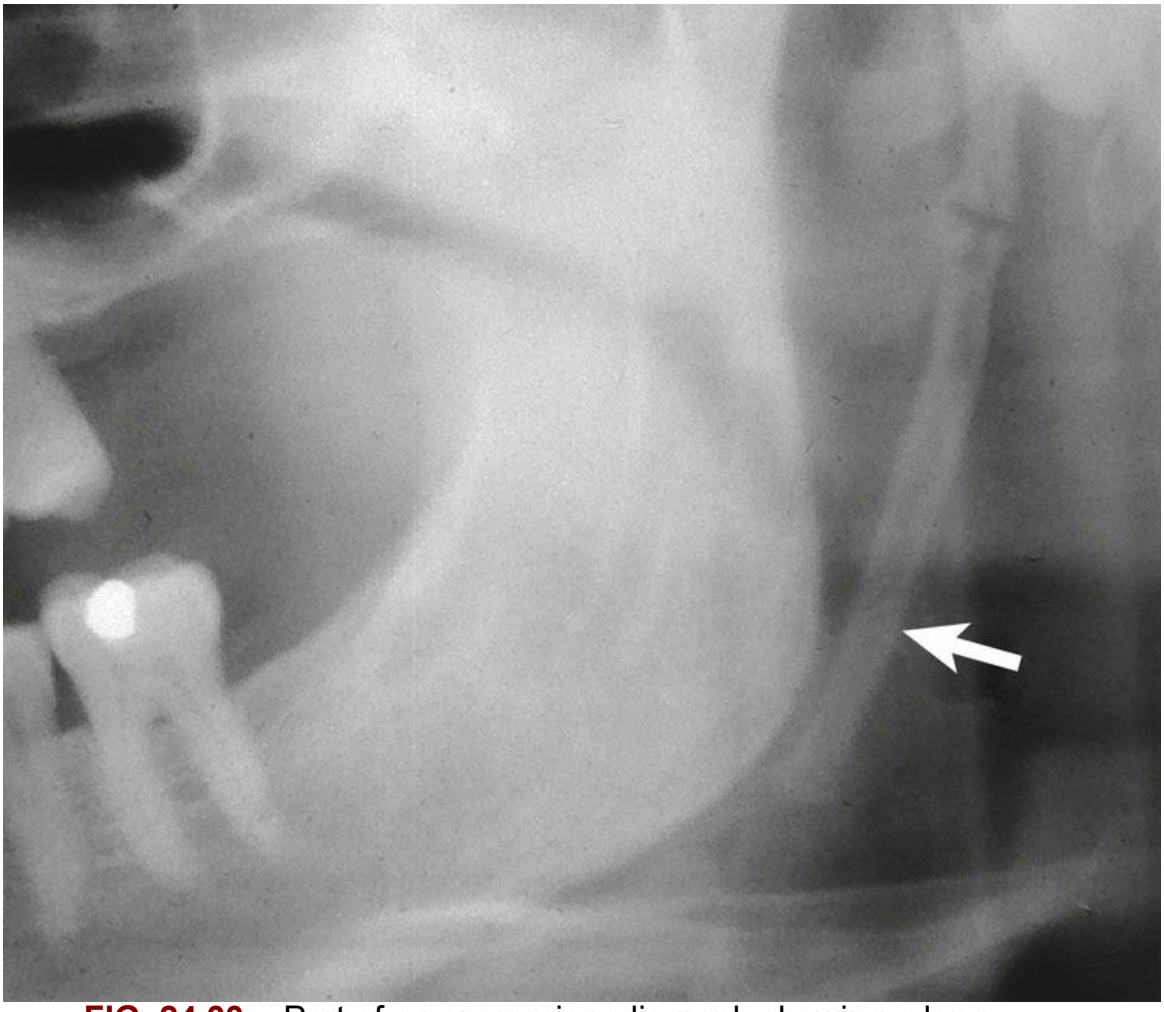


FIG. 24.33 Part of a panoramic radiograph showing a long calcified stylohyoid ligament (arrowed), a feature of Eagle's syndrome.

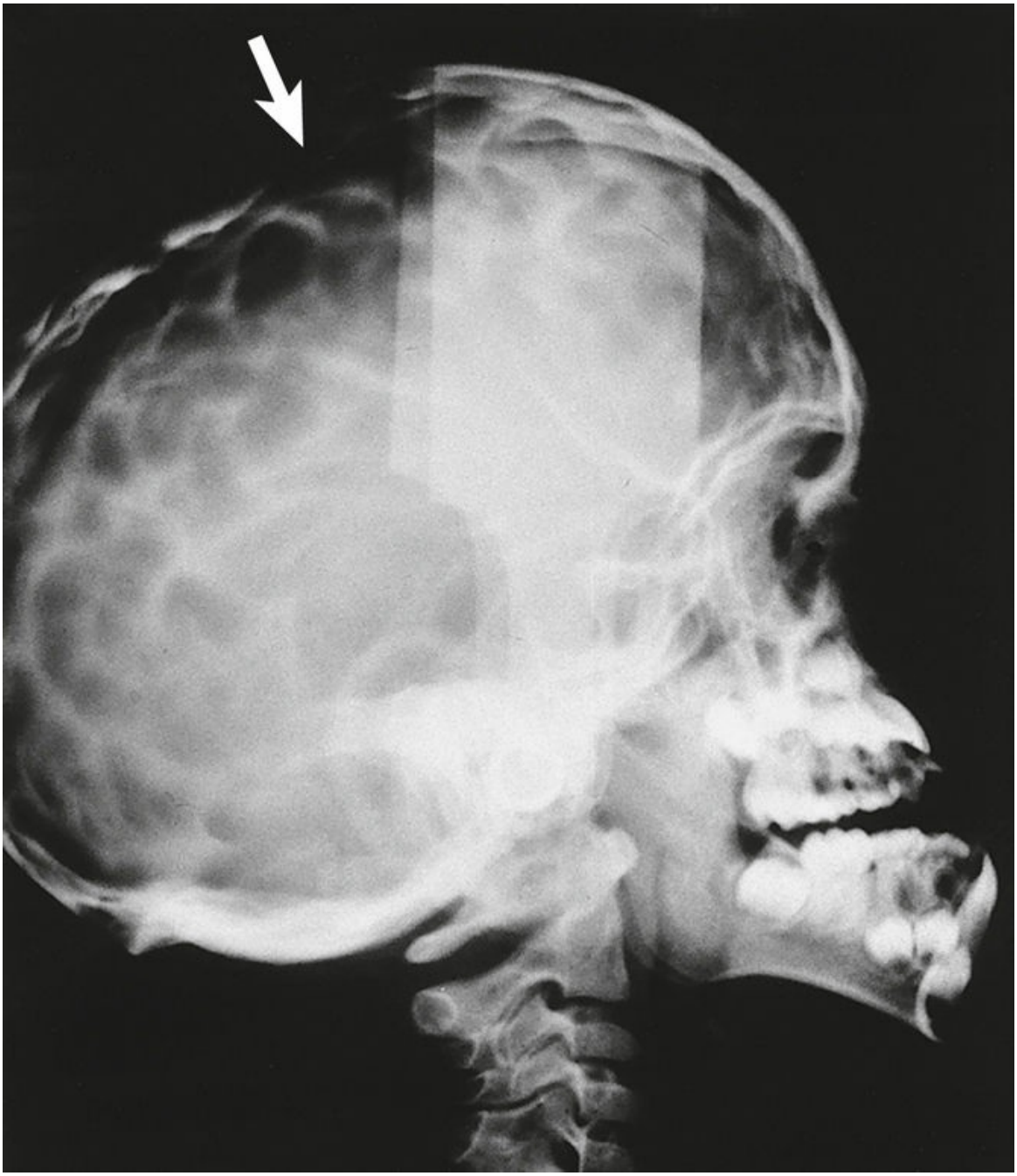


FIG. 24.34 True cephalometric lateral skull showing the typical *copper beaten* appearance of the cranium resulting from craniosynostosis – premature fusion of the cranial sutures. This appearance is seen in both Crouzon's and Apert's syndromes. In this patient, there is also indentation of the anterior fontanelle (arrowed) and the maxilla is hypoplastic.

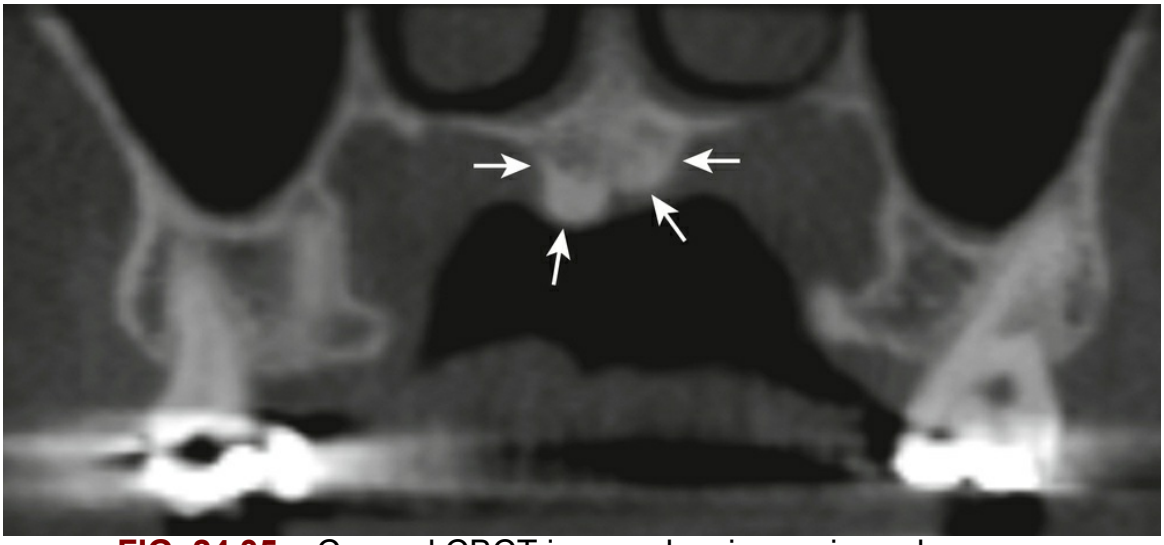


FIG. 24.35 Coronal CBCT image showing an irregular exostosis – palatal torus (arrowed).

Radiographic Assessment of Mandibular Third Molars

Clinical symptoms associated with lower wisdom teeth are common, the usual treatment being extraction. Many of the factors that influence that decision and determine the difficulty of the extraction are revealed by the preoperative radiographic assessment.

Radiographic Views Used

The usual radiographic examinations used include:

- Periapicals
- Panoramic radiographs
- Oblique laterals
- Cone beam computed tomography (CBCT).

All images should be of good quality. In particular, conventional plain images should accurately depict the geometrical relationship of the lower third molar to its surrounding structures. CBCT may be

indicated where conventional imaging has demonstrated two or more of the radiographic signs that suggest an *intimate relationship* between the roots of the third molar and the inferior dental (ID) canal (see later). However, CBCT should only be performed in those cases where it is likely to change the management or outcome for the patient. In a recent meta-analysis, it was shown that the use of CBCT did not decrease the number of neurosensory disturbances following third molar removal.

Radiographic Interpretation

The specific features that need to be identified can be divided into those related to:

- The lower third molar itself
- The lower second molar
- The surrounding bone.

Lower Third Molar Assessment

The main features to examine include:

- Angulation
- The crown
- The roots
- The relationship of the apices with the inferior dental (ID) canal
- The depth of the tooth in the alveolar bone
- The buccal or lingual obliquity.

Angulation

The third molar (see Fig. 24.36) could be:

- Mesioangular
- Distoangular
- Horizontal

- Vertical
- Transverse
- Inverted.

The crown

Note in particular:

- The size
- The shape
- The presence and extent of caries
- The presence and severity of resorption.

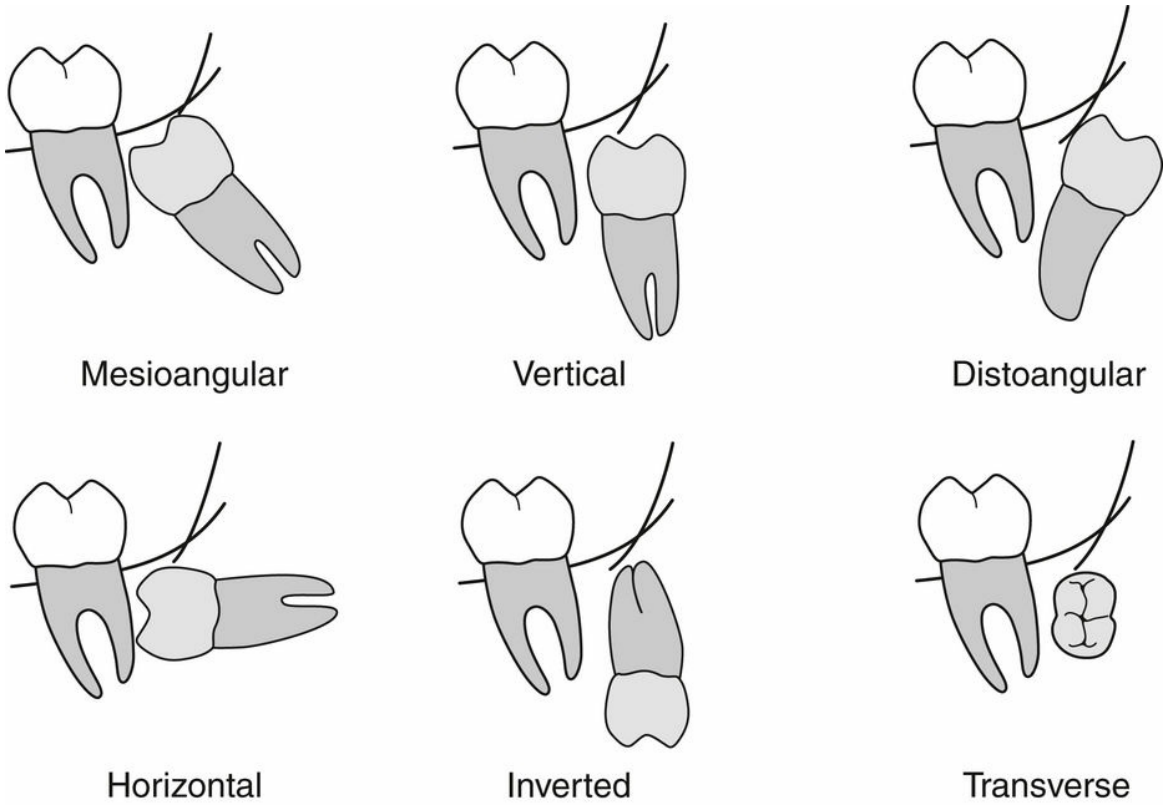


FIG. 24.36 Diagrams illustrating the typical positions and angulations of unerupted lower third molars.

The roots

Note in particular:

- The number
- The shape
- Curvatures, whether they are favourable or unfavourable (see Fig. 24.37)
- The stage of development.

The relationship of the apices to the ID canal

The apices of the lower third molar often appear close to the ID canal. This apparent closeness is usually due to these structures being superimposed. However, an *intimate relationship* does sometimes exist. The root may be grooved by the canal, or rarely, included within the developing root, as illustrated in Figs. 24.38 –24.49 .

The normal radiographic appearance of the ID canal (two thin, parallel radiopaque lines – the so-called *tramlines*) and the variations that indicate a possible *intimate relationship* are shown in Fig. 24.39 . These variations include:

- Loss of the tramlines
- Narrowing of the tramlines
- A sudden change in direction of the tramlines or root
- A radiolucent band evident across the root if the tooth is grooved by or contains the ID bundle.

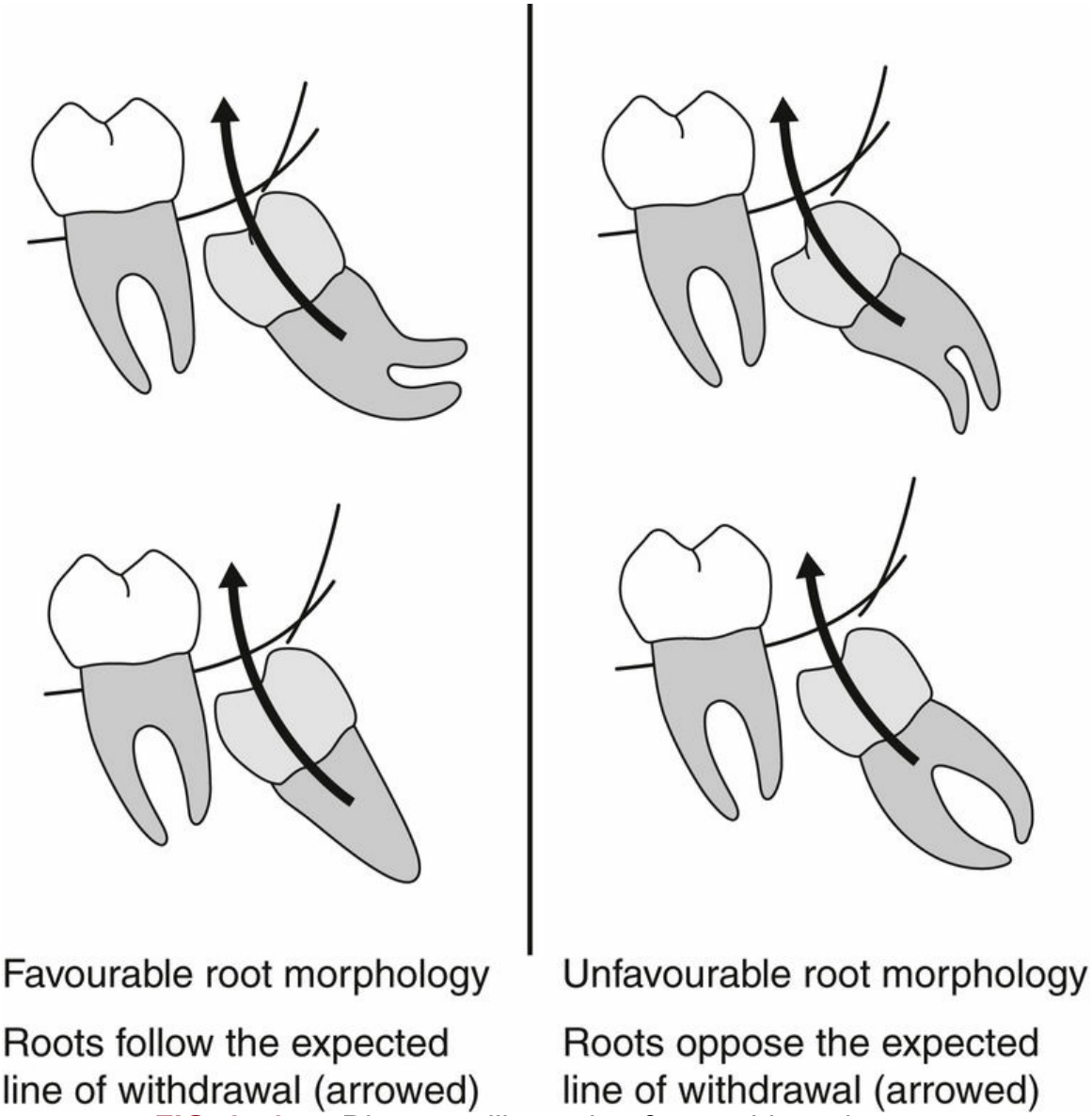


FIG. 24.37 Diagrams illustrating *favourable* and *unfavourable* root curvatures.

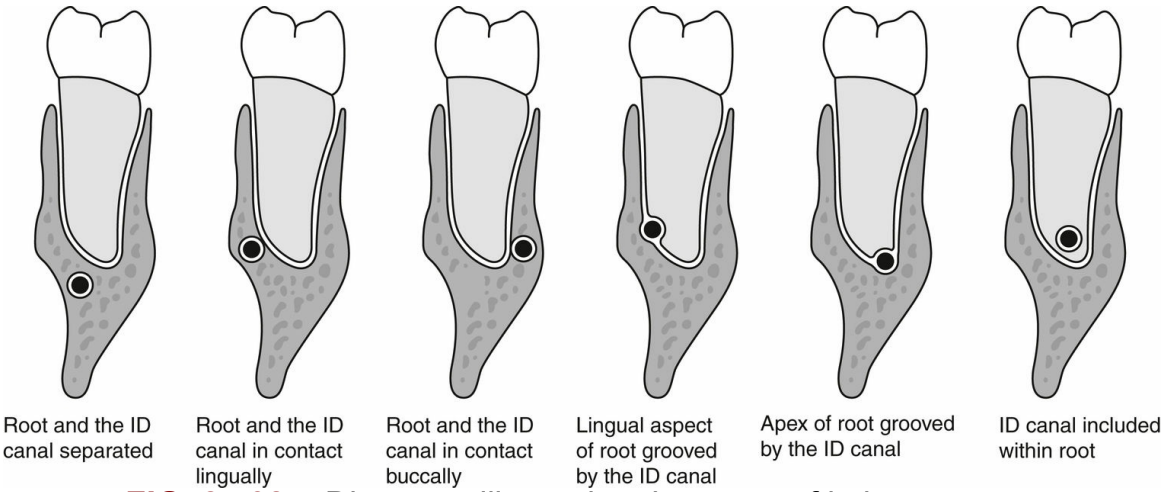


FIG. 24.38 Diagrams illustrating the types of intimate relationships that can exist between the lower third molar root and the inferior dental (ID) canal.

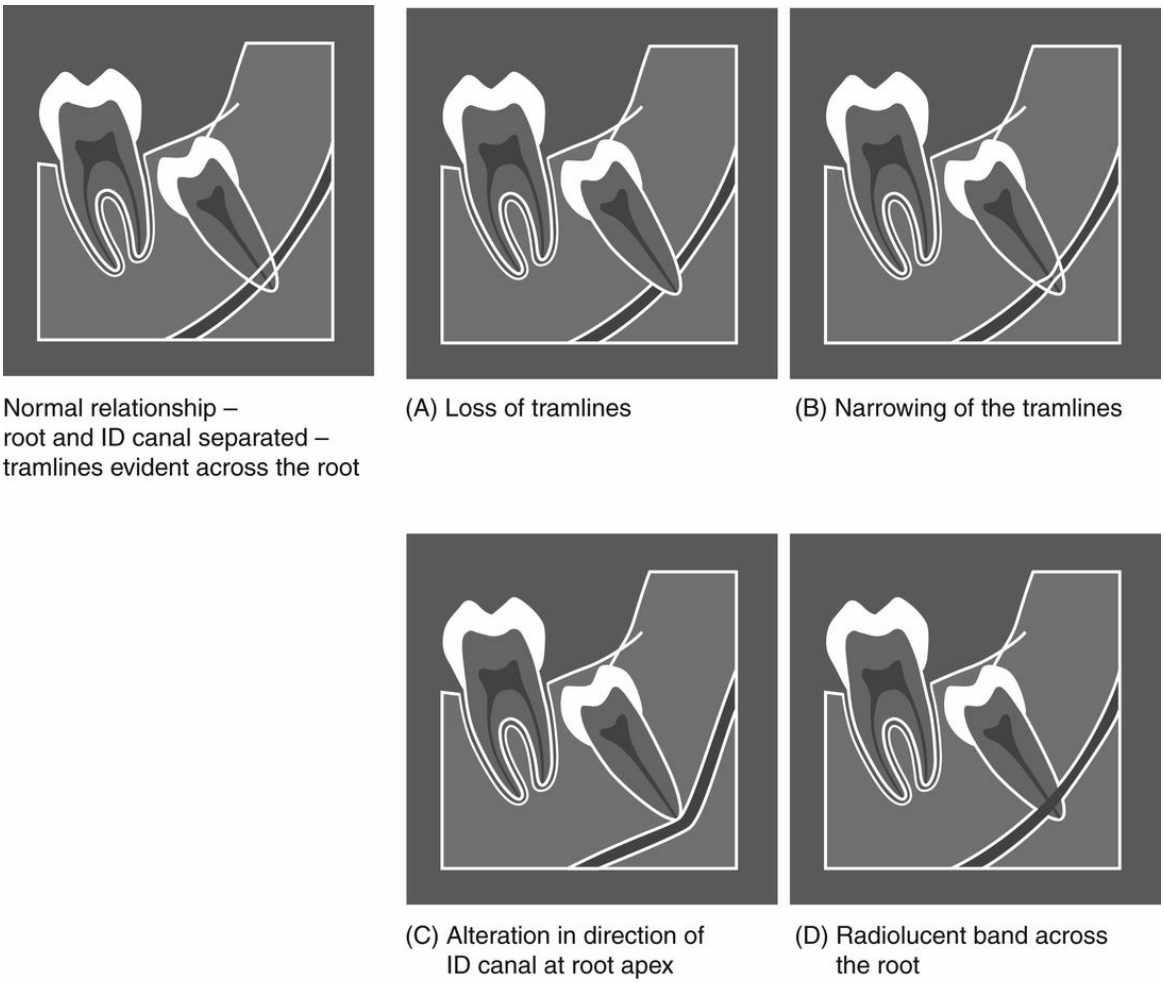


FIG. 24.39 Diagrams illustrating the radiographic appearances of a normal inferior dental canal, and **(A–D)** those indicating an *intimate relationship* between the inferior dental (ID) canal and the tooth apex.

The depth of the tooth in the alveolar bone

Two main methods have been used historically to assess tooth depth:

- Winter's lines
- Using the roots of the second molar as a guide.

Winter's lines

In this method (see Fig. 24.40), three imaginary lines (traditionally described by number or colour) are drawn on a geometrically accurate

periapical radiograph, as follows:

- The first or *white* line is drawn along the occlusal surfaces of the erupted first and second molars.
- The second or *amber* line is drawn along the crest of the interdental bone between the first and second molars, extending distally along the internal oblique ridge, NOT the external oblique ridge. This line indicates the margin of the alveolar bone surrounding the tooth.
- The third or *red* line is a perpendicular dropped from the *white* line to the point of application for an elevator, but is measured from the *amber* line to this point of application. This line measures the depth of the third molar within the mandible. (As a general rule, if the *red* line is ≥5 mm in length, the extraction is considered sufficiently difficult for the tooth to be removed under general anaesthetic or using local anaesthetic and sedation.)

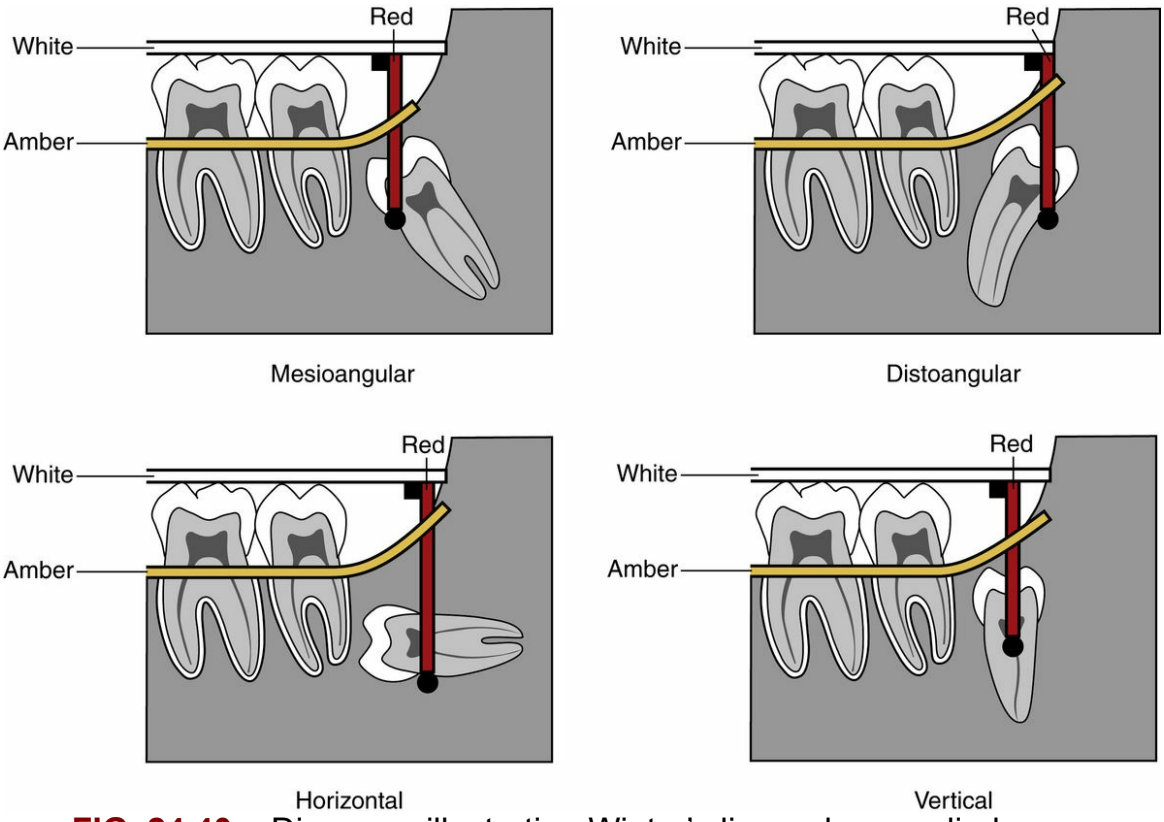


FIG. 24.40 Diagrams illustrating Winter's lines when applied to unerupted third molars in different positions.

Using the roots of the second molar as a guide

This method (see Fig. 24.41) can be summarized as follows:

- The roots of the adjacent second molar are divided horizontally into thirds
- A horizontal line is then drawn from the point of application for an elevator to the second molar
- If the point of application lies opposite the coronal, middle or apical third, the extraction is assessed as being easy, moderate or difficult, respectively.

The buccal or lingual obliquity

- *Buccal obliquity* – the crown of the wisdom tooth is inclined towards the cheek

- *Lingual obliquity* – the crown of the wisdom tooth is inclined towards the tongue.

The lie of the tooth in the horizontal plane cannot be determined accurately from a periapical radiograph. The views of choice for this assessment include:

- Lower oblique occlusal
- Lower 90° occlusal, centred on the side of interest (see Chapter 11).

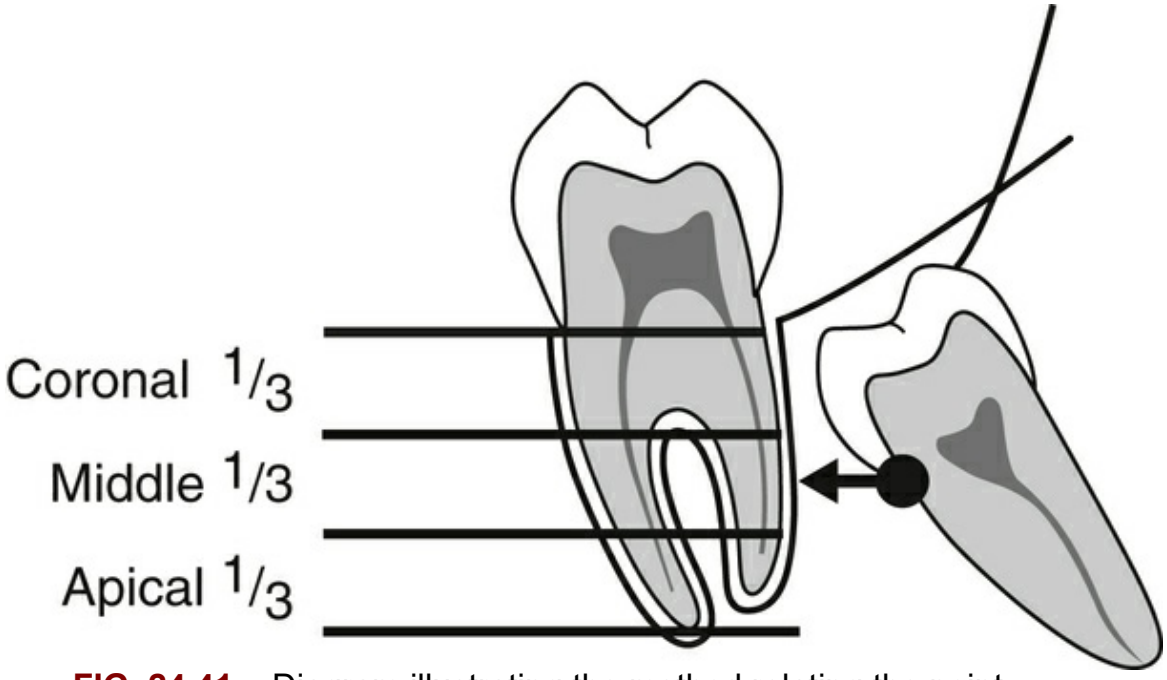


FIG. 24.41 Diagram illustrating the method relating the point of application of an elevator to the roots of the lower second molar to assess the depth of the third molar in the alveolar bone.

Lower Second Molar Assessment

The second molar is assessed to decide the prognosis of the tooth and whether the second molar should be extracted instead of, or as well as,

the third molar. The main features to examine include:

- The crown
- The roots.

The crown

Note in particular:

- The condition and extent of existing restorations
- The presence of caries
- The presence and severity of resorption.

The roots

Note in particular:

- The number
- The shape, and if it is conical
- The periodontal status
- The condition of the apical tissues.

Assessment of the Surrounding Bone

The main features to examine include:

- The anteroposterior position of the ascending ramus, to determine access to the tooth and the amount of overlying bone
- The texture and density of the bone
- Evidence of previous pericoronal infection.

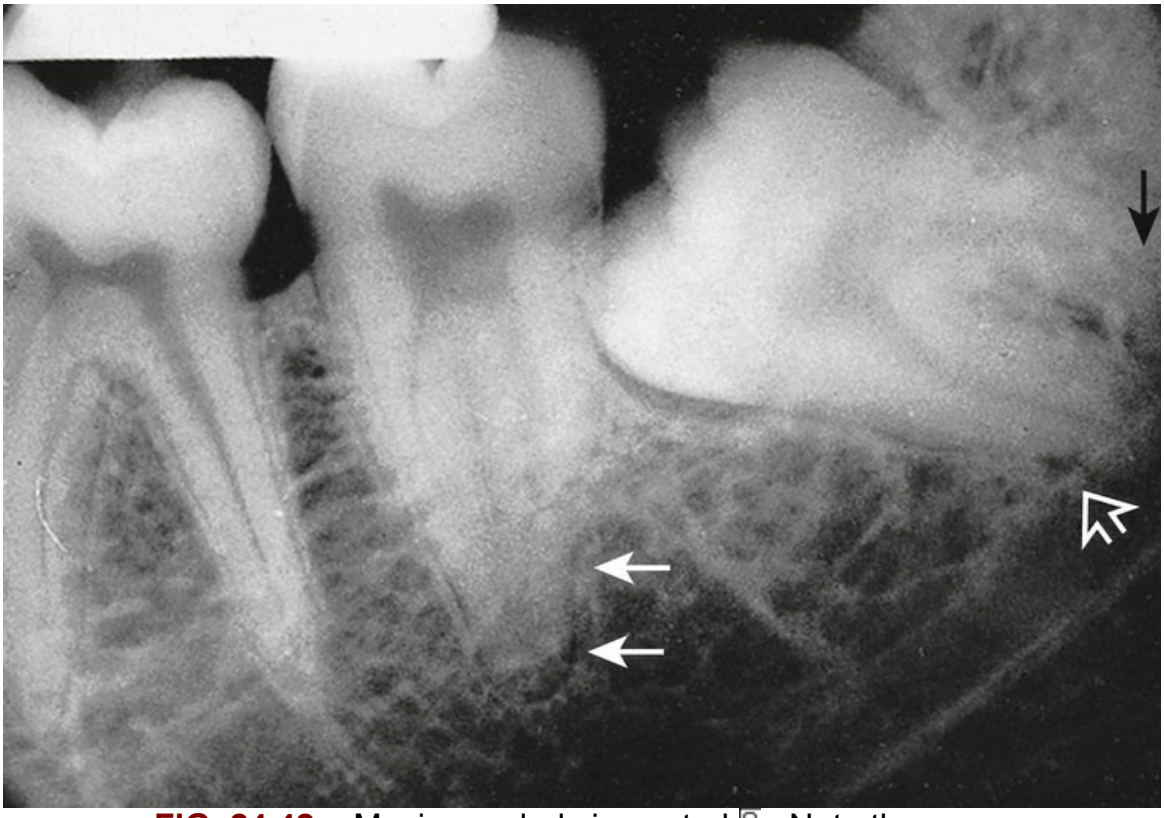


FIG. 24.42 Mesioangularly impacted 8. Note the unfavourable root curvatures (black arrow), the uninterrupted upper tramline of the inferior dental canal (open white arrow) and the conically shaped root of 7 (solid white arrows).

All these points relating to the third molar, the second molar and the surrounding tissues are considered together, and a conclusion drawn as to the overall difficulty of the proposed extraction.

Examples of unerupted lower third molars, illustrating some of the more important radiographic features, are shown in Figs. 24.42 –24.49 .



FIG. 24.43 Slightly distoangularly impacted $\overline{8}|$. Note the favourable conically shaped roots, the uninterrupted upper tramline of the inferior dental canal (open white arrows) and the radiolucent area distal to the crown (black arrows) caused by the residual follicle.

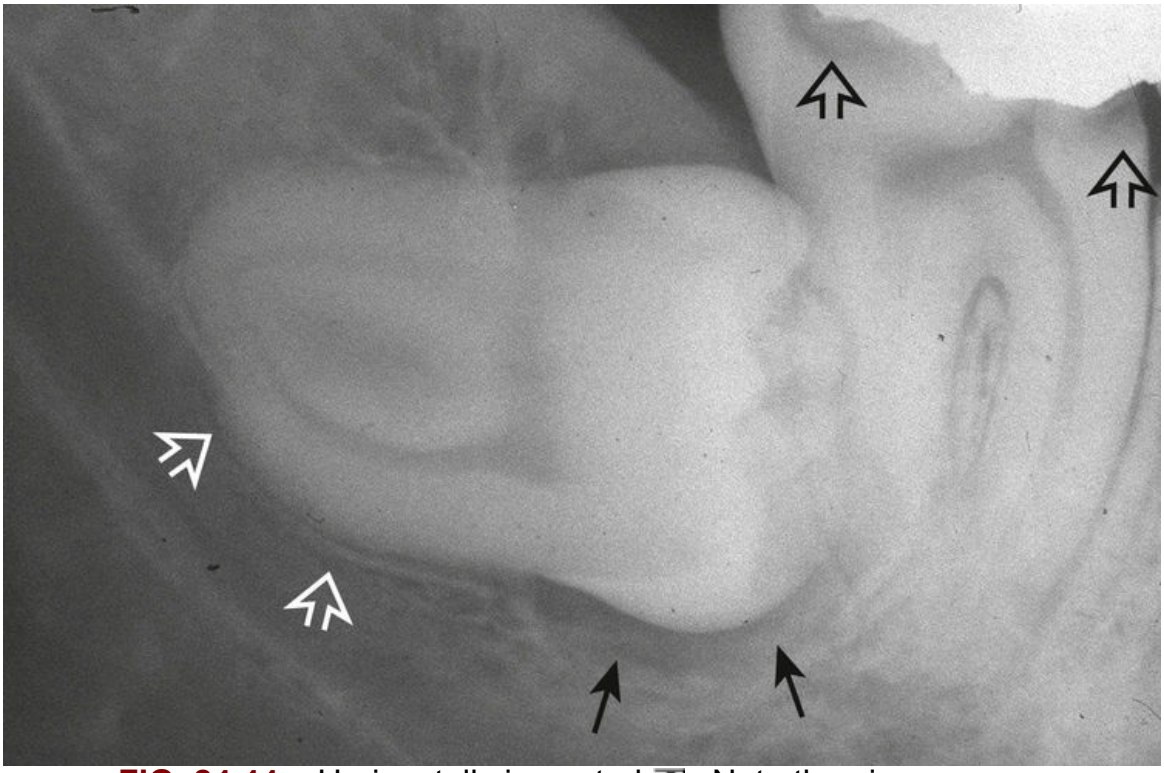


FIG. 24.44 Horizontally impacted 8. Note the pincer-shaped roots and their indentation of the upper margin of the inferior dental canal (open white arrows), and the radiolucency beneath the crown (solid black arrows) caused by the follicle. In addition, note the caries lesions in 7 (open black arrows).

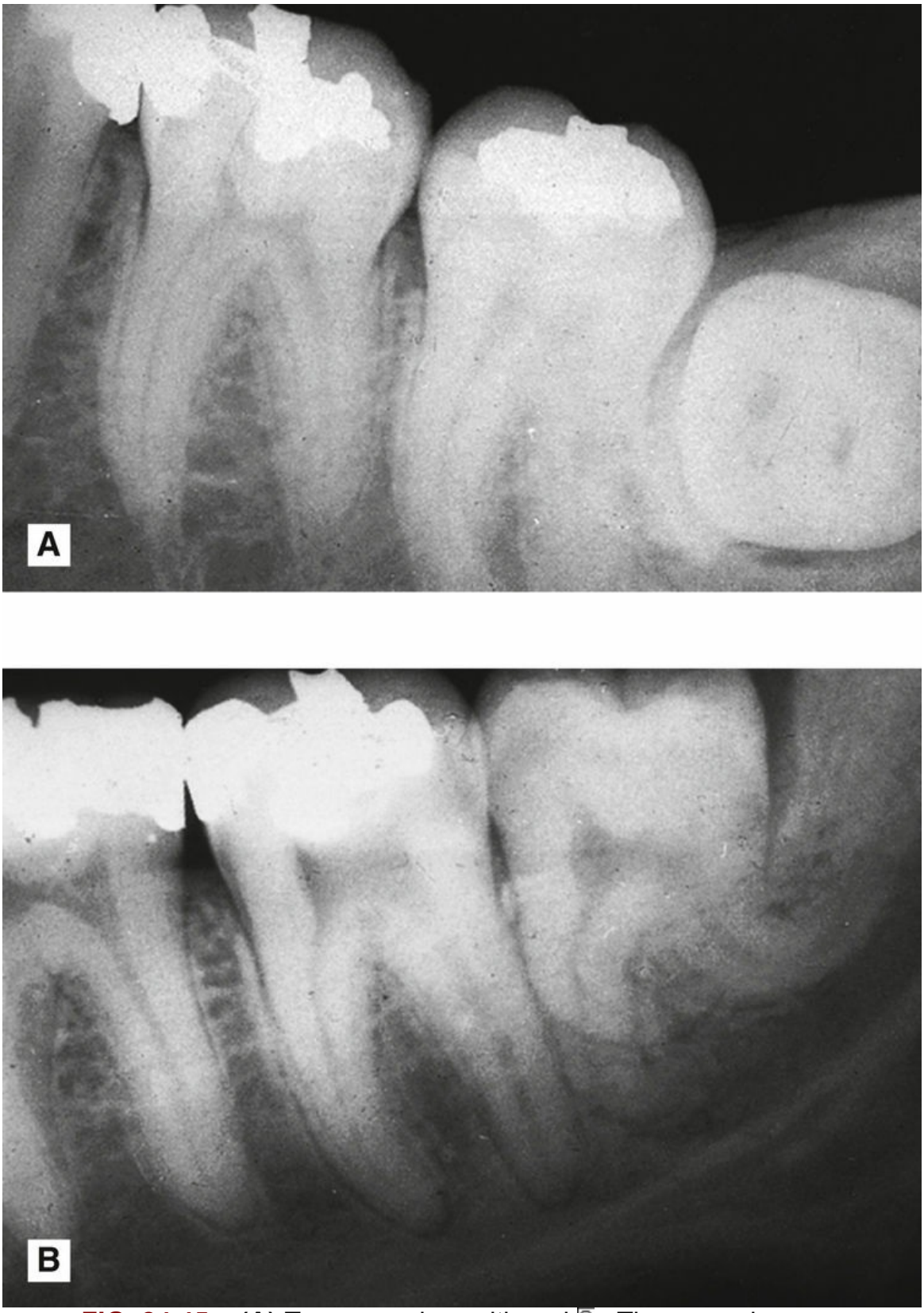
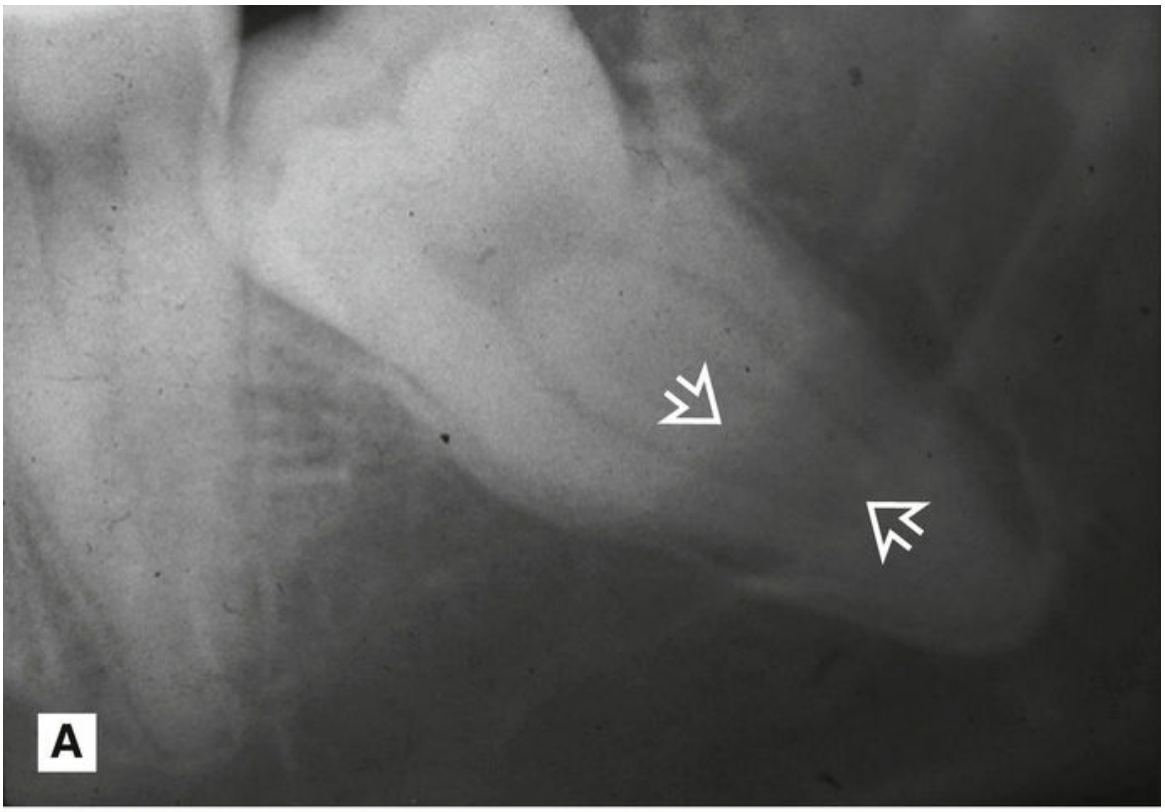


FIG. 24.45 **(A)** Transversely positioned 8 . The crown is viewed end-on. Note that the buccolingual obliquity of the

tooth cannot be determined from this radiograph. **(B)**
Vertically positioned 8 with very unfavourable root curvatures.


A

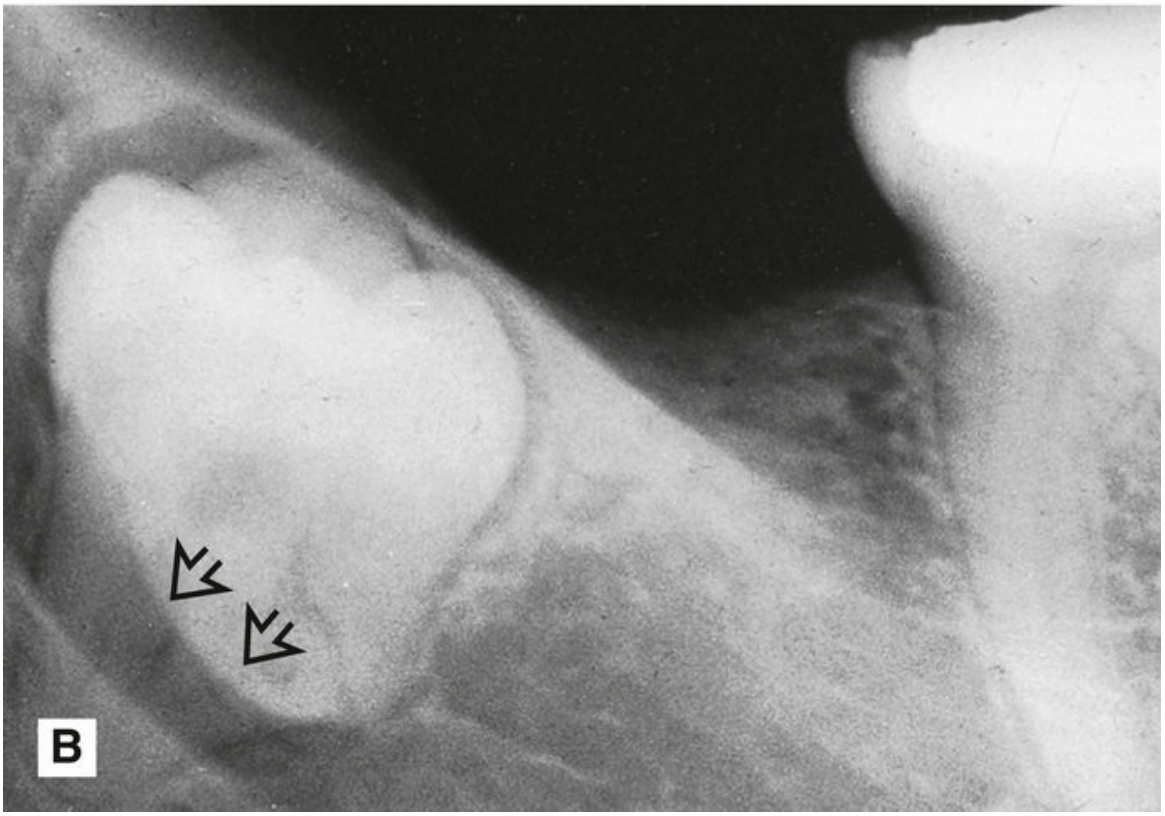

B

FIG. 24.46 Two radiographs showing some of the radiographic features suggestive of an *intimate relationship* with the inferior dental canal. **(A)** A radiolucent band is evident across the root (arrowed) and there is a change in direction of the inferior dental (ID) canal. **(B)** A radiolucent band evident across the root and the ID canal is narrowed (arrowed).

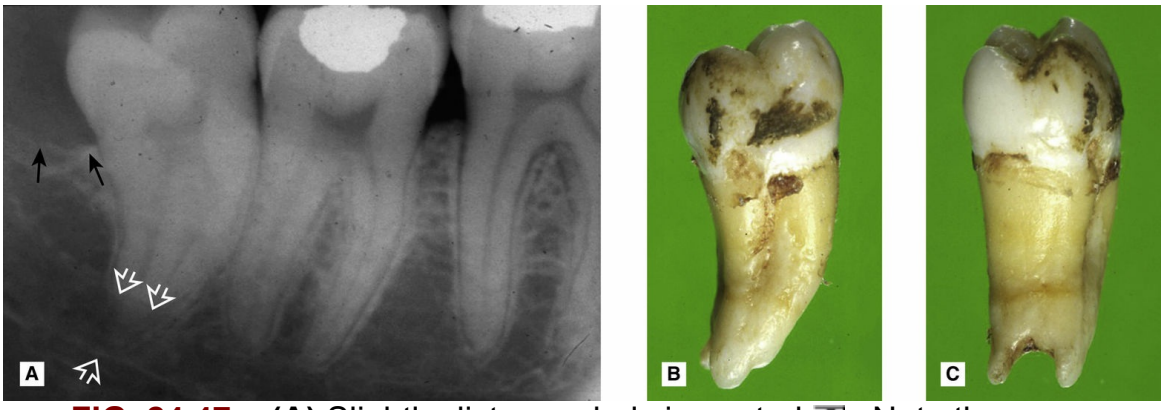


FIG. 24.47 **(A)** Slightly distoangularly impacted 8. Note the extensive area of bone resorption distal to the crown (black arrows) caused by previous pericoronal infection. There is a radiolucent band across the tooth apex that is also hazy in outline (open white arrows) caused by the inferior dental canal, implying an intimate relationship. **(B)** The extracted 8 viewed as in the radiograph from the buccal aspect. **(C)** The extracted tooth viewed from the distal aspect showing clearly the notching of the tooth apex by the inferior dental canal. This explains the radiolucent band across the apex – there is simply less tooth tissue in this zone, because of the position of the inferior dental canal.

Specimen and radiograph courtesy of Dr A. Sidi.

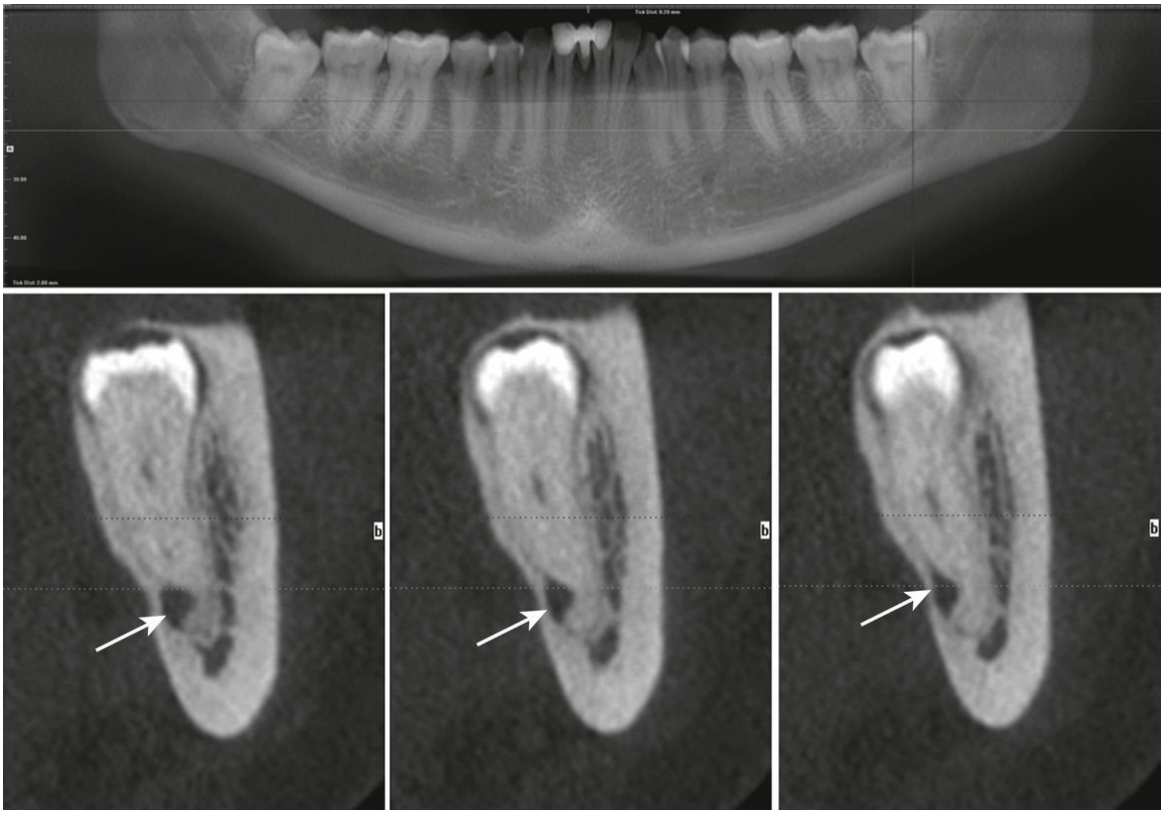


FIG. 24.48 CBCT images showing the inferior dental canal grooving the roots of the lower left third of the molar (arrowed).

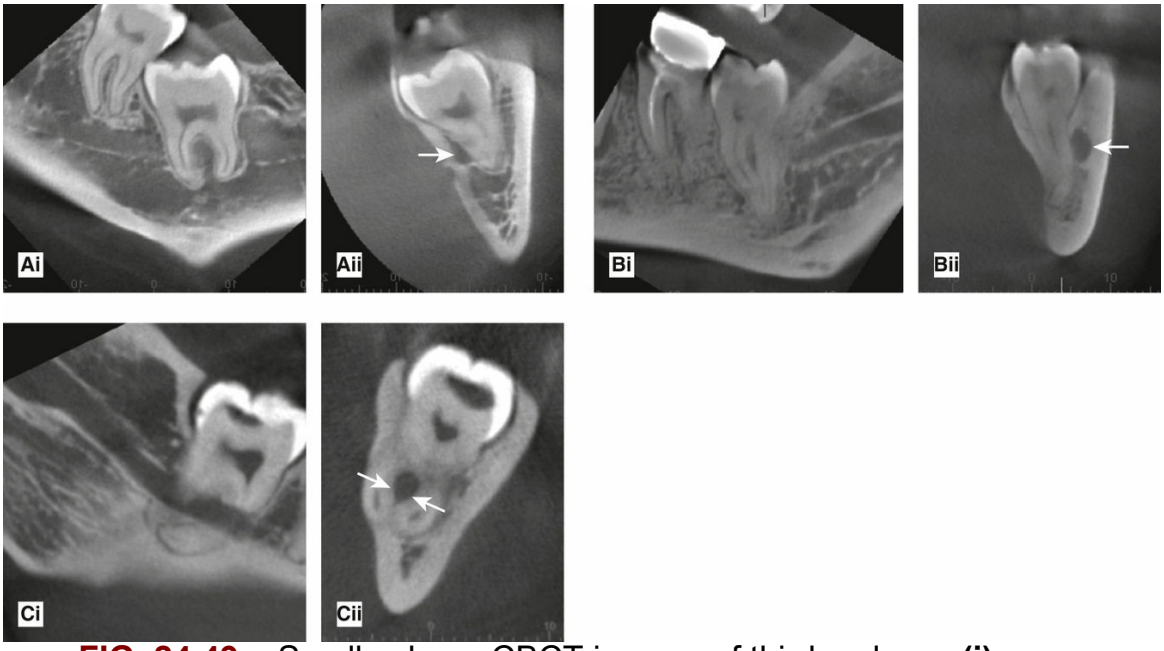


FIG. 24.49 Small volume CBCT images of third molars—**(i)** sagittal; **(ii)** coronal—showing **(A)** lingually positioned inferior dental (ID) canal (arrowed), **(B)** buccally positioned ID canal (arrowed) and **(C)** ID canal included within the root of 8| (arrowed).

Courtesy of Dr J. Brown and Mr J. Rout.

Radiographic Assessment of Unerupted Maxillary Canines

The upper canines are often misplaced and fail to erupt as a result of their long path of eruption, the timing of their eruption and the frequency of upper arch overcrowding. Again, many of the factors that influence the treatment of this anomaly can be obtained from the radiographic assessment, the purpose of which is two-fold:

- To determine the size and shape of the canine and any related disease, including possible resorption of the adjacent lateral incisor
- To determine the position of the canine.

Assessment of the Canine Size and Shape and the Surrounding Tissues

Radiographic Views Used

The usual radiographs (see Figs. 24.50 and 24.59) used include:

- Periapicals
- Upper standard occlusal
- Panoramic radiograph
- CBCT.

Radiographic Interpretation

The specific features that need to be examined relate to:

- The crown
- The root
- Surrounding structures.

The crown

Note in particular:

- Crown size (in relation to the space available in the arch)
- Crown shape
- The presence and severity of resorption
- The presence of any related disease, such as a dentigerous cyst
- The effect on adjacent teeth, such as resorption.

The root

Note in particular:

- Root size
- Root shape
- Stage of development.

Surrounding structures

Note in particular:

- The deciduous canine
  - Root length
  - Degree of resorption
- The presence of an odontome or supernumerary
- The condition of the surrounding bone.



FIG. 24.50 Examples of the radiographs used typically to assess unerupted canines and the surrounding structures. **(A)** Panoramic radiograph showing unerupted 3|3 and |3 **. (B)** Upper standard occlusal showing both upper canines unerupted, a dentigerous cyst associated with 3| , extensive destruction of the alveolar bone and resorption of |3 . **(C)** Periapical showing unerupted 3| with retained c .

Assessment of the Position of the Canine – Localization

There are several methods available for localization depending on available facilities. They can be used for canines and other unerupted teeth as well as odontomes and supernumeraries. Although emphasis in this section is on canines, examples of localization of other unerupted developmental anomalies are also shown.

Main Localization Methods

- Parallax in the horizontal plane
- Parallax in the vertical plane
- CBCT.

The principle of parallax

Parallax is defined as *the apparent displacement of an object because of different positions of the observer.* In other words, if two objects, in two separate planes, are viewed from two different positions, the objects will appear to move in different directions in relation to one another, from one view to the next as shown in Fig. 24.51 .

Using the principle of parallax, if two views of an unerupted canine are taken with the X-ray tubehead in two different positions, the resultant radiographs will show a difference in the position of the unerupted canine relative to the incisors, as follows:

- If the canine is **palatally** positioned, it will seem to have moved in the **same** direction as the X-ray tubehead.
- If the canine is **buccally** positioned, it will seem to have moved in the **opposite** direction to the X-ray tubehead.
- If the unerupted canine is in the **same plane** as the incisors, i.e. in the line of the arch, it will seem **not to have moved** at all.

A useful acronym to remember the movements of parallax is SLOB, standing for:

S ame
L ingual
O pposite
B uccal.

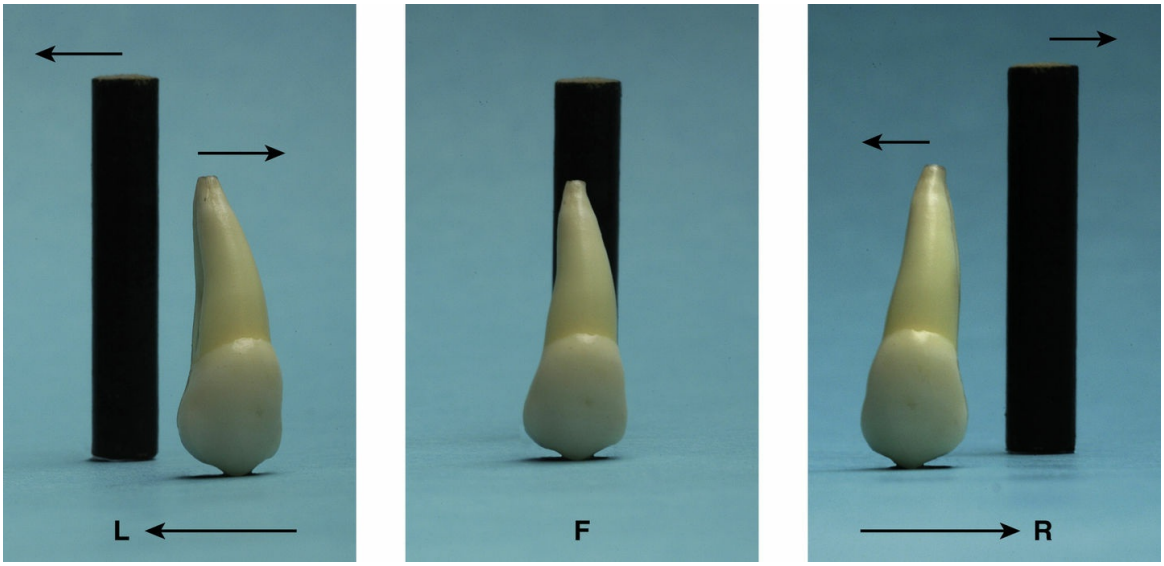


FIG. 24.51 The principle of parallax. Photographs of a small black cylinder positioned behind a tooth. From directly in front **(F)** , the tooth and cylinder are superimposed. With the camera moved to the left **(L)** , the tooth and cylinder are both visible and seem to have moved in different directions. The cylinder, being further away from the camera, seems to have moved in the same direction as the camera, i.e. to the left, while the tooth seems to have moved in the opposite direction. With the camera moved to the right **(R)** a similar apparent movement of the tooth and cylinder relative to the camera takes place, with the cylinder seeming to have moved to the right and the tooth to the left.

Parallax in the horizontal plane

The movement of the X-ray tubehead is in the horizontal plane, for example:

- Two periapicals – one centred on the upper central incisor and

the other centred on the canine region as shown in Fig. 24.52 .

- An upper standard occlusal, centred in the midline plus a periapical or an upper oblique occlusal, centred on the canine region.

Examples are shown in Figs. 24.53 –24.55 .

NOTE: The advantage of the upper standard occlusal for the initial view is that it shows both sides of the arch and unerupted canines are often bilateral.

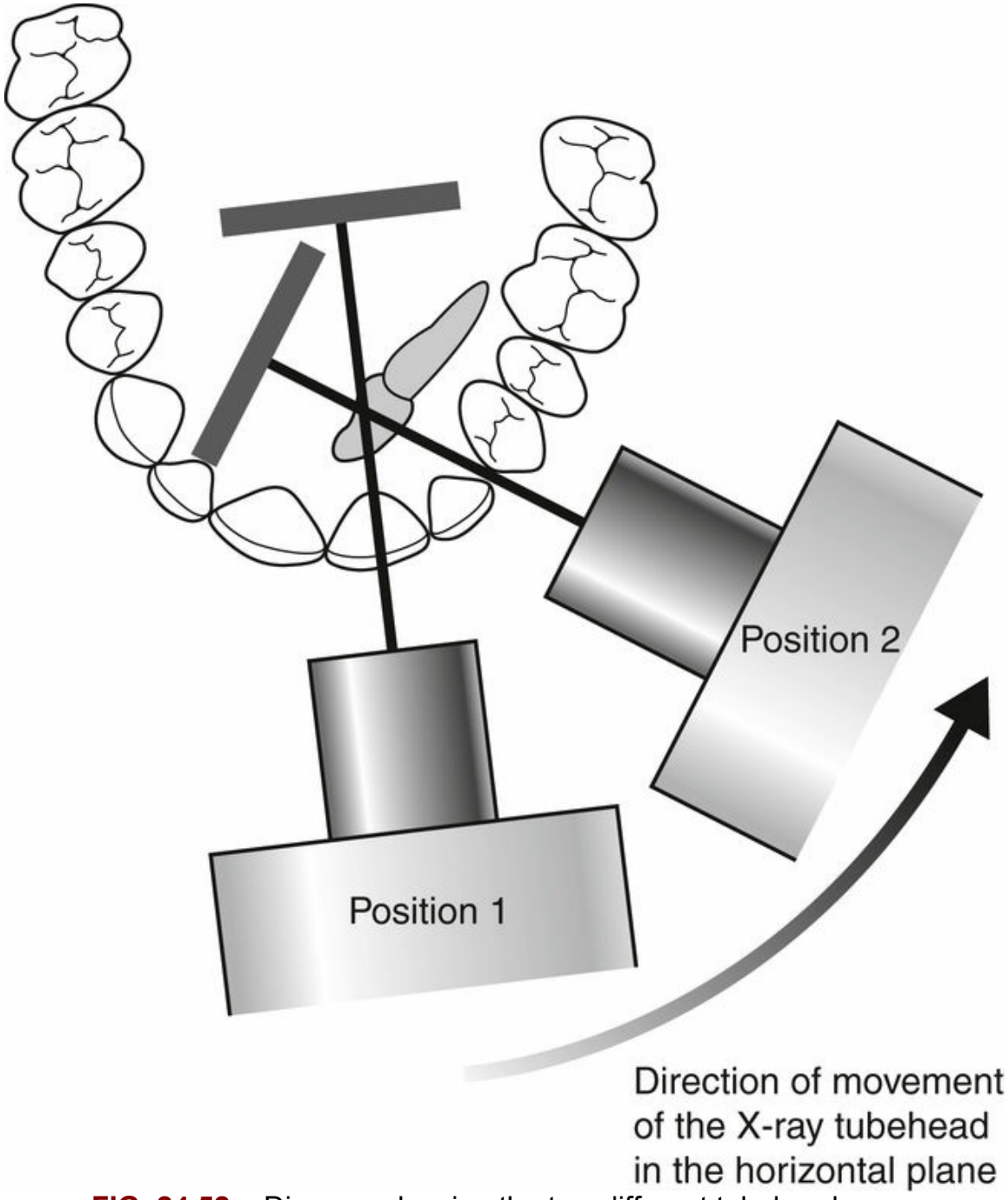


FIG. 24.52 Diagram showing the two different tubehead positions required for parallax in the horizontal plane: position 1 centred on the upper central incisor and position 2 centred on the canine region.

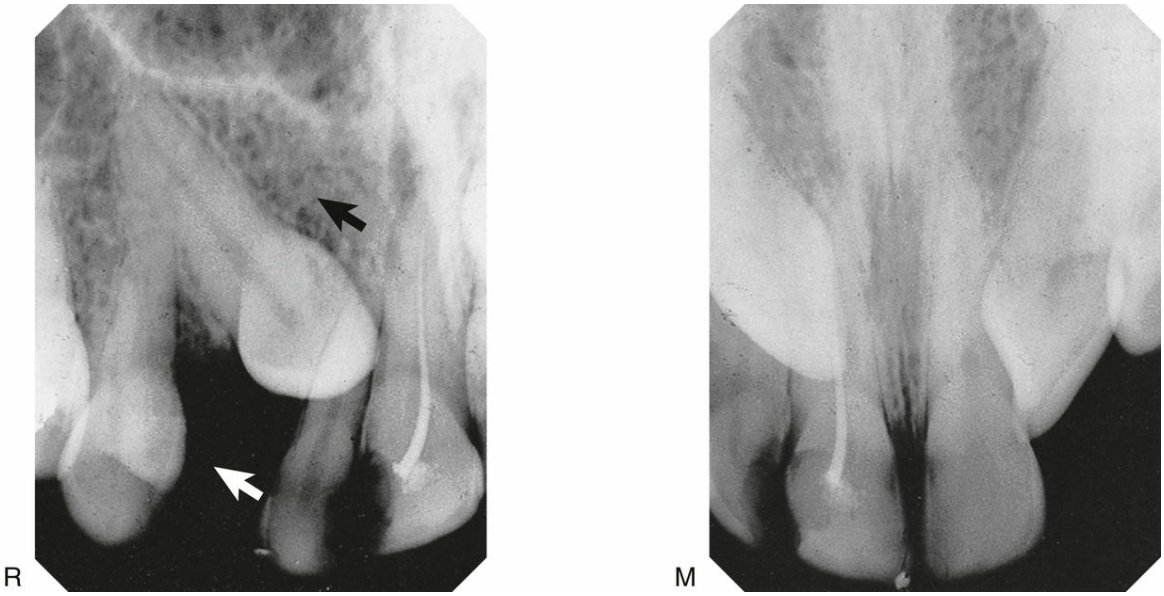


FIG. 24.53 Two periapicals showing the relative positions of the unerupted 3| to the incisors – **(M)** in the midline and **(R)** from the right. The X-ray tubehead (white arrow) and the canine (black arrow) seem to have moved in the *same* direction. The canine is thus palatally positioned.

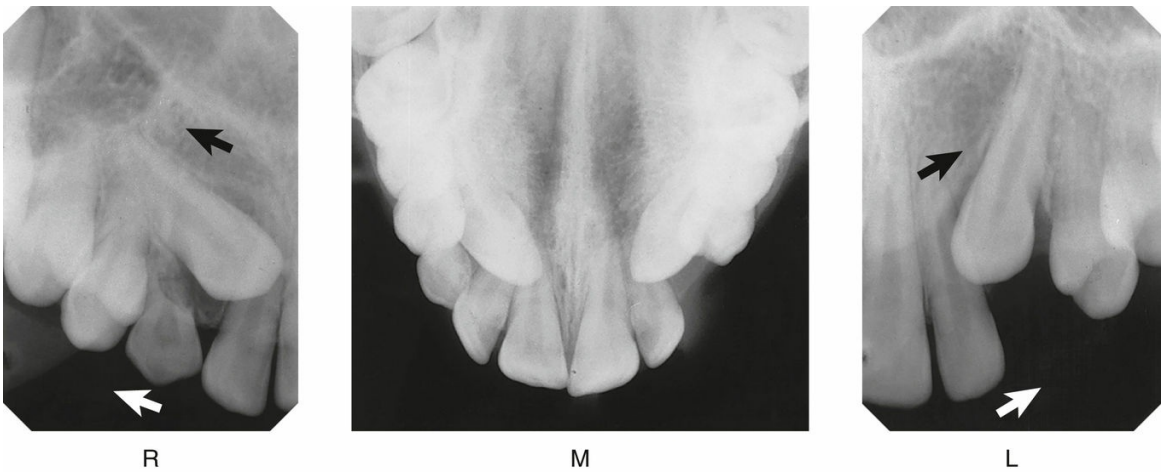


FIG. 24.54 An upper standard occlusal (the mid-line view) and two periapicals centred on the unerupted canines on either side. The teeth can be localized as follows:

1. Examine the midline view radiograph **(M)** , centred on the upper central incisors. The tip of the RIGHT canine appears opposite the root canal of 1| ; the tip of the LEFT canine

appears opposite the mesial aspect $\underline{2}$.

2. Examine radiograph **(R)** , the periapical centred on the RIGHT canine region (i.e. the X-ray tubehead has been moved distally in the direction of the white arrow). The tip of the canine appears opposite the mesial aspect of $\underline{2}$. Therefore, it seems to have moved distally in the direction of the black arrow, i.e. in the *same* direction as the X-ray tubehead was moved.

3. Examine radiograph **(L)** , the periapical centred on the LEFT canine region. The tip of the canine appears opposite the root canal of $\underline{2}$. Again both the X-ray tubehead (white arrow) and the canine (black arrow) seem to have moved in the *same* direction.

Thus, the crowns of both the right and left canines are *palatally* positioned in relation to the incisors.

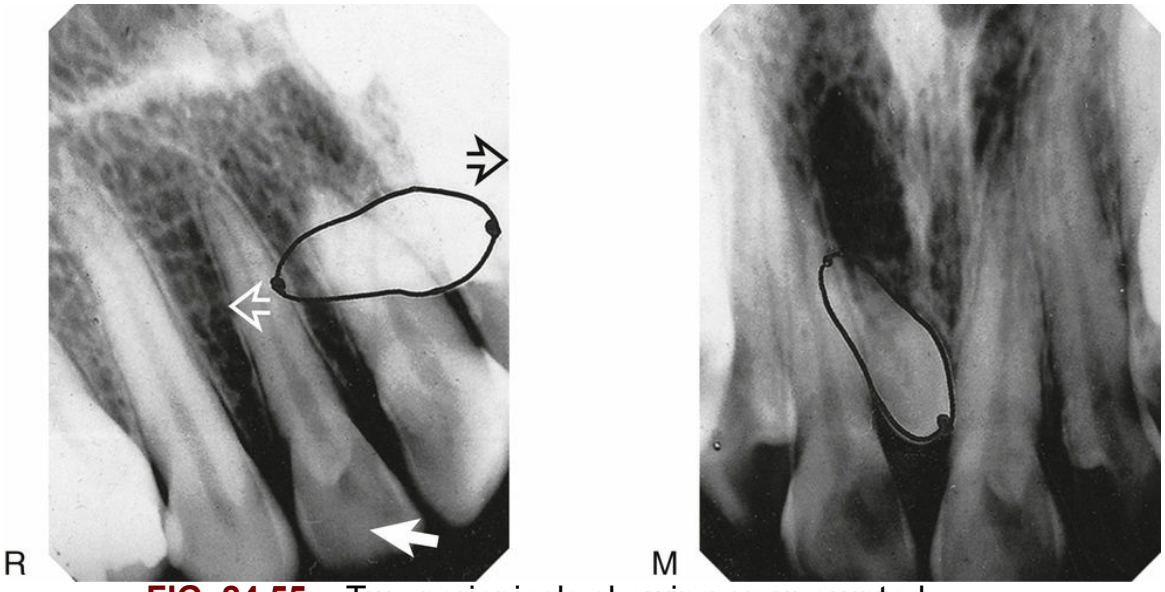


FIG. 24.55 Two periapicals showing an unerupted mesiodens. It can be localized as follows:

1. Examine the mid-line radiograph **(M)** . The tip of the mesiodens' crown seems to be opposite the mesial aspect of $\underline{1}$ while its apex seems to be opposite the root canal of $\underline{1}$.

2. Examine the periapical centred on the RIGHT canine region **(R)** . The tip of the mesiodens crown seems to be opposite the root canal of $\underline{1}$, while its apex seems to be opposite the

mesial aspect of 2 .
3. The X-ray tubehead was moved distally in the direction of the large white solid arrow.
4. The crown of the mesiodens seems to have moved mesially (black open arrow), i.e. in the *opposite* direction to the tubehead. It is thus buccally placed.
5. The apex seems to have moved in the *same* direction (white open arrow) as the tubehead and is thus palatally placed.
The mesiodens thus lies across the arch, between the central incisors, with its crown buccally positioned and its apex palatally positioned.

Parallax in the vertical plane

The movement of the X-ray tubehead is in the vertical plane, for example:

- A panoramic radiograph – the X-ray beam is aimed upwards at 8° to the horizontal
- An upper standard occlusal – the X-ray beam is aimed downwards at 65°–70° to the horizontal as shown in Figs. 24.56 and 24.57 .

NOTE: This combination of views is used frequently in orthodontics, when patients with unerupted canines are usually assessed. Use of these films to their full potential may obviate the need for further films merely to localize the unerupted canines.

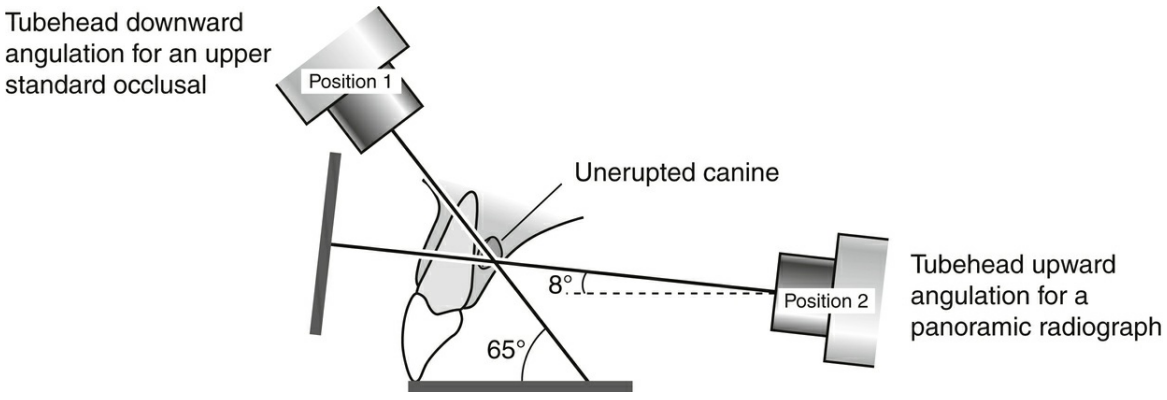


FIG. 24.56 Diagram showing the two different tubehead positions when taking a panoramic radiograph and an upper standard occlusal, allowing parallax in the vertical plane.

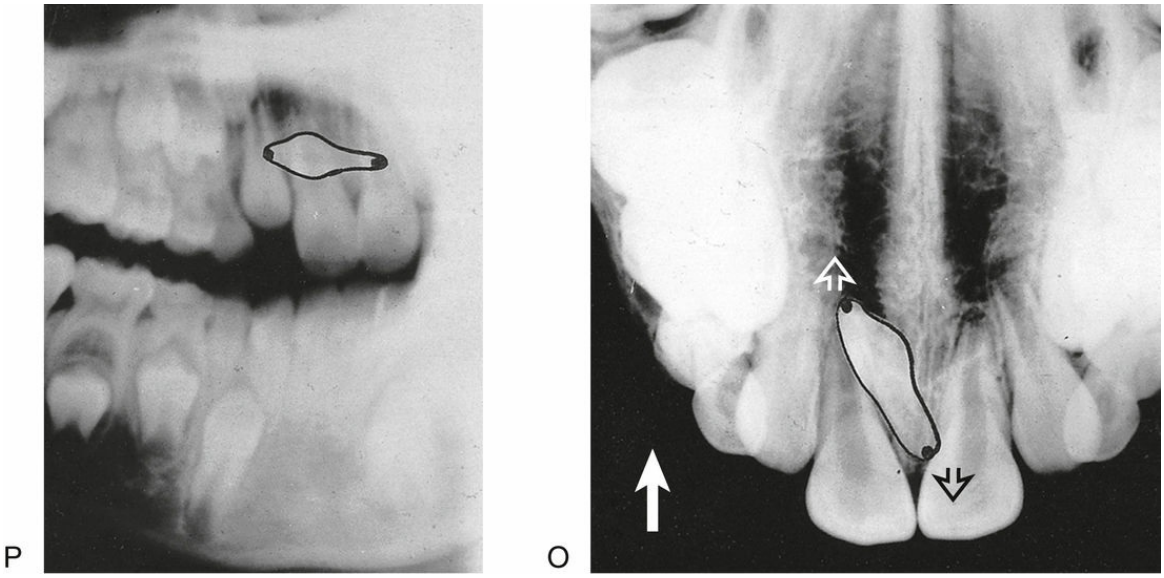


FIG. 24.57 Part of a panoramic radiograph and an upper standard occlusal showing an unerupted mesiodens. It can be localized as follows:

1. Examine the panoramic radiograph (P) taken with the tubehead aimed upwards at 8° to the horizontal. The tip of the mesiodens' crown seems to be opposite the neck of the lateral incisor, while its apex seems to be opposite the root of 1 .
2. Examine the occlusal radiograph (0) taken with the tubehead aimed downwards at 65° to the horizontal. The tip of the mesiodens' crown now seems to be beyond the apex of 2 , while its apex seems to be opposite the crown of 1 .
3. The X-ray tubehead has moved vertically upwards from view (P) to view (0) in the direction of the solid white arrow.
4. The crown of the mesiodens seems to have moved in the *same* direction (white open arrow) and is thus palatally placed.
5. The apex of the mesiodens seems to have moved in the *opposite* direction (black open arrow), and is thus buccally placed.

The mesiodens thus lies across the arch between the central

incisors, with its crown palatally positioned and its apex buccally positioned.

Cone Beam Computed Tomography (CBCT)

Small volume CBCT can be used – in selected cases – for both the assessment and localisation of developmental anomalies such as unerupted canines, if conventional radiographs fail to provide adequate diagnostic information. The British Orthodontic Society's 2015 *Guidelines for the Use of Radiographs in Clinical Orthodontics* supports this approach and recommends CBCT be reserved for those equivocal cases where incisor root resorption is suspected from conventional imaging or those with potential complications as there is improved accuracy of localisation and identification of incisor root resorption. Two examples are shown in Figs. 24.58 and 24.59 .



FIG. 24.58 Small volume CBCT showing palatally positioned maxillary canines and resorption of 2.

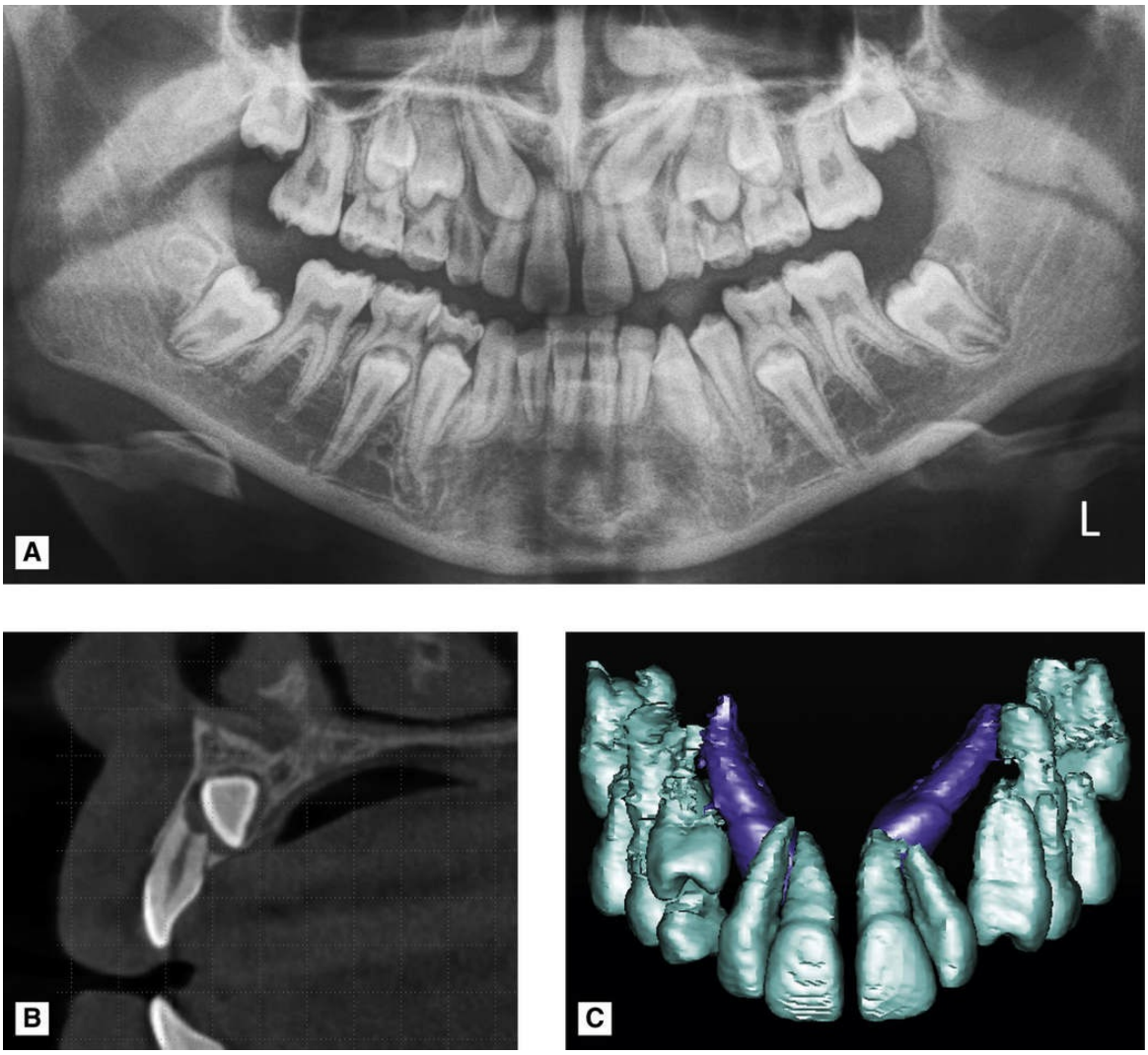


FIG. 24.59 **(A)** Panoramic radiograph suggesting resorption of the ⌊2 . **(B)** Sagittal CBCT image confirming root resorption of ⌊2 . **(C)** Segmented surface rendered view confirming the positions of the unerupted canines in relation to the upper incisors. (©DentsplySirona – Simplant® Pro.)

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

25

Radiological Differential Diagnosis – Describing a Lesion

Introduction

Despite the many different conditions that can affect the jaws, they can present radiographically only as areas of relative *radiolucency* or *radiopacity* compared with the surrounding bone. Even this division based on radiodensity is not clear-cut – some lesions fall into **both** categories, but at different stages in their development.

As a result, many of these pathological conditions resemble one another closely. This similarity often creates considerable confusion. Fortunately, the sites where the lesions develop, how they grow and the effects they have on adjacent structures tend to follow recognizable patterns. As mentioned in Chapter 19 , it is the recognition of these particular patterns that provides the key to interpretation and the formation of a radiological *differential* diagnosis.

A detailed description helps to identify these patterns and determine the lesion's basic characteristics. For example, it may reveal whether the lesion is a cyst or a tumour, whether it is composed of hard or soft tissue and whether, in the case of a tumour, it is benign or malignant. The resultant list of possible diagnoses in turn often determines the patient management and mode of treatment. The final definitive diagnosis is almost always based on histological examination.

Detailed Description of a Lesion

Initial mention should be made of the patient's age and ethnic

background, followed by a systematic description of the lesion, which should include comments on its:

- Site or anatomical position
- Size
- Shape
- Outline/edge or periphery
- Relative radiodensity and internal structure
- Effect on adjacent surrounding structures
- Time present, if known.

Site or Anatomical Position

This should be stated precisely, for example the lesion(s) could be:

- Localized to the mandible, affecting:
    - – the anterior region
    - – the body – above or below the inferior dental canal, or related to the teeth
    - – the angle
    - – the ramus
    - – the condylar process
    - – the coronoid process
    - – both sides (bilateral)
    - – several sites
- Localized to the maxilla, affecting:
    - – the anterior region
    - – the posterior region
    - – both sides (bilateral)
    - – several sites
- Generalized, affecting:
    - – both jaws
    - – and/or other bones – multiple lesions may also affect the:
        - * cranial vault
        - * long bones

* cervical spine

- Originating from a point or epicentre relative to surrounding structures, e.g.:
  - in bone or soft tissue
  - above or below the inferior dental canal
  - in or outside the inferior dental canal
  - in or outside the maxillary antrum
  - inside or outside a tooth follicle
  - at a tooth root apex.

In the mandible, so-called *odontogenic lesions* develop above the inferior dental canal, while *non-odontogenic lesions* develop above, within or below the canal. Thus, some conditions have a predilection for certain areas whilst others develop in one site only. For example, radicular cysts develop at the apices of non-vital teeth, while the nasopalatine duct cyst only develops anteriorly in the midline of the maxilla. The site or anatomical position of a lesion may therefore provide the initial clue as to its identity.

Size

Conventionally, the lesion is sized in one of two ways including:

- Measuring the dimensions in centimetres
- Describing the boundaries, i.e. 'the lesion extends from … to … in one dimension and extends from … to … in the other dimension' as shown in Fig. 25.1 .

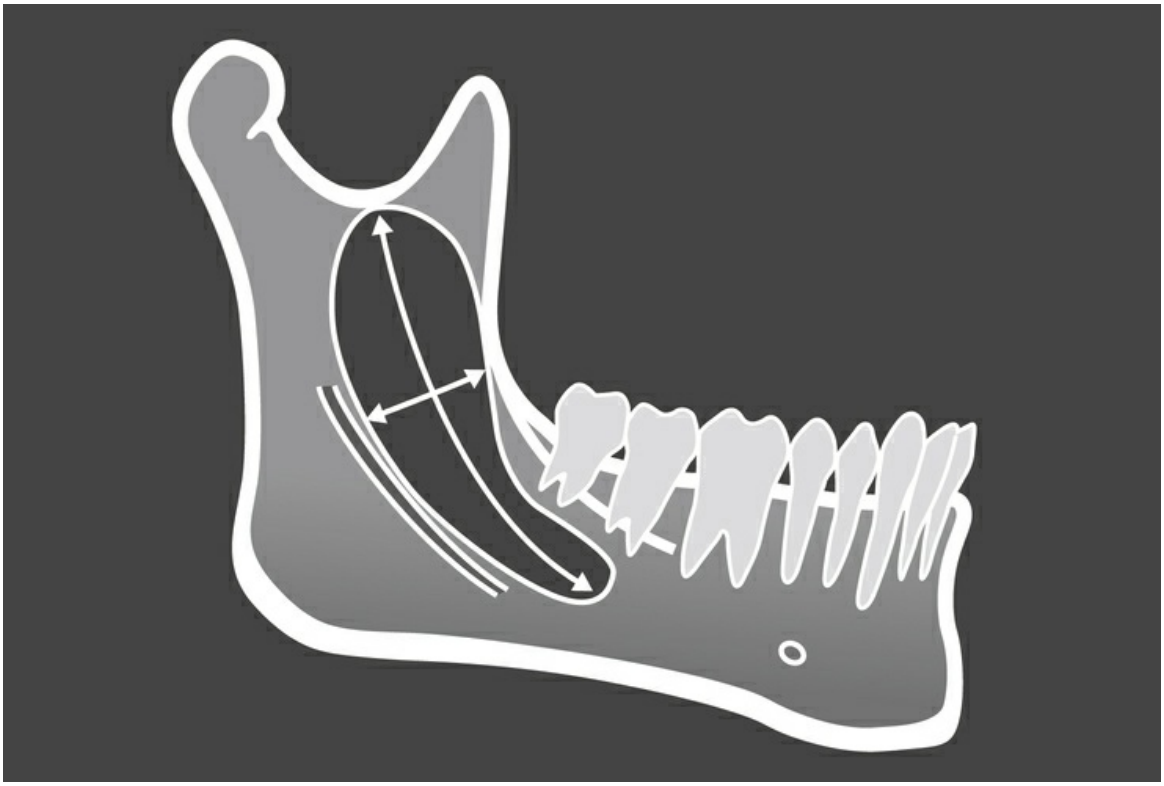


FIG. 25.1 Diagram showing the radiographic appearance of a radiolucent lesion at the angle of the mandible illustrating how to size a lesion, e.g. 'It extends from the mesial aspect of the $\overline{7}$ up to the sigmoid notch, and from the anterior border of the ramus down to the inferior dental canal,' or 'It is approximately 6 cm × 2 cm'.

The size of a lesion is not a particularly helpful differentiating feature, as both benign and malignant lesions may present when large or small. However, a few conditions have little or no growth potential and are therefore almost always small (e.g. 1–2 cm), such as Stafne's idiopathic bone cavity, whilst tumours, such as ameloblastoma can grow, if untreated, to an enormous size (10 cm or more). Thus, the size of a lesion, while not being specific, may still give some idea of the type of underlying condition.

Shape

Conventionally, the shape of the lesion is described using one or more of the following terms (see Fig. 25.2):

- Unilocular
- Multilocular
- Pseudolocular
- Round
- Oval
- Scalloped or undulating
- Irregular.

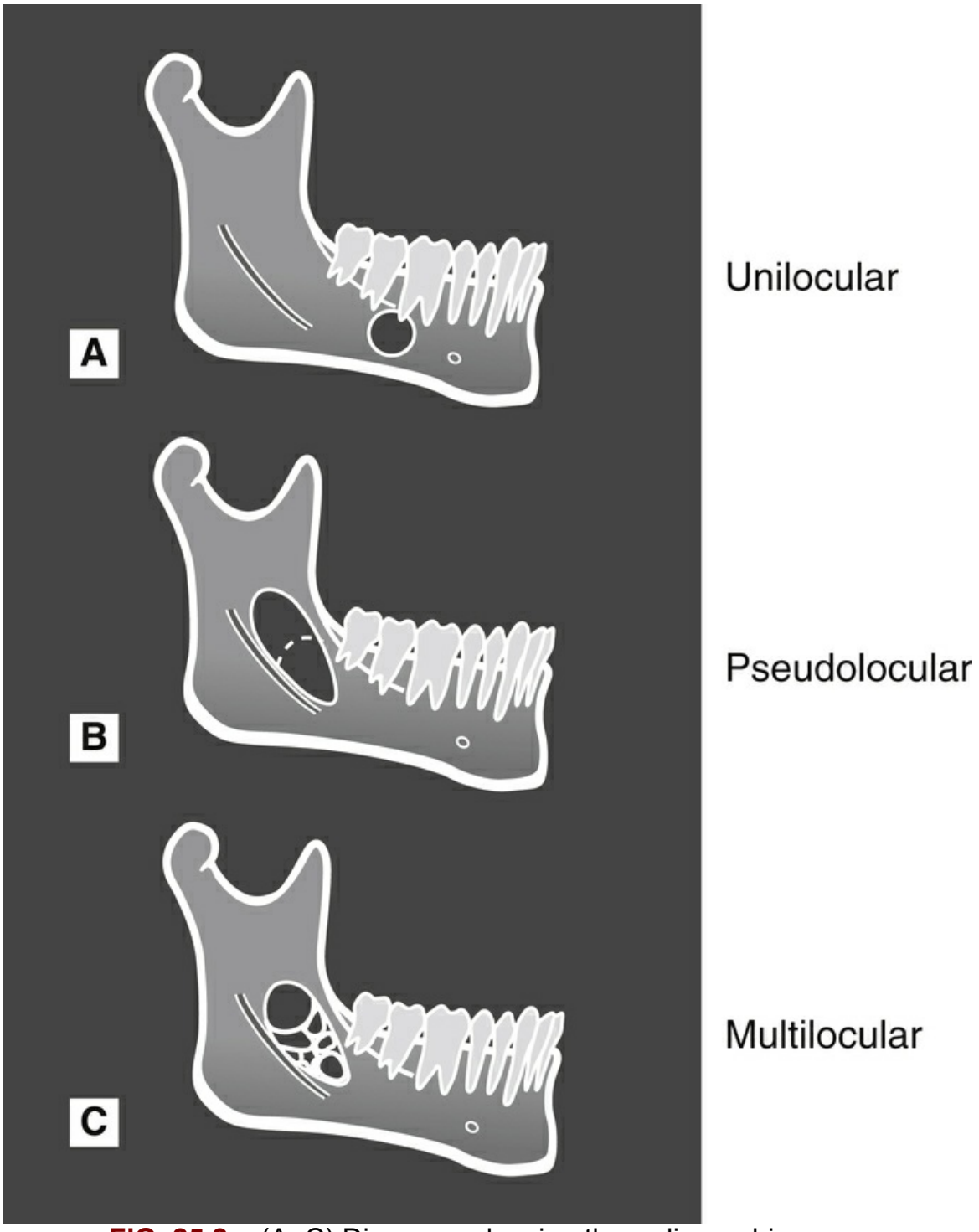


FIG. 25.2 (A–C) Diagrams showing the radiographic appearance of the various shapes of lesions.

The shape of a lesion is one of the more useful and specific characteristics that contribute to the radiological diagnosis. For

example, the radicular cyst is round and unilocular while the giant cell lesions tend to be multilocular. An irregular shape suggests either irregular growth, such as the simple bone cyst which typically arches up to extend between the roots of the teeth, or destruction indicating either an inflammatory or malignant lesion.

Outline/Edge or Periphery

The outline or periphery of lesions is described conventionally as being discrete and well defined or non-discrete and poorly defined and as having various additional characteristics (see Fig. 25.3).

Discrete or Well-defined Outlines

These may also be:

- Smooth
- Punched-out, i.e. showing no peripheral bone reaction
- Corticated, i.e. having a thick or thin surrounding radiopaque (white) cortex

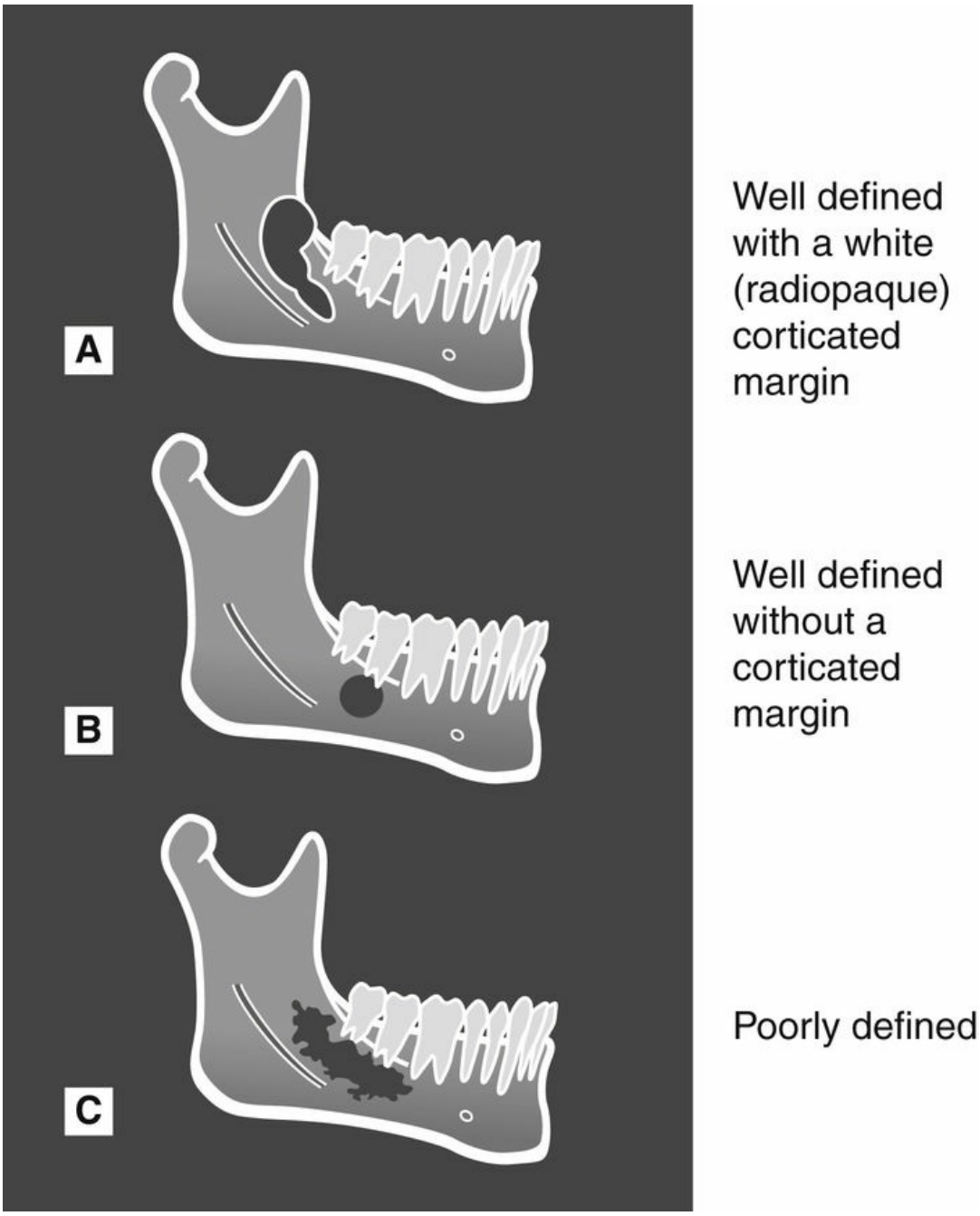


FIG. 25.3 **(A–C)** Diagrams showing the radiographic appearance of different lesion outlines or edges.

- Sclerotic, i.e. having a non-uniform radiopaque boundary
- Encapsulated, i.e. surrounded by a radiolucent (black) line which may be complete or partial.

Non-discrete or Poorly Defined Outlines

These may also:

- Blend in with normal anatomy and show a gradual change between trabecular patterns
- Show signs of invasion and appear ragged or *moth-eaten.*

The outline or periphery provides information about the nature of the lesion, e.g. whether it is benign or malignant and what the speed of growth or development seems to be. The more benign and slow growing the lesion is, the more likely it is to have a well-defined corticated outline. The malignant, more rapidly growing lesions tend to have poorly defined margins because the speed of bone destruction outstrips any bony repair.

Unfortunately, when a lesion such as a cyst becomes acutely infected, the normal outline can often be obliterated and the appearance may suggest a different, more sinister condition.

Relative Radiodensity and Internal Structure

The radiodensity of the lesion should be assessed relative to the surrounding tissues. Radiolucent lesions are only evident within otherwise hard (radiopaque) tissues as a result of a decrease in mineralization, resorption of mineralized tissue or a decrease in thickness. As stated in Chapter 2 , the amount of photoelectric absorption and hence opaque/whiteness of a structure is $\propto Z^3$. The atomic number (Z) of bone is approximately 12 ($Z^3 = 1728$), whereas the atomic number of soft tissue is approximately 7 ($Z^3 = 343$). A soft tissue lesion replacing bone will therefore appear radiolucent.

Radiopaque lesions are evident in bone because of an increase in mineralization, increase in thickness, or superimposition on some other structure. They are also evident following calcification in soft tissues (see Chapter 27), having replaced air in the maxillary antra (see Chapter 28) or as a result of an increase in thickness of either normal or abnormal soft tissue.

Thus, relative to the surrounding tissues, the radiodensity of the

lesion could be:

- Uniformly radiolucent
- Radiolucent with patchy internal opacities (mixed)
- Radiopaque.

The relative radiodensity also helps in the differentiating process by highlighting the **internal structure** of partially or completely radiopaque lesions. The alternatives include:

- Fine bone trabeculae, e.g. a *ground glass* appearance
- Thick, coarse trabeculae with enlarged trabecular spaces, e.g. a *honeycomb* appearance
- Haphazard sclerotic bone, e.g. *cotton wool* patches
- Homogeneous dense cortical bone
- Discrete bony septa, which could be:
  - thin or coarse
  - straight or curved
  - prominent or faint
- Cementum – oval or round amorphous calcification
- Identifiable dental tissue – enamel and/or dentine
- No specific pattern.

Effects on Adjacent Surrounding Structures

The following structures need to be checked (see Fig. 25.4):

The Teeth

There may be evidence of:

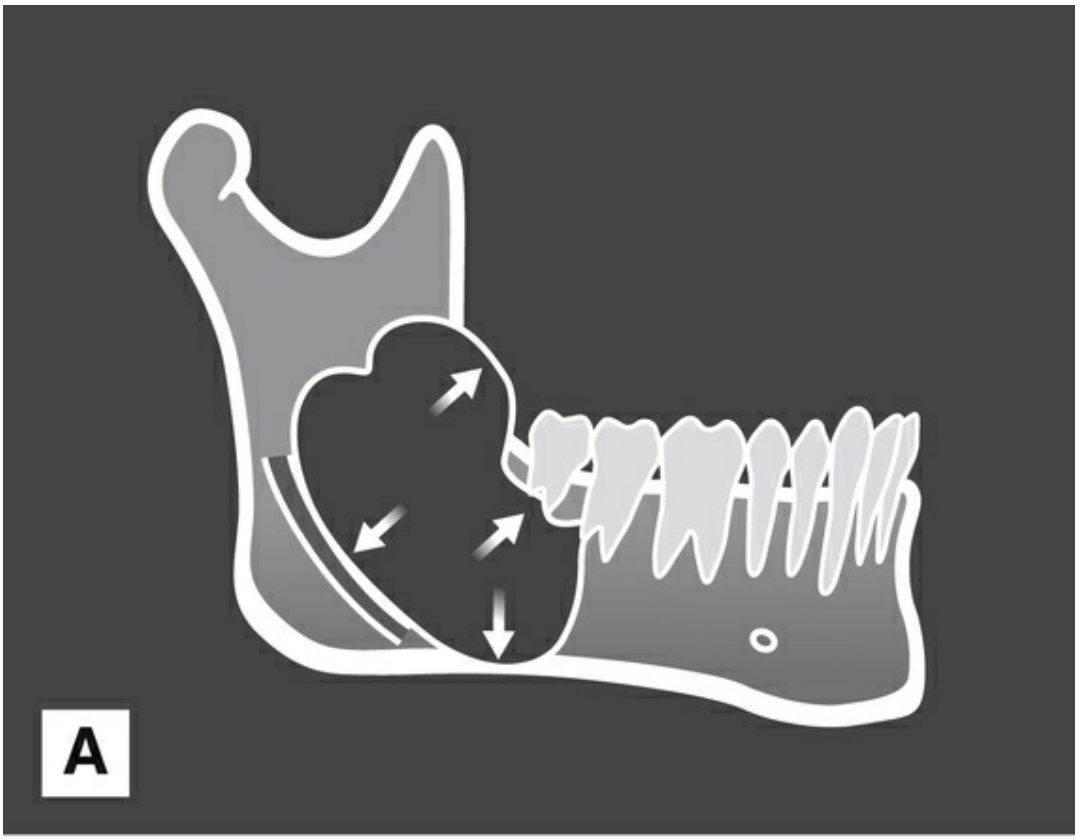
- Resorption, which is a feature of long-standing, benign but locally aggressive lesions, chronic inflammatory lesions, and malignancy
- Displacement
- Delayed eruption

- Disrupted development, resulting in abnormal shape and/or density
- Loss of associated lamina dura
- Increase in the width of the periodontal ligament space
- Alteration in the size of the pulp chamber
- Hypercementosis.

Surrounding Bone

There may be evidence of:

- Expansion:
  - Buccal
  - Lingual/palatal
  - In other directions


A

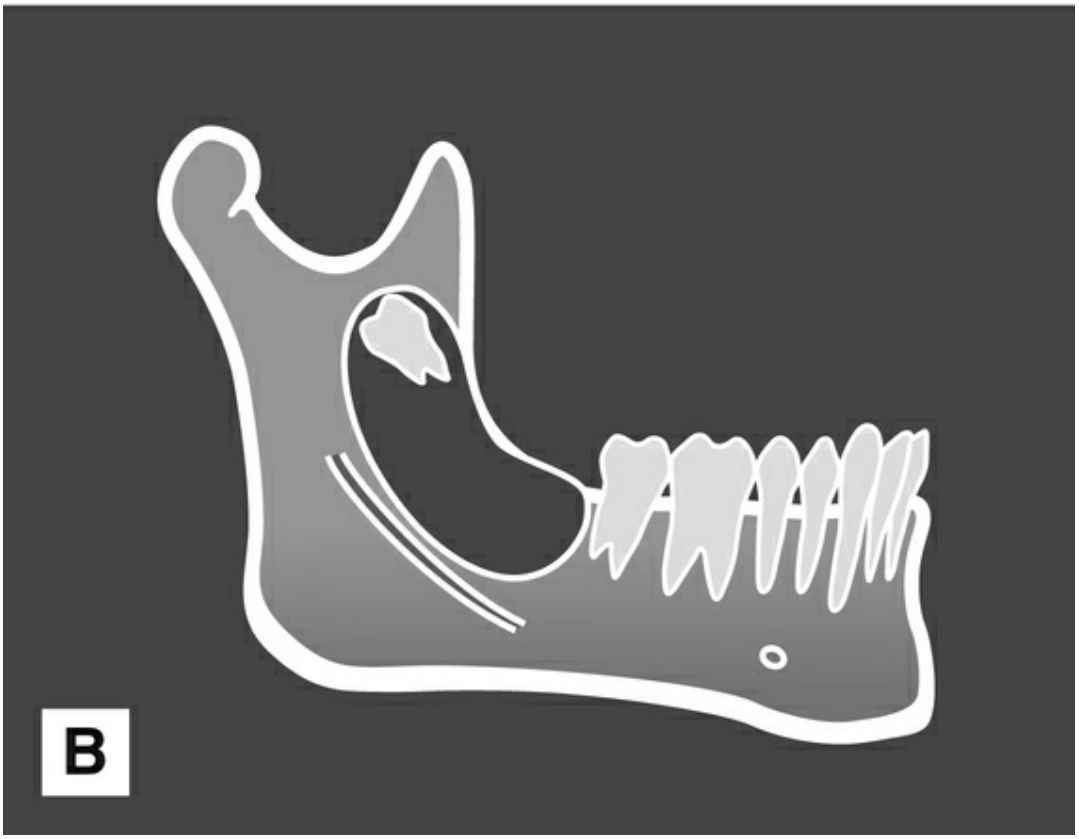

B

FIG. 25.4 Diagrams showing the radiographic appearance of some of the typical effects that a lesion can have on adjacent structures. **(A)** Expansion, displacement of inferior dental canal, tooth and bone resorption. **(B)** Tooth displacement.

- Displacement or involvement of surrounding structures, including the:
  - Cortex of the inferior dental canal
  - Mental foramen
  - Lower border cortex of the mandible
  - Floor of the antrum
  - Floor of the nasal cavity
  - Orbits
- Ragged destruction
- Increased density (sclerosis)
- Subperiosteal new bone formation
- An increase in the normal width of the inferior dental canal
- Irregular bone remodelling, resulting in an abnormal shape or unusual overall bone pattern.

Surrounding Soft Tissues

There may be evidence of invasion of the soft tissues producing a soft tissue mass.

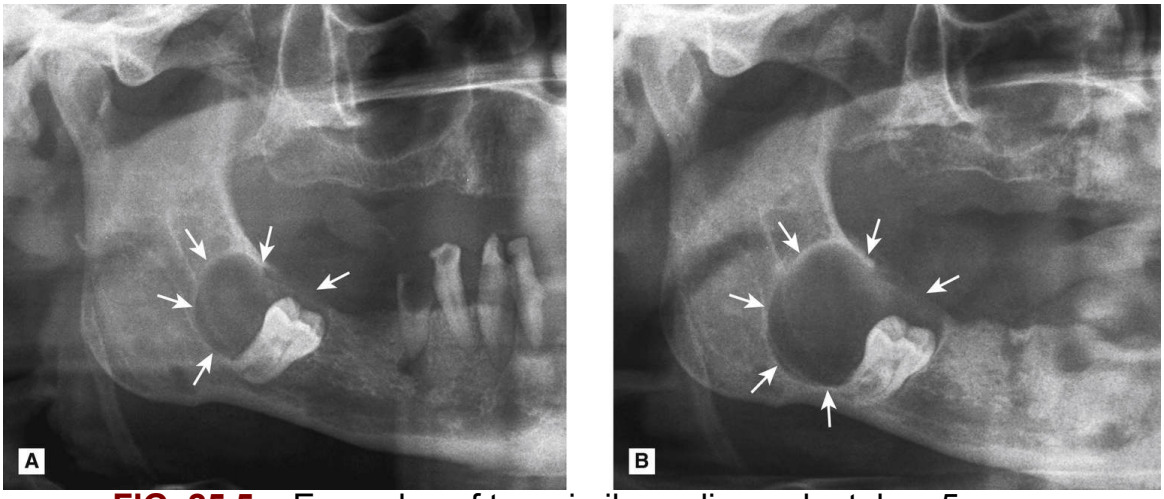


FIG. 25.5 Examples of two similar radiographs taken 5 years apart showing the increase in size of the cystic lesion (arrowed) over the years.

Knowing what effects on adjacent surrounding structures a lesion is having provides information about the nature of the lesion and its mode of growth. For example, the more dangerous the lesion, the more damaging and destructive its effects, and the faster its growth. Some lesions grow and expand in particular ways, such as the odontogenic keratocyst, which tends to infiltrate the cancellous bone and grow along the body of the mandible and produces little buccal or lingual expansion, whilst an ameloblastoma in the same site tends to expand and infiltrate in all directions.

Time Present

The length of time the lesion has been present – days, weeks or years – should be determined, if possible. Unfortunately, this information is not always available. The patient may not be aware of the lesion and there may be no records of when it first became evident. If sequential radiographs are available, they can be very useful in providing information on the rate of growth, or development, of a lesion (see Fig. 25.5). This information in turn may provide a clue about the nature of the lesion because slow-growing lesions tend to be benign, whilst fast-growing, aggressive lesions are usually malignant.

Footnote

This methodical, systematic description of the features of a lesion forms the basis of the step-by-step differential diagnostic process and is used throughout Chapters 26 and 27 Chapters 26Chapters 27. As is shown later, several of the same features are shared by different conditions. Thus, no one feature alone gives enough information to provide the diagnosis. All the features should be considered carefully to determine their relevance and importance.

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

26

Differential Diagnosis of Radiolucent Lesions of the Jaws

Introduction

This chapter is designed to simplify the process of arriving at a *radiological differential diagnosis* when confronted with a radiolucency of unknown cause on a plain radiograph. This process requires clinicians to follow a methodical step-by-step approach and to know the **typical** features of the various possibilities. Such a step-by-step guide is suggested and summarized in Fig. 26.1 . Although most lesions are still detected using plain radiographs, this process can be greatly facilitated in many cases if advanced imaging modalities, described in Chapters 16 and 18 , such as computed tomography (CT), cone beam computed tomography (CBCT) or magnetic resonance imaging (MRI), are available.

Unfortunately, most of the lesions encountered share several similar features and often individual conditions can present in many different ways. Thus, the summary of features for the more important conditions included in this chapter is an attempt to unravel some of the inevitable confusion. Also, for simplicity, the frequency with which the various lesions present has been divided arbitrarily into common, uncommon and rare. It is hoped and intended that the reader should expand on this short notes style framework by referring to the suggested reading list.

Step-By-Step Guide

Step I

Systematically describe the radiolucency (as outlined in Chapter 25), including its:

- Site or anatomical position
- Size
- Shape
- Outline/edge or periphery
- Relative radiodensity
- Effects on adjacent surrounding structures
- Time present – if known.

Step II

Decide whether or not the radiolucency is:

1. *A normal anatomical feature*
   - In the mandible, e.g.:
     – Mental foramen
     – ID canal
     – Sparse trabecular pattern
     – Developing tooth crypt
   - In the maxilla, e.g.:
     – Antrum
     – Nasal fossa
     – Nasopalatine fossa.
2. *Artefactual*

These radiolucencies are dependent largely on the type of radiograph being examined, but examples include:

- Radiolucency as a result of overexposure
- Superimposed radiolucent air shadows.

3. *Pathological*

If pathological, the radiolucency could be:

- Congenital
- Developmental
- Acquired.

Step III

If the pathological radiolucency is *acquired,* decide within which of the following main disease categories it may be placed:

- Infection localized to the apical tissues
  - – Acute
  - – Chronic
- Infection spreading within the jaw
  - – Osteomyelitis
  - – Osteoradionecrosis
- Traumatic lesions
- Cysts
- Tumours
  - – Odontogenic
  - – Non-odontogenic
- Allied lesions
  - – Giant cell lesions or bone cysts
  - – Fibro-osseous lesions
  - – Other lesions.

Step IV

Consider the classification and subdivision of cysts and other similar radiolucencies within each of the other main disease categories as shown in Table 26.1 . This resultant list includes most of the more likely diagnostic possibilities for the unknown radiolucent lesion.

Step V

Compare the radiological features of the unknown radiolucency with the **typical** radiological features of these possible conditions. Then construct a list showing, in order of likelihood, all the conditions that the lesion might be. This list forms the *radiological differential diagnosis*.

Infection is described elsewhere (apical in Chapter 21; spreading in Chapter 28) and trauma is described in Chapter 29 . The rest of this chapter is devoted principally to differentiating between the different cysts – the most common of the remaining categories – and the other lesions that often present as very similar radiolucencies.

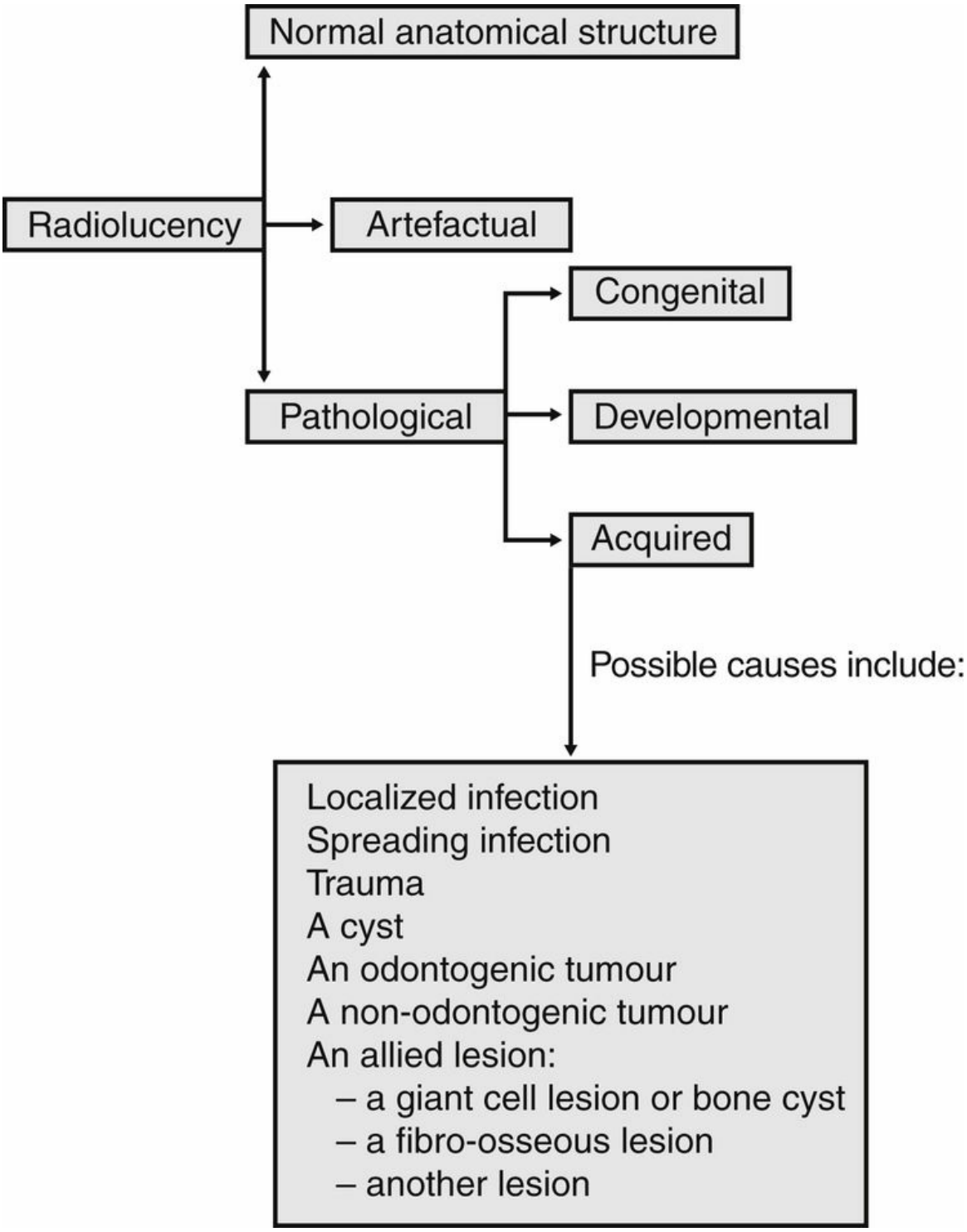


FIG. 26.1 Summary of the step-by-step guide to producing a differential diagnosis.

TABLE 26.1

Classification of the main cysts, tumours and other bone lesions that can present as a radiolucency, based broadly on the 2017 World Health Organization classification of odontogenic and maxillofacial bone tumours.

Cysts

Odontogenic cysts of inflammatory origin

Radicular (dental) cyst and residual cyst

Inflammatory collateral cysts (buccal bifurcation or paradental)

Odontogenic developmental cysts

Dentigerous cyst

Odontogenic keratocyst

Lateral periodontal cyst and botryoid odontogenic cyst

Calcifying odontogenic cyst

Glandular odontogenic cyst (sialo-odontogenic cyst)

Non-odontogenic developmental cysts

Nasopalatine duct cyst

Odontogenic tumours

Benign epithelial odontogenic tumours

Ameloblastoma

Unicystic Ameloblastoma

Calcifying epithelial odontogenic tumour (Pindborg tumour)

Adenomatoid odontogenic tumour

Benign mixed epithelial and mesenchymal odontogenic tumours

Ameloblastic fibroma

Benign mesenchymal odontogenic tumours

Odontogenic fibroma

Odontogenic myxoma/myxofibroma

Cementoblastoma

Malignant odontogenic tumours

Odontogenic carcinomas

- Ameloblastic carcinoma
- Primary intraosseous carcinoma

- Clear cell odontogenic carcinoma

Odontogenic sarcomas

Non-odontogenic tumours

Intrinsic benign maxillofacial bone and cartilage tumours

Chondroma

Fibroma

Non-odontogenic tumours cont'dIntrinsic benign maxillofacial vascular and neural tumours

Central haemangioma

Neuroma

Neurofibroma

Intrinsic malignant maxillofacial bone and cartilage tumours

Osteosarcoma

Chondrosarcoma

Fibrosarcoma

Soft tissue malignant tumours involving bone

Squamous cell carcinoma

Secondary metastatic bone tumours

Breast, bronchus, lung, kidney and prostate

Lymphoreticular tumours of bone

Multiple myeloma

Burkitt's lymphoma

Ewing's tumour

Langerhans cell histiocytosis

Eosinophilic granuloma

Hand-Schüller-Christian disease

Letterer-Siwe disease

Allied lesions

Giant cell lesions and bone cysts

Central giant cell granuloma

Cherubism

Aneurysmal bone cyst

Simple bone cyst

Fibro-osseous lesions

Cemento-ossifying fibroma

Fibrous dysplasia

Cemento-osseous dysplasia

- Periapical cemento-osseous dysplasia
- Focal cemento-osseous dysplasia
- Florid cemento-osseous dysplasia

Other lesions

Stafne's idiopathic bone cavity

Typical Radiographic Features of Radiolucent Cysts and Tumours

Inflammatory Odontogenic Cysts

Radicular (Dental) Cyst (see Fig. 26.2)

This inflammatory cyst develops from the epithelial remnants of Hertwig's root sheath – the cell rests of Malassez.

- ***Age*** : Usually adults, 20–50 year-olds.
- ***Frequency*** **:** Most common of all jaw cysts (about 70%).
- ***Site*** **:** Apex of any nonvital tooth, particularly upper lateral incisors.
- ***Size*** **:** 1.5–3.0 cm in diameter (if smaller the radiographic distinction between cyst and granuloma cannot usually be made).
- ***Shape*** **:** – Round
  – Unilocular.
- ***Outline*** **:** – Smooth
  – Well-defined
  – Well-corticated if long-standing (unless infected) and continuous with the lamina dura of the associated tooth.

- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Adjacent teeth displaced, rarely resorbed
  – Buccal expansion
  – Displacement of the antrum.

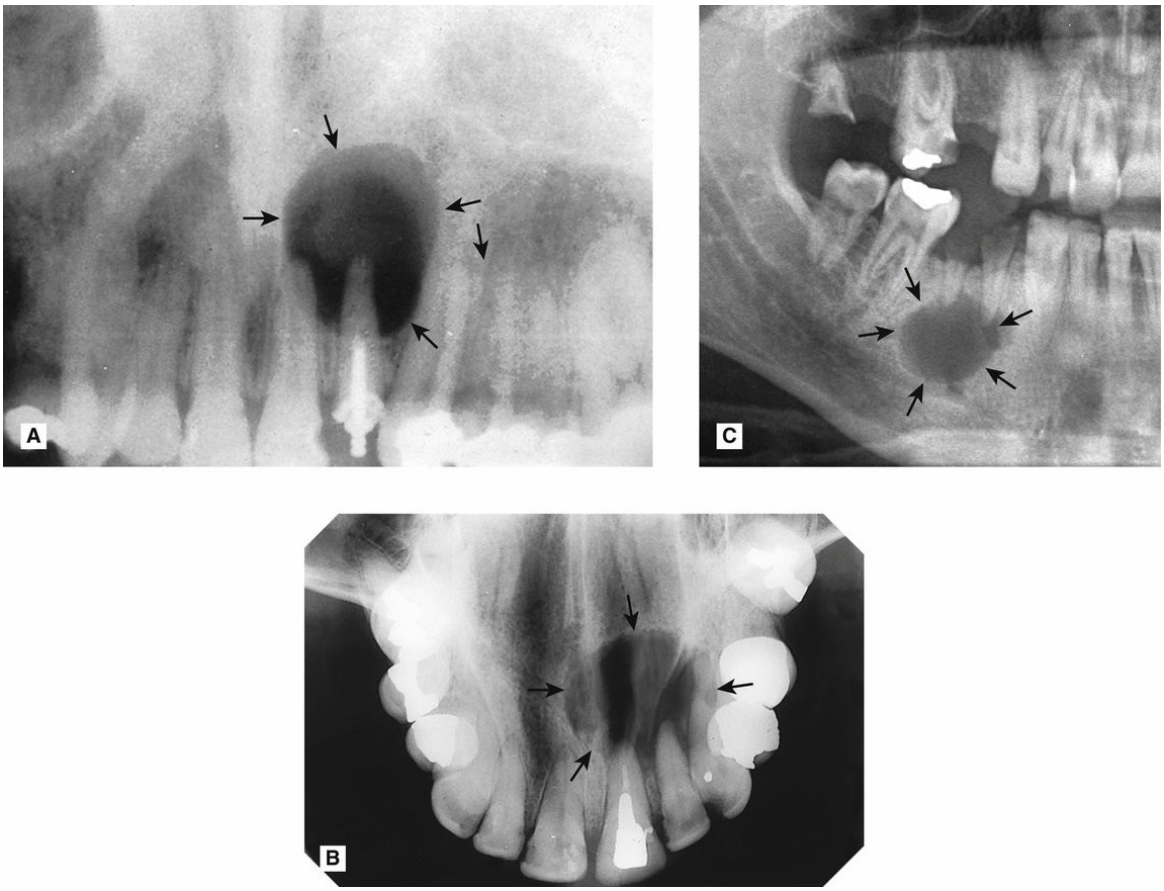


FIG. 26.2 **(A)** Static panoramic (Panoral) radiograph showing a typical radicular (dental) cyst (arrowed) associated with the non-vital ⌊2 . **(B)** Upper standard occlusal showing a large radicular cyst (arrowed) associated with the root-filled ⌊1 . **(C)** Part of a panoramic radiograph showing a typical unilocular radicular cyst (arrowed) associated with the non-vital 5⌋ .

Residual Radicular Cyst (see Fig. 26.3)

This term refers to a radicular (dental) cyst remaining after the causative tooth has been extracted.

- ***Age*** **:** Adults, over 20 years old.
- ***Site*** **:** Apical regions of the tooth-bearing portion of the jaws.
- ***Size*** **:** Variable, usually 2–3 cm in diameter.
- ***Shape*** **:** – Round
  – Unilocular.

- ***Outline*** **:** – Smooth
  – Well-defined
  – Usually well-corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Adjacent teeth displaced, rarely resorbed
  – Buccal expansion
  – Displacement of the antrum.

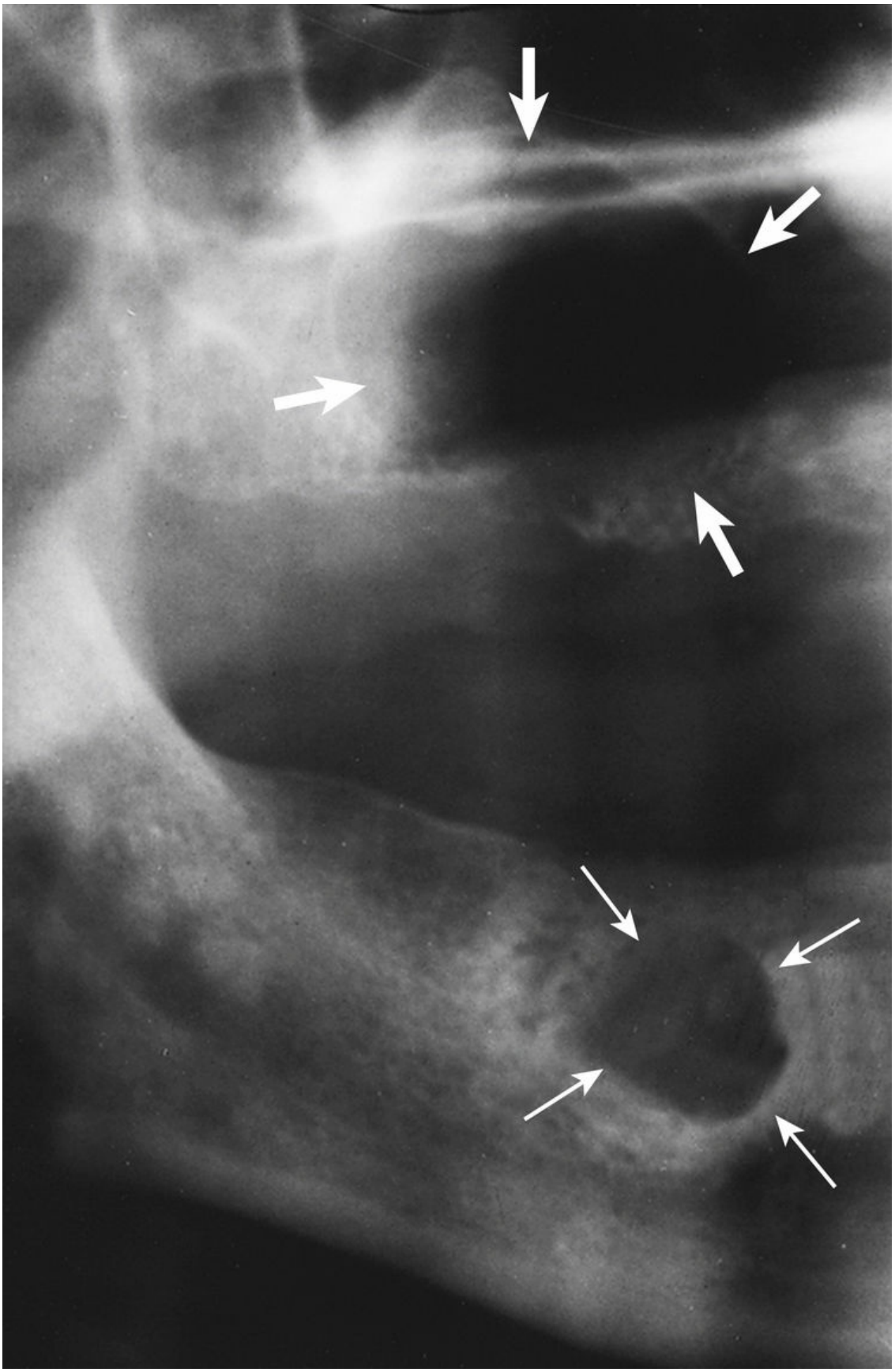


FIG. 26.3 Part of a panoramic radiograph showing two residual radicular cysts (arrowed), one in the maxilla and one in the mandible.

Inflammatory Collateral Cyst (Buccal Birfurcation Cyst, Paradental Cyst) (see Fig. 26.4)

This is an inflammatory cyst thought to develop from either the reduced enamel epithelium or from sulcular/junctional epithelium.

- ***Age*** **:** Children and adolescents (first and second molars), adults (third molars).
- ***Site*** **:** Buccal aspect of erupting lower molars. Sometimes associated with a buccal enamel spur or pearl.
- ***Size*** **:** Variable, up to 3 cm in diameter.
- ***Shape*** **:** Unilocular.
- ***Outline*** **:** – Smooth
  – Well-defined
  – Usually well-corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Associated teeth often tipped or displaced, but not resorbed
  – Buccal expansion.

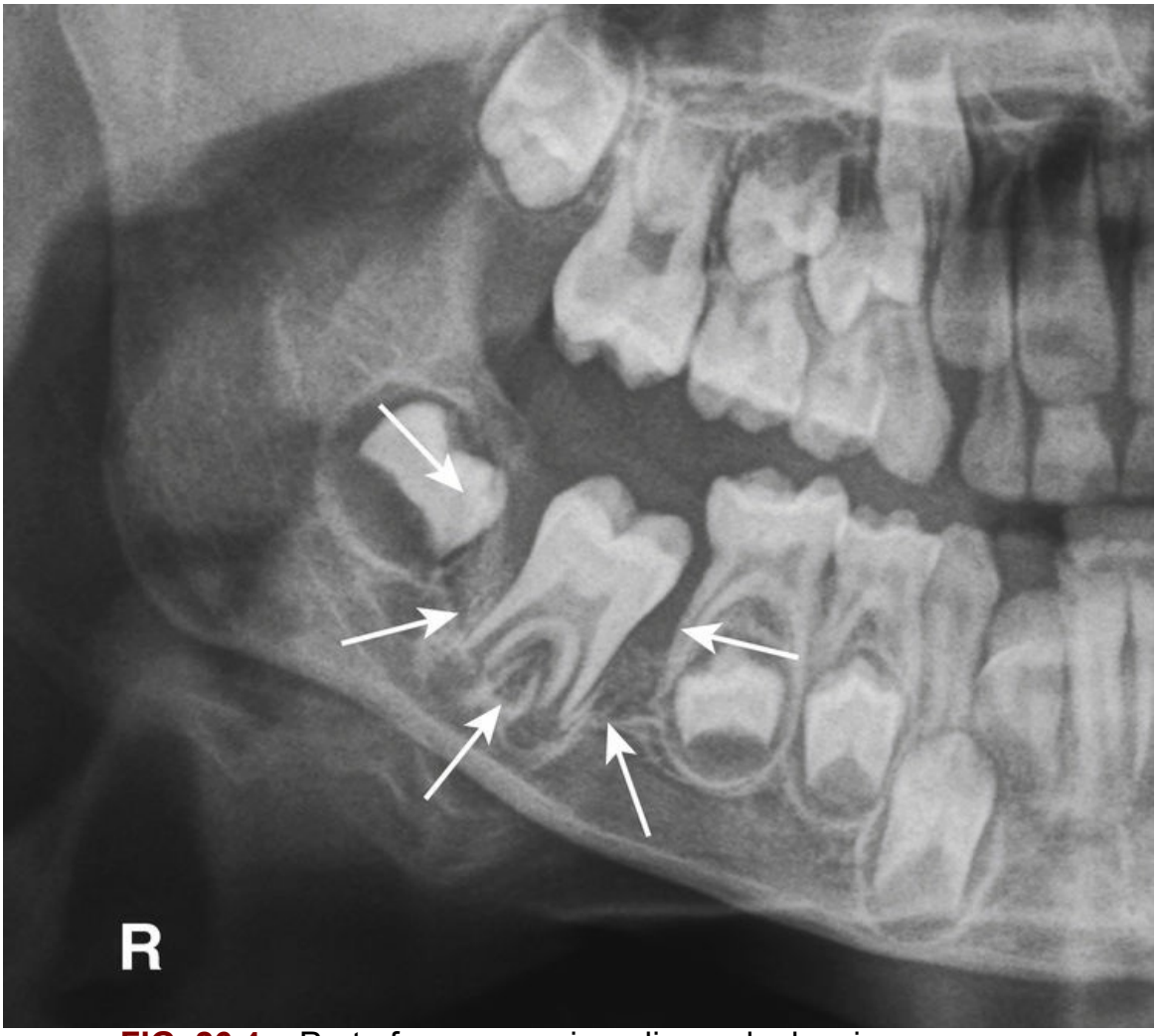


FIG. 26.4 Part of a panoramic radiograph showing an inflammatory collateral cyst (arrowed) in the right mandible of a 7-year-old child associated with $\overline{61}$.

Odontogenic Developmental Cysts

Dentigerous Cyst (see Fig. 26.5)

This cyst develops from the remnants of the reduced enamel epithelium after the tooth has formed.

- ***Age*** **:** Usually adolescents or young adults, 20–40 year-olds, occasionally the elderly.
- ***Frequency*** **:** About 20% of all cysts.

- ***Site*** **:** Associated with the crown of an unerupted and displaced tooth, typically teeth where eruption is impeded, e.g. $\underline{3|3}$ and $\underline{8|8}$.
- ***Size*** **:** Very variable, cyst suspected if follicular space exceeds 3 mm but may grow to several centimetres in diameter and extend up into the ramus.
- ***Shape*** **:** – Round or oval, typically enveloping the crown symmetrically
  - – Unilocular
  - – Three varieties are described depending on the cyst/crown relationship:
    - * central
    - * lateral
    - * circumferential.
- ***Outline*** **:** – Smooth
  - – Well-defined
  - – Often well-corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Associated tooth unerupted and displaced
  - – Adjacent teeth:
    - * displaced
    - * Resorbed in about 50%
    - * enveloped by large cysts
  - – Buccal or medial expansion, can be extensive with large cysts causing facial asymmetry and displacement of the antrum.

NOTE: The term *eruption* cyst is used to describe a dentigerous cyst when it is in the soft tissues overlying the unerupted tooth.

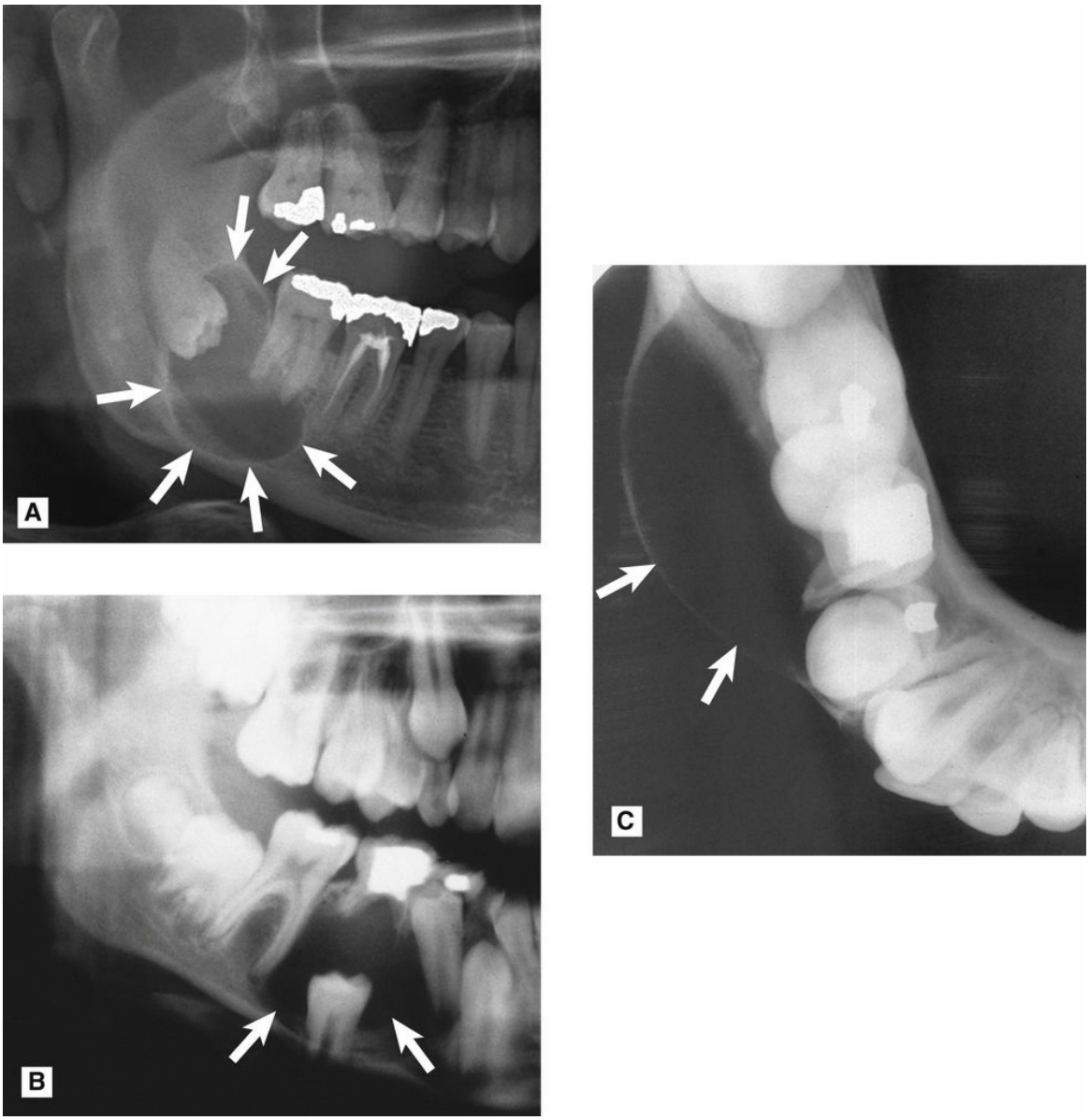


FIG. 26.5 **(A)** Part of a panoramic radiograph showing a typical unilocular dentigerous cyst (arrowed) associated with the unerupted and displaced $\overline{8}$. **(B)** Part of a panoramic radiograph showing a unilocular central dentigerous cyst (arrowed) associated with the unerupted and inferiorly displaced $\overline{5}$. **(C)** Right side of a lower 90° occlusal of the same patient showing the typical buccal expansion (arrowed).

Odontogenic Keratocyst (see Fig. 26.6)

In the 2017 World Health Organization (WHO) classification, the

odontogenic keratocyst has been reclassified as a cyst rather than a tumour partly because in most cases it does not behave like a neoplasm. The WHO defines it as an odontogenic cyst characterised by a thin regular lining of parakeratinised stratified squamous epithelium with palisading hyperchromatic basal cells. It arises from remnants of the dental lamina – the cell rests of Serres – often instead of the normal tooth which is therefore typically missing from the series. Lesions are typically solitary but multiple odontogenic keratocysts are a feature of *nevoid basal cell carcinoma syndrome* (Gorlin's syndrome), which also includes multiple basal cell carcinomas, and skeletal anomalies, e.g. bifid ribs and calcification of the falx cerebri.

- ***Age*** **:** Very variable, peak incidence between second and third decades.
- ***Frequency*** **:** Rare.
- ***Site*** **:** – Posterior body/angle of the mandible extending into the ramus
  – Anterior maxilla in canine region.
- ***Size*** **:** Variable, but often large in the mandible.
- ***Shape*** **:** – Oval, extending along the body of the mandible with little mediolateral expansion
  – Pseudolocular or multilocular.
- ***Outline*** **:** – Smooth and scalloped
  – Well-defined and well-corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Adjacent teeth – minimal displacement, rarely resorbed
  – Extensive expansion within the cancellous bone
  – May cause cortical perforation
  – May include crown of $\overline{8|8}$ by enfolding so resembling a dentigerous cyst.

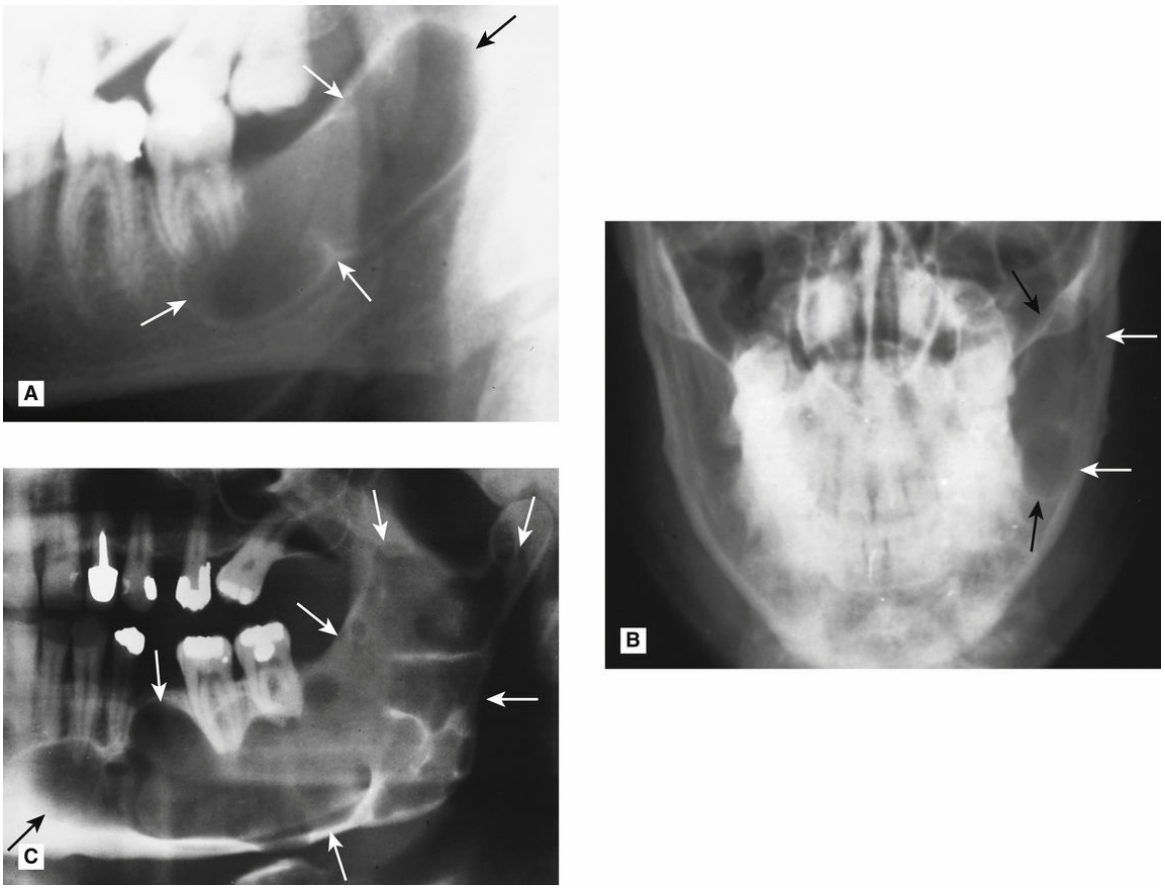


FIG. 26.6 **(A)** Oblique lateral of the left side of the mandible showing a typically extensive pseudolocular odontogenic keratocyst (arrowed) which has apparently developed instead of 8̄ . (B) PA jaws of the same patient showing that it has caused minimal mediolateral expansion (arrowed). **(C)** Left side of a panoramic radiograph showing a very large multilocular odontogenic keratocyst (arrowed) occupying almost all the left side of the mandible.

Lateral Periodontal Cyst and Botryoid Odontogenic Cyst (see Fig. 26.7)

These are developmental odontogenic cysts thought to develop from the dental lamina, the reduced enamel epithelium or the cell rests of Malassez on the lateral surface or between the roots of erupted teeth. The lateral periodontal cyst is often unilocular. The term *botryoid odontogenic cyst* is used to describe a variant that typically has a multilocular appearance.

- ***Age*** **:** Adults over 30 years old.
- ***Frequency*** **:** Rare.
- ***Site*** **:** Lateral surface of the roots of vital teeth in the lower canine/premolar region or upper lateral incisor region.
- ***Size*** **:** Small, less than 1 cm in diameter.
- ***Shape*** **:** – Unilocular, very occasionally multilocular
  – Round.
- ***Outline*** **:** – Smooth
  – Well-defined and well-corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Adjacent teeth displaced if cyst becomes large, rarely resorbed
  – Buccal expansion if large.

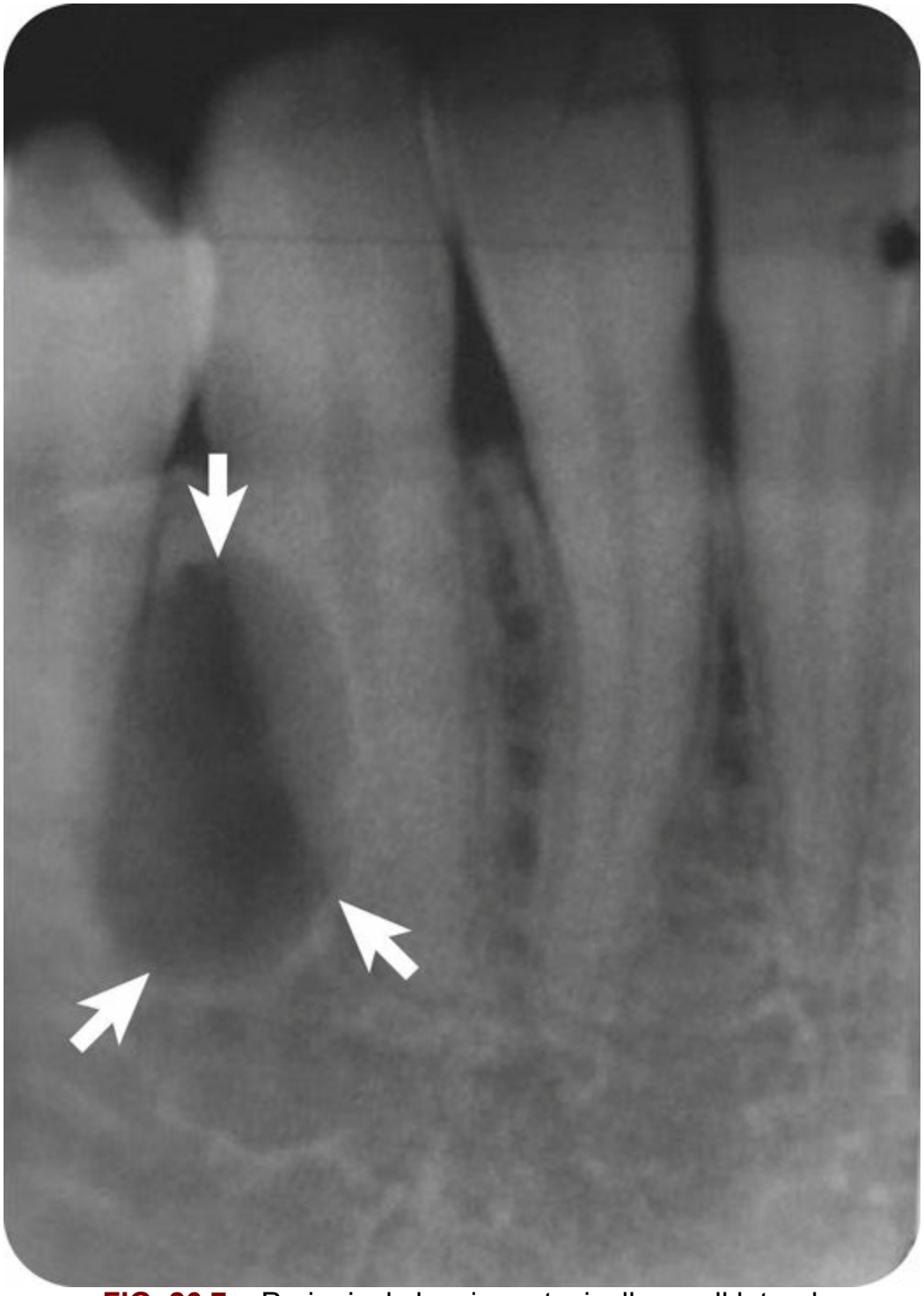


FIG. 26.7 Periapical showing a typically small lateral periodontal cyst (arrowed) between the 3| and 4|.

Calcifying Odontogenic Cyst

In the 2017 WHO classification the calcifying odontogenic cyst or Gorlin's cyst is reclassified as a cyst rather than a tumour. It presents typically anteriorly in either the mandible or the maxilla as a unilocular, well-defined, well-corticated radiolucency resembling any other odontogenic cyst. It can affect any age group having been reported in patients from 5 to 92 years old. One-third of cases are associated with an unerupted tooth or odontome. Unlike other odontogenic cysts, as this lesion matures, a variable amount of calcified material of tooth-like density becomes evident scattered throughout the radiolucency. The opacities can range from small flecks to large masses (see Fig. 27.8).

Glandular Odontogenic Cyst (Sialo-odontogenic Cyst)

This rare odontogenic cyst is also classified by the WHO as a developmental cyst. It has epithelial features that simulate salivary gland or glandular differentiation (see Fig. 26.8). It presents typically in the mandible in the fourth to fifth decade as either a unilocular or multilocular expansile radiolucency that may displace adjacent teeth but does not tend to resorb them.

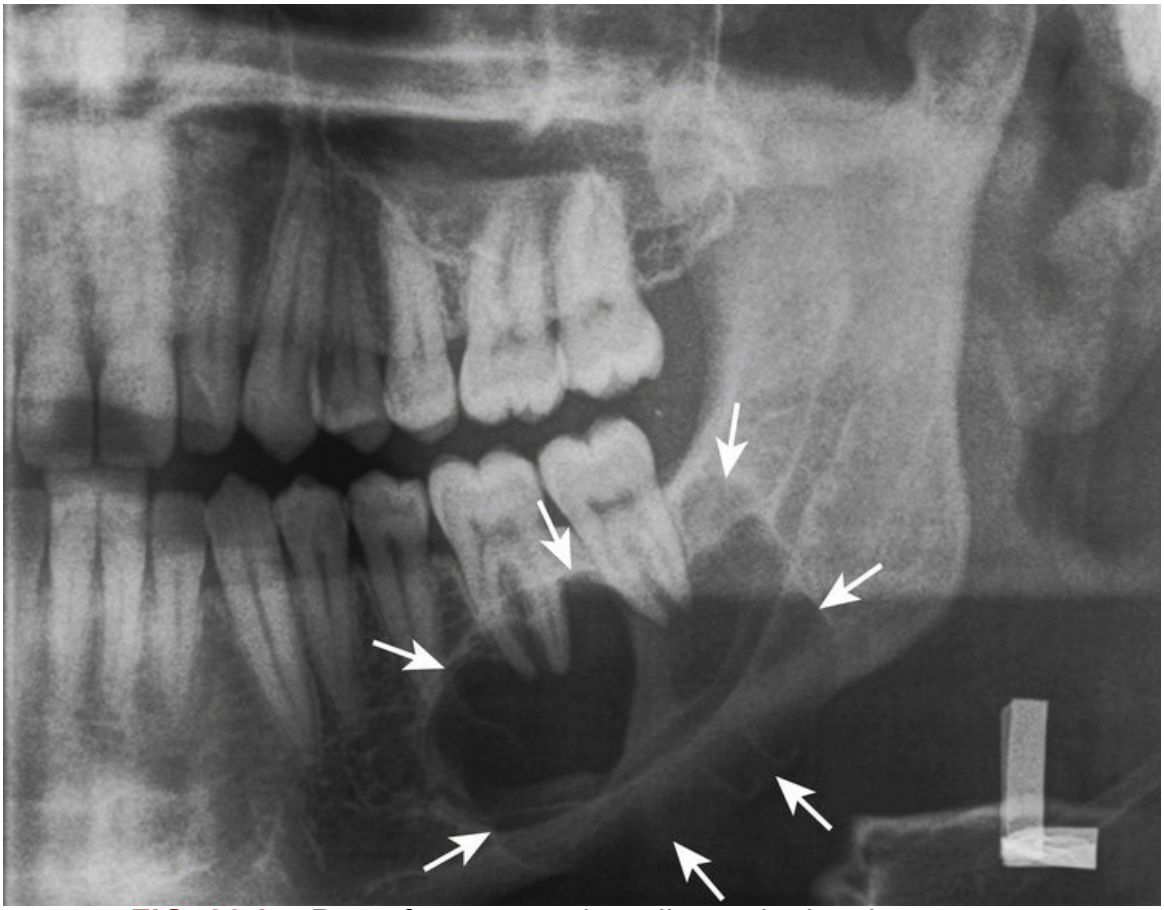


FIG. 26.8 Part of a panoramic radiograph showing a multilocular glandular odontogenic cyst (arrowed) in the left mandible below the ⌈6 and ⌈7 , which are not displaced or resorbed.

Non-odontogenic Developmental Cysts

Nasopalatine Duct/Incisive Canal Cyst (see Fig. 26.9)

This cyst develops from epithelial remnants of the nasopalatine duct or incisive canal.

- ***Age*** **:** Variable, but most frequently detected in middle age (40- to 60-year-olds).
- ***Frequency*** **:** Most common of all non-odontogenic cysts, affecting about 1% of the total population.

- ***Site*** **:** Midline, anterior maxilla just posterior to the upper central incisors.
- ***Size*** **:** Variable, but usually from 6 mm to several centimetres in diameter.
- ***Shape*** **:** – Round, oval or may resemble an inverted tear drop (superimposition of the nasal septum or anterior nasal spine may cause the cyst to appear heart-shaped)
  – Unilocular.
- ***Outline*** **:** – Smooth
  – Well-defined
  – Well-corticated (unless infected).
- ***Radiodensity*** **:** Uniformly radiolucent but radiopaque shadows sometimes superimposed.
- ***Effects*** **:** – Adjacent teeth – distal displacement, rarely resorbed
  – Palatal expansion (only identifiable if extensive).

NOTE: Differentiation is sometimes required between a nasopalatine duct cyst and a large normal nasopalatine foramen. Several features need to be considered including:

- ***Size*** : If over 6 mm, a cyst is more likely
- ***Shape*** : Foramina are usually oval or irregular
- ***Outline*** : Foramina are usually well-defined laterally but not all the way round
- ***Relative radiodensity*** : A cyst tends to be more radiolucent having resorbed bone.

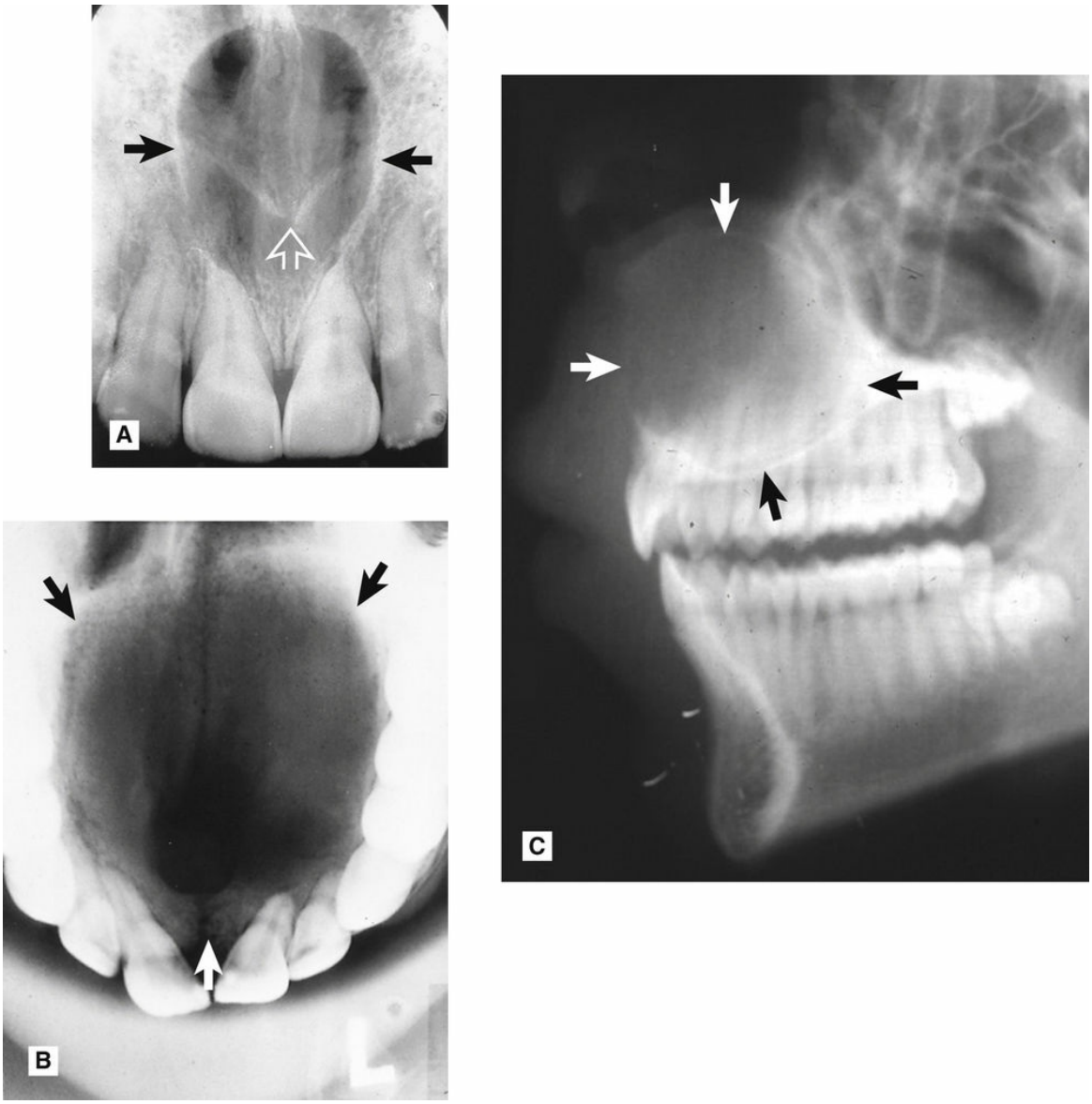


FIG. 26.9 **(A)** Periapical showing a typical nasopalatine duct cyst (solid arrows) in the midline between the upper central incisors. Note the superimposed shadow of the anterior nasal spine (open white arrow). **(B)** Upper occlusal showing a very extensive nasopalatine duct cyst (arrowed) occupying nearly the entire palate. **(C)** Lateral view of the same patient showing the expansion of the cyst into the nasal cavity and palate (arrowed).

Typical Radiographic Features of

Tumours

Benign Epithelial Odontogenic Tumours

Ameloblastoma

The WHO (2017) define the ameloblastoma as a benign, intraosseous, progressively growing, epithelial odontogenic neoplasm arising from the dental lamina characterised by expansion of the jaw and a tendency for local recurrence if not adequately removed. There are four main types:

- Solid/multicystic
- Extra-osseous/peripheral
- Desmoplastic
- Unicystic.

Solid/multicystic ameloblastoma (see Fig. 26.10)

- ***Age*** **:** Adults 30–60 years old.
- ***Frequency*** **:** Rare, but still the most common odontogenic tumour.
- ***Site*** **:** – 80% posterior body/angle/ramus of mandible
  – Anterior mandible in black Africans.
- ***Size*** **:** Very variable depending on the age of the lesion, may become very large if neglected and cause gross facial asymmetry.
- ***Shape*** **:** – Multilocular, distinct septa dividing the lesion into compartments with large, apparently discrete areas centrally and with smaller areas on the periphery
  – Occasionally unilocular in early stages
  – Rarely honeycomb or *soap-bubble* appearance or multicystic.
- ***Outline*** **:** – Smooth and scalloped
  – Well-defined
  – Well-corticated.

- ***Radiodensity*** **:** – Radiolucent

– Internal radiopaque septa.

- ***Effects*** **:** – Adjacent teeth displaced, loosened, often resorbed
  - Extensive expansion in all dimensions
  - Maxillary lesions can extend into the paranasal sinuses, orbit or base of the skull.



FIG 26.10 **(A)** Part of a panoramic radiograph showing the typical multilocular appearance of a large ameloblastoma at the angle of the right mandible, with extensive expansion (solid arrows) and resorption of adjacent teeth (open arrows). **(B)** Left side of a panoramic radiograph showing a bilocular

ameloblastoma (arrowed) distal to the lower second molar. **(C)** Part of a panoramic radiograph showing an ameloblastoma in a more unusual anterior position (arrowed) causing displacement of the adjacent teeth. **(D)** Lower occlusal of the same patient showing the buccolingual extent of the lesion (arrowed).

Unicystic ameloblastoma (see Fig. 26.11)

Unicystic ameloblastoma accounts for 5%–15% of all ameloblastomas and is found equally in the mandible and the maxilla. It usually presents as a unilocular radiolucency associated with the crown of an unerupted tooth (peak age: 16 years), or as a unilocular radiolucency at the apices of teeth, resembling a radicular cyst (peak age: 35 years).

NOTE : Because different ameloblastomas can mimic a large variety of other radiolucent lesions, this possibility must always be borne in mind when formulating a radiological differential diagnosis.

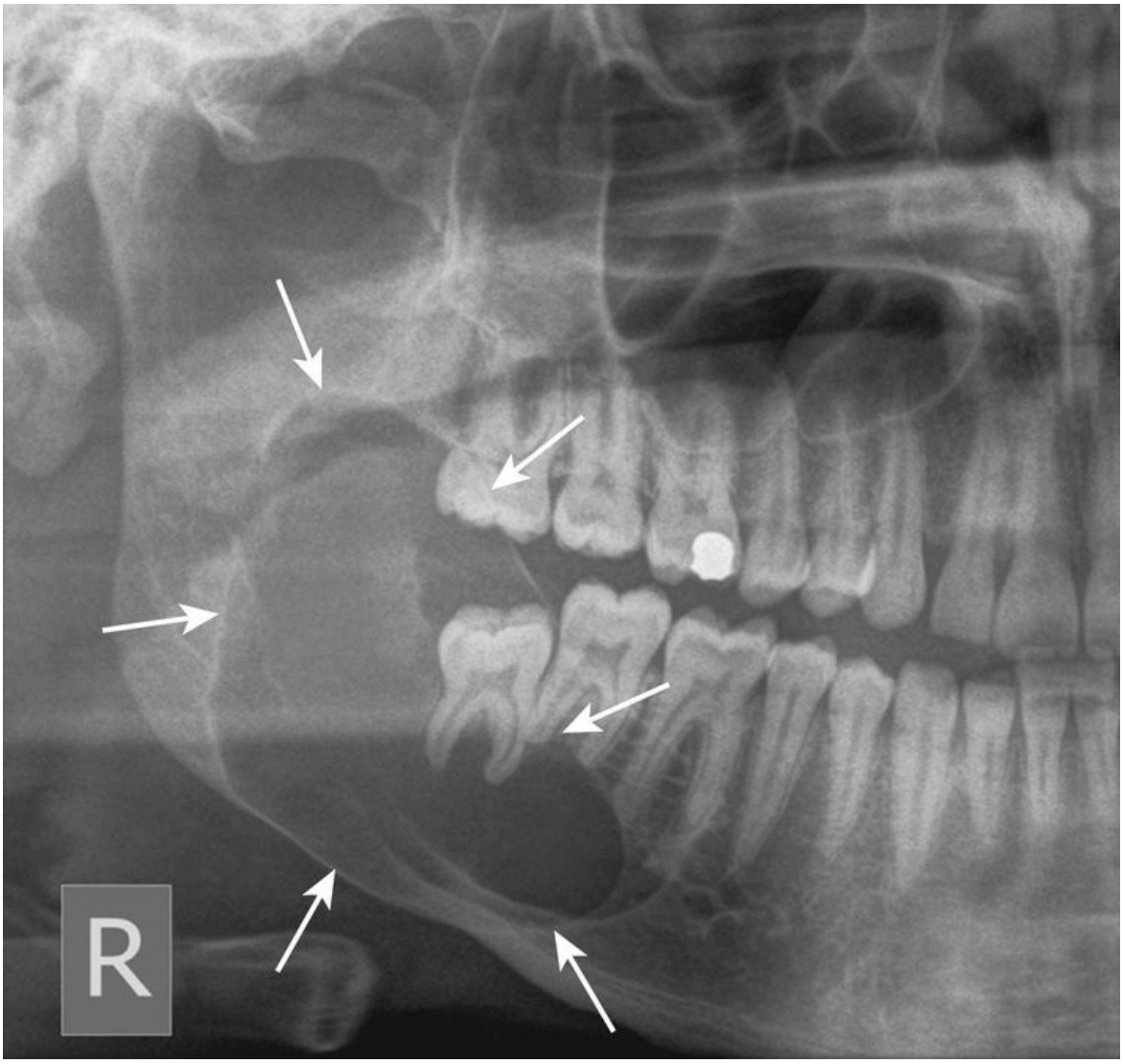


FIG. 26.11 Part of a panoramic radiograph showing a large unicystic ameloblastoma (arrowed) in the posterior mandible.

Other Benign Epithelial Odontogenic Tumours

Two other important benign epithelial odontogenic tumours that can present as a radiolucency include:

- Calcifying epithelial odontogenic tumour or Pindborg tumour
- Adenomatoid odontogenic tumour.

These lesions often develop internal calcified material and more

typically present as lesions of variable opacity. They are therefore described briefly here and in greater detail in Chapter 27 .

Calcifying Epithelial Odontogenic Tumour, Pindborg Tumour (see Fig. 26.12)

This rare odontogenic tumour usually presents in the premolar/molar region of the mandible in 20–60-year-old adults. They can be either unilocular or multilocular, but tend to remain relatively small, although they can cause expansion of surrounding cortical bone. They are often associated with an unerupted tooth, particularly $\overline{8|8}$. The outline of the lesion tends to be of variable definition and cortication but is frequently scalloped. They are often radiolucent in their early stages; then numerous scattered radiopacities usually become evident within the lesion, often most prominent around the crown of any associated unerupted tooth. This appearance is sometimes described as *driven snow.* Adjacent teeth can be either displaced and/or resorbed (see Fig. 27.8).

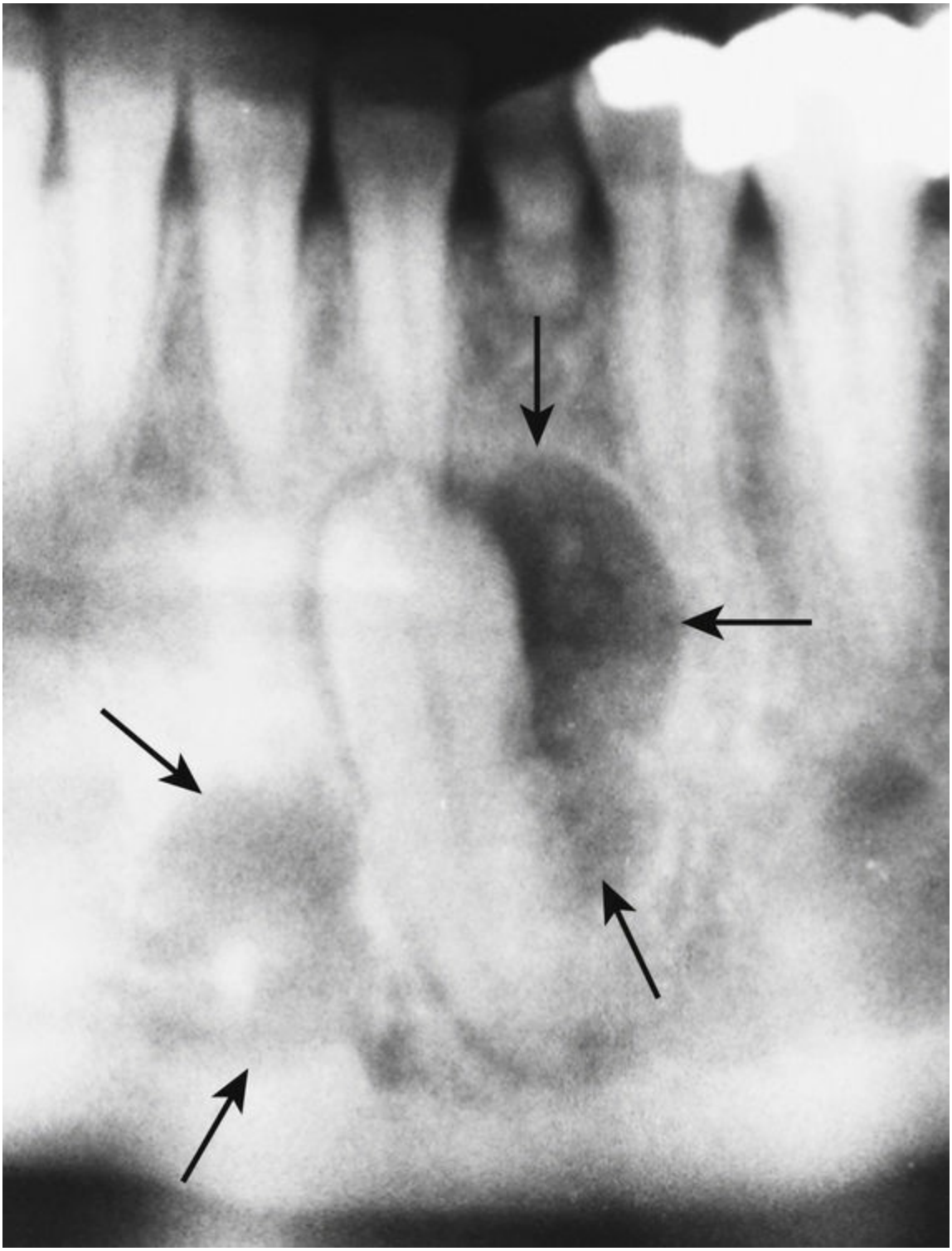


FIG. 26.12 Part of a panoramic radiograph showing a calcifying epithelial odontogenic tumour (arrowed) associated with the unerupted lower left canine, with only faint internal calcification.

Adenomatoid Odontogenic Tumour (see Fig. 26.13)

Another rare odontogenic tumour, but unusually the most frequent site affected is the anterior maxilla in the incisor/canine region. Young adults are usually affected. The lesion tends to be unilocular, round or oval, and often surrounds an entire unerupted tooth. When radiolucent in their early stages, they can closely resemble a dentigerous cyst. However, as the lesion matures, small opacities *(snowflakes)* within the central radiolucency may be seen peripherally. Adjacent teeth are often displaced as the lesion expands but are rarely resorbed (see Fig. 27.10).



FIG. 26.13 Periapical of the anterior maxilla showing an adenomatoid odontogenic tumour (arrowed) with internal calcification, associated with the unerupted upper right canine.

From Browne RM, Edmondson HD, Rout PG. Atlas of dental and

maxillofacial radiology 1995 Mosby-Wolfe, London, with permission.

Benign Mixed Epithelial and Mesenchymal Odontogenic Tumours

Ameloblastic Fibroma (see Fig. 26.14)

A rare, benign, mixed odontogenic tumour originating from both the odontogenic epithelium and the connective tissue of the developing tooth germ. Histologically, it consists of odontogenic ectomesenchyme resembling dental papilla and epithelial strands and rests resembling dental lamina and enamel organ. Radiographically these tumours closely resemble ameloblastomas but develop in a younger age group.

- ***Age*** **:** Children and adolescents – mean age 14 years.
- ***Frequency*** **:** Rare.
- ***Site*** **:** Posterior mandible (usually) or maxillary premolar/molar region.
- ***Size*** **:** Variable.
- ***Shape*** **:** – Multilocular
  – Unilocular in the early stages.
- ***Outline*** **:** – Smooth
  – Well-defined
  – Well-corticated.
- ***Radiodensity*** : Radiolucent with internal radiopaque septa if multilocular.
- ***Effects*** **:** – Adjacent teeth displaced
  – Buccal/lingual expansion of the jaw
  – 50% associated with an unerupted or malpositioned tooth.

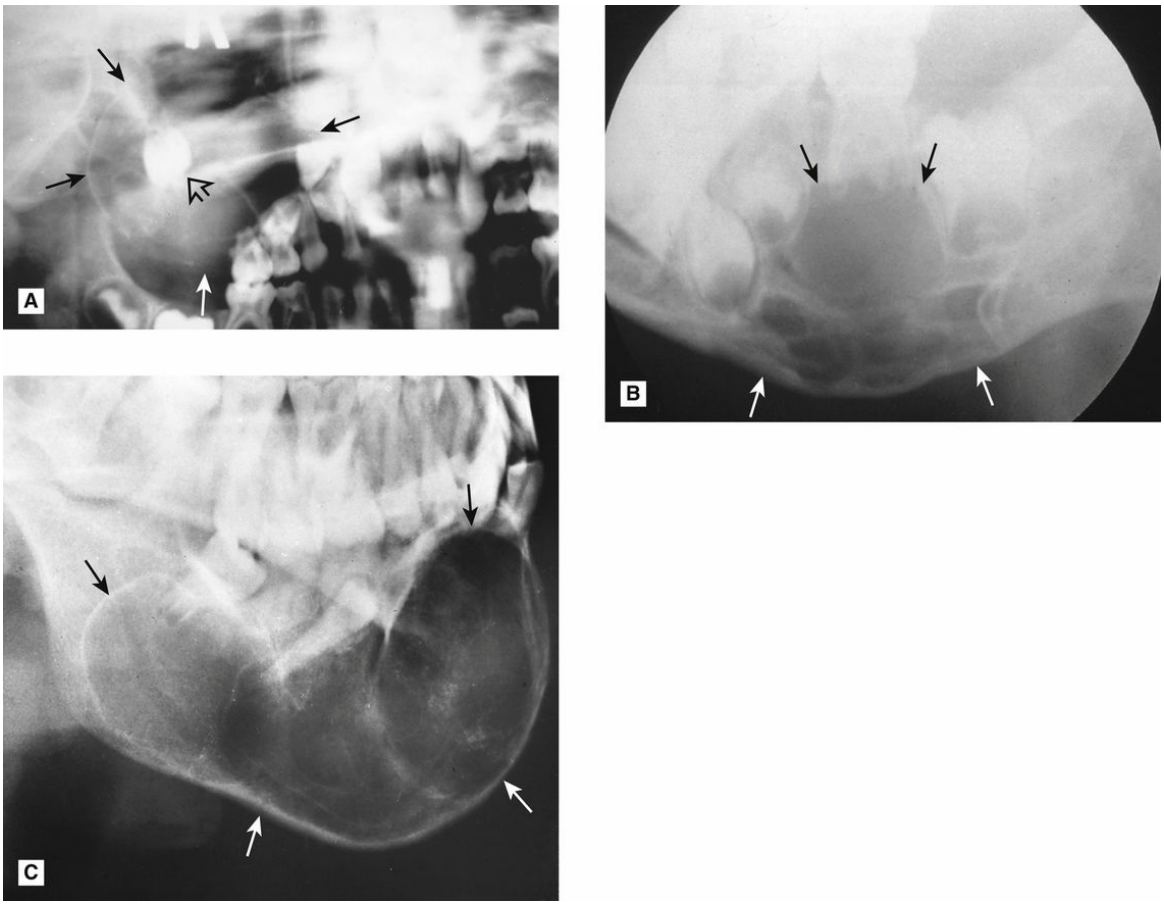


FIG. 26.14 **(A)** Part of a panoramic radiograph of a 4-year-old child showing a large ameloblastic fibroma in the right maxilla, causing marked expansion (solid arrows) and displacement of the developing first molar (open arrow). (Courtesy of Mrs J. E. Brown.) **(B)** Oblique lateral of another small child showing a multilocular ameloblastic fibroma (arrowed) in the left body of the mandible causing displacement of the developing premolars and expansion of the lower border. **(C)** Oblique lateral showing a very extensive ameloblastic fibroma (arrowed) of the right side in a 17-year-old.

Benign Mesenchymal Odontogenic Tumours

Odontogenic Fibroma (see Fig. 26.15)

The WHO (2017) now classify this rare tumour as a separate entity and define it as "a neoplasm of mature fibrous connective tissue, with

variable amounts of inactive-looking odontogenic epithelium with or without evidence of calcification". Typically lesions present as cyst-like well-defined, unilocular radiolucencies with dense corticated margins. Rarely, calcified material may develop internally and adjacent teeth may be displaced.

Odontogenic myxoma/myxofibroma (see Fig. 26.16)

This intra-osseous neoplasm is characterized histologically by stellate and spindle-shaped cells embedded in an abundant myxoid or mucoid extracellular matrix originating from the odontogenic connective tissue fibroblasts of the developing tooth germ.

- ***Age*** **:** Young adults – most diagnosed in the second to fourth decades.
- ***Frequency*** **:** Rare, but the third most common odontogenic tumour.
- ***Site*** : Posterior mandible or posterior maxilla.
- ***Size*** **:** Variable, but may become very large if untreated.
- ***Shape*** **:** – Multilocular *(honeycomb* or *soap-bubble appearance)*
  – Occasionally unilocular.
- ***Outline*** **:** – Smooth and often scalloped
  – Well-defined with variable cortication.

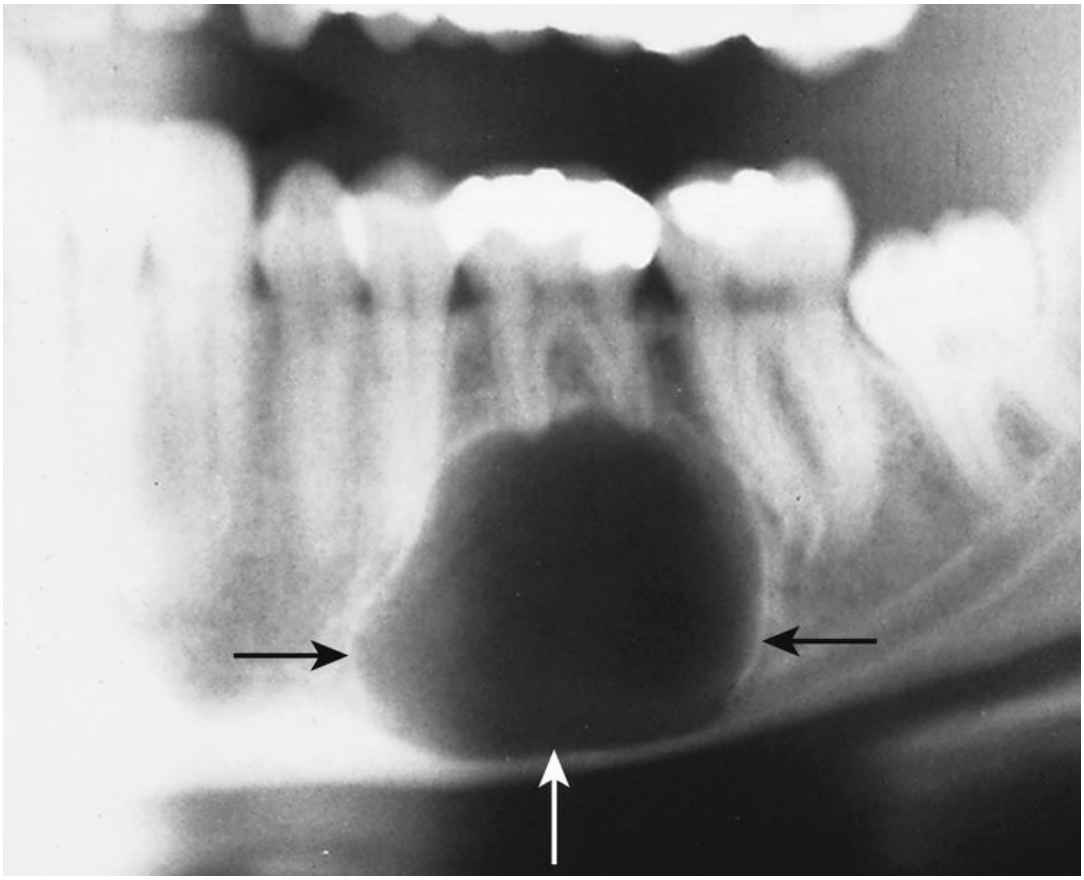


FIG. 26.15 Part of a panoramic radiograph showing a round, unilocular, well-defined radiolucency (arrowed) at the apex of ⌈6 which was clinically vital. Histopathology confirmed an odontogenic fibroma.

- ***Radiodensity*** **:** Radiolucent with fine internal radiopaque septa or trabeculae often arranged at right angles to one another, producing an appearance sometimes described as resembling the *strings of a tennis racket* or the letters X and Y.
- ***Effects*** **:** – Adjacent teeth displaced and loosened, occasionally resorbed
  - – May be associated with a missing or unerupted tooth
  - – Extensive buccal and lingual expansion with possible cortical perforation when large.

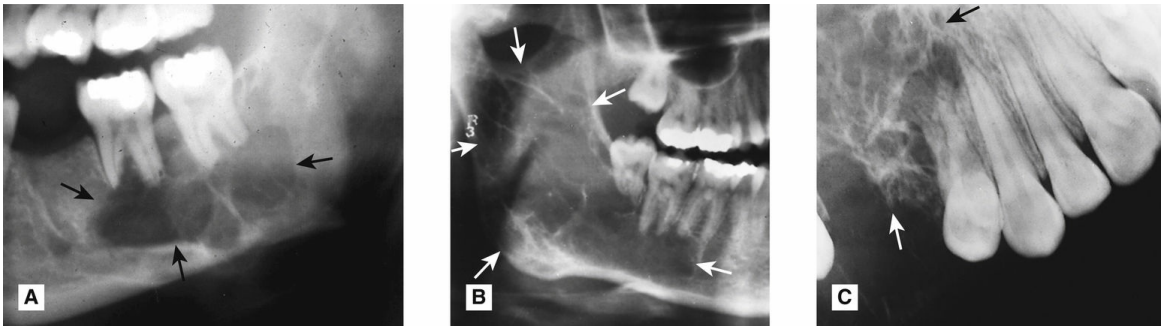


FIG. 26.16 **(A)** Left side of a panoramic radiograph showing the typical multilocular appearance of an odontogenic myxoma (arrowed) in the body of the mandible. **(B)** Right side of a panoramic radiograph showing an extensive odontogenic myxoma (arrowed) with final internal septa. **(C)** Part of an upper oblique occlusal showing a multilocular almost *honeycomb* appearance of an odontogenic myxoma (arrowed) in the maxilla.

Intrinsic Benign Maxillofacial Vascular Tumours

Central haemangioma (see Fig. 26.17)

This is a rare, benign tumour that occasionally affects the jaws, particularly the mandible. It is usually regarded as a developmental malformation (hamartoma) of the blood vessels in the marrow spaces, rather than a true neoplasm.

Central haemangioma can present at any age but is usually discovered in adolescents. It can produce a very variable radiographic appearance. These variations are important because of the life-threatening nature of the lesion; they include:

- Most commonly a multilocular, expanding lesion that may be associated with displacement and resorption of associated teeth. The size and number of locules can vary considerably, and, if numerous, can present with a *honeycomb* appearance.
- A moderately well-defined zone of radiolucency within which the trabecular spaces are enlarged and the trabeculae themselves are coarse and thick and are said to be arranged like a *hub* or the *spokes of a wheel.*

- Rarely, a relatively well-defined, round, cystlike radiolucency – not distinctive in any way.
- Large lesions may cause cortical expansion, occasionally producing the *sunray* or *sunburst* appearance.

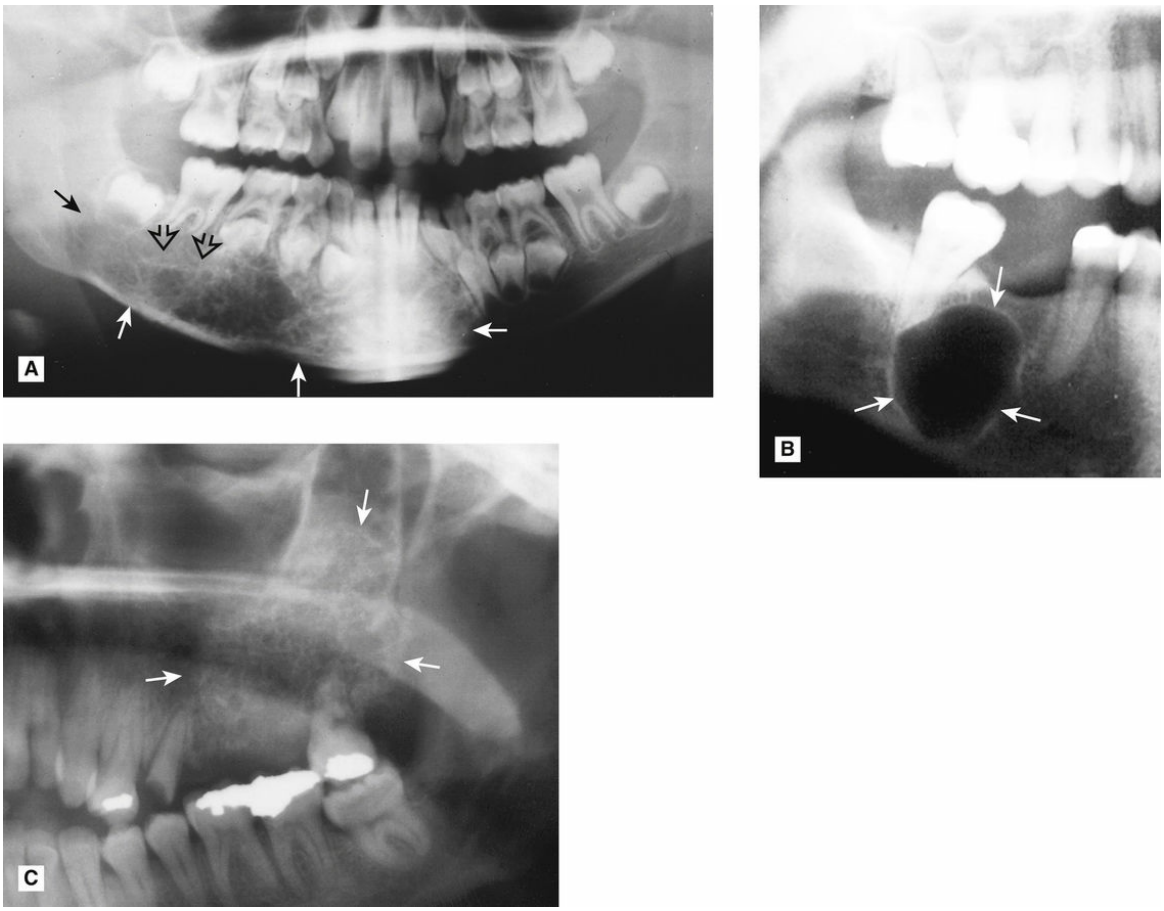


FIG. 26.17 **(A)** Part of a panoramic radiograph of an 8-year-old child showing a large central haemangioma occupying most of the body of the mandible (solid arrows). The typical *honeycomb* appearance is evident on the right (open arrows) and there is evidence of root resorption. **(B)** Part of a panoramic radiograph showing a unilocular cyst-like haemangioma (arrowed). (Courtesy of Mr K. Hussain.) These two examples highlight the very variable appearance of this important lesion. **(C)** Left side of a panoramic radiograph showing the multilocular *honeycomb* appearance of a large haemangioma in the posterior maxilla (arrowed).

Intrinsic Malignant Maxillofacial Bone and Cartilage Tumours

Osteosarcoma (see Fig. 26.18)

An osteosarcoma is a rare, rapidly destructive malignant tumour of bone. From a radiological viewpoint, there are three main types:

- Osteolytic – no neoplastic bone formation
- Osteogenic/osteosclerotic – neoplastic osteoid and bone formed
- Mixed lytic and sclerotic – patches of neoplastic bone formed.
- ***Age*** **:** Young adults under 30 years old.
- ***Frequency*** **:** Rare, but the most common primary malignant bone tumour.
- ***Site:*** Usually the mandible.

- ***Size***:
- ***Shape***:
- ***Outline***:
- ***Radiodensity***:
- ***Effects***:

} All very variable depending on the type of lession (lytic or sclerotic) and how long it has been. present.

Early Features

- Nonspecific, poorly defined radiolucent area around one or more teeth
- Widening of the periodontal ligament space.

Later Features

- Osteolytic lesion
  - Unilocular, ragged area of radiolucency
  - Poorly defined, *moth-eaten* outline
  - So-called *spiking* resorption and/or loosening of associated teeth
- Osteogenic and mixed lesions
  - Poorly defined radiolucent area

– Variable internal radiopacity with obliteration of the normal trabecular pattern
– Perforation and expansion of the cortical margins by stretching the periosteum, producing the classic, but rare *sunray* or *sunburst* appearance (see Chapter 27)
– *Spiking* resorption and/or loosening of associated teeth
– Distortion of the alveolar ridge.

Fibrosarcoma and Chondrosarcoma

Both of these primary malignant tumours of bone are rare and produce the irregular, poorly defined radiolucent areas often indicative of the rapid bone destruction of malignancy.

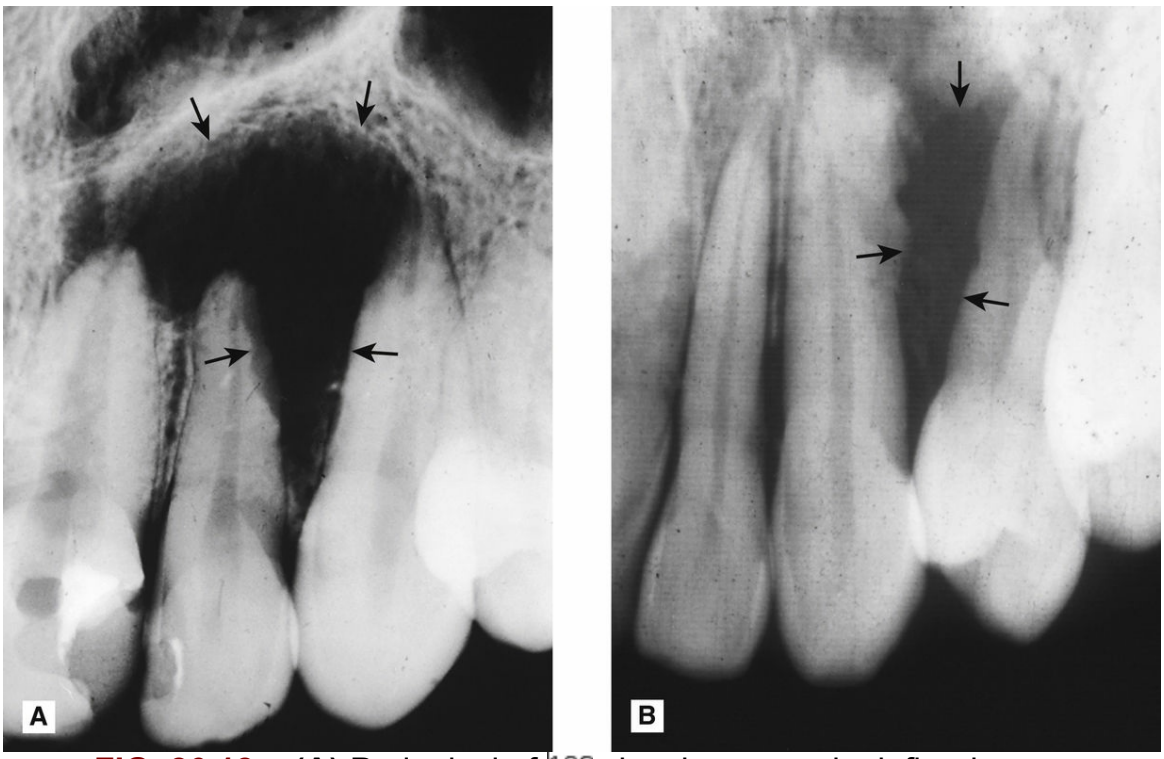


FIG. 26.18 **(A)** Periapical of 123 showing a poorly defined ragged area of radiolucency (arrowed) with resorption of the lateral aspect of 2 root. Biopsy revealed an osteolytic osteosarcoma. **(B)** Periapical showing a similar smaller poorly defined area of bone destruction between 34 (arrowed), which

was again shown to be an osteosarcoma.

Soft Tissue Malignant Tumours Involving Bone

Squamous cell carcinoma (see Fig. 26.19)

Squamous cell carcinomas of the oral mucosa directly overlying bone, in their latter stages, often invade the underlying bone to produce a destructive radiolucency.

- ***Age*** **:** Adults over 50 years old.
- ***Frequency*** **:** Rare, but the most common oral malignant tumour.
- ***Site*** **:** Mandible, or maxilla if originating in the antrum.
- ***Size*** **:** Variable.
- ***Shape*** **:** Irregular area of bone destruction, often initially saucer-shaped.
- ***Outline*** **:** – Irregular and *moth-eaten*
  – Poorly defined
  – Not corticated.
- ***Radiodensity*** **:** Radiolucent, radiodensity dependent on degree of destruction.
- ***Effects*** **:** – Adjacent teeth may be displaced, loosened and/or resorbed or left *floating in space*
  – Destruction of surrounding bone may lead to pathological fracture.

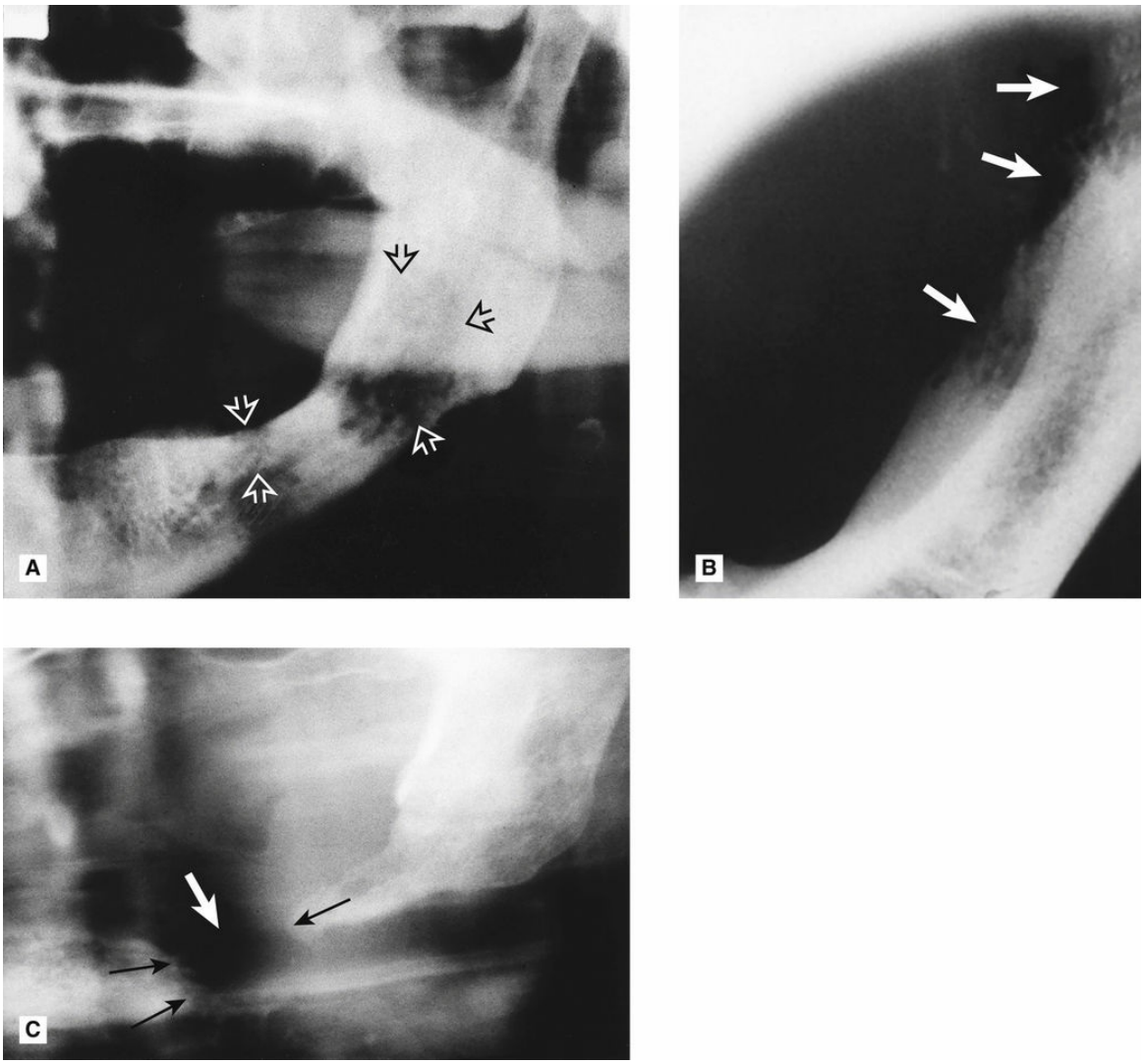


FIG. 26.19 **(A)** Part of a panoramic radiograph of a patient who presented with a large squamous cell carcinoma on the left ventral surface of his tongue and the floor of his mouth. The radiograph shows two areas of poorly defined radiolucency (arrowed) with a ragged or *moth-eaten* appearance. **(B)** Left side of a lower 90° occlusal of the same patient showing the bony destruction (arrowed) of the lingual surface of the mandible as the soft tissue tumour invades the bone. **(C)** Part of a panoramic radiograph of another patient who presented with a very large squamous cell carcinoma of the floor of the mouth that had penetrated through the mandible (white arrow) causing a pathological fracture. The ragged bone edges are marked with the black arrows.

Secondary Metastatic Bone Tumours (see Fig. 26.20 ; see also Chapter 21)

Carcinomas from the bronchus, breast, prostate, kidney and thyroid sometimes metastasize to the jaws and produce the typical destructive radiolucency of a malignant lesion.

- ***Age*** **:** Adults over 40 years old.
- ***Frequency*** **:** Rare, but the second most common malignant tumours of the jaws.
- ***Site*** **:** Usually centrally in the mandible, molar and premolar regions, occasionally at the apex of a tooth.
- ***Size*** **:** Variable, dependent on the length of time the lesion has been present.
- ***Shape*** **:** Irregular area or areas of bone destruction.
- ***Outline*** **:** – Irregular and *moth-eaten*
  – Poorly defined, not corticated.
- ***Radiodensity*** **:** Radiolucent, but some carcinomas from the prostate and breast may be osteogenic and show areas of bone production/sclerosis.
- ***Effects*** **:** – Adjacent teeth may be displaced, loosened and/or resorbed
  – Destruction of surrounding bone
  – Involvement of overlying soft tissues.

NOTE: The radiographic appearance, while strongly indicating a destructive malignant lesion, does not enable the distinction between a primary or secondary tumour to be made.

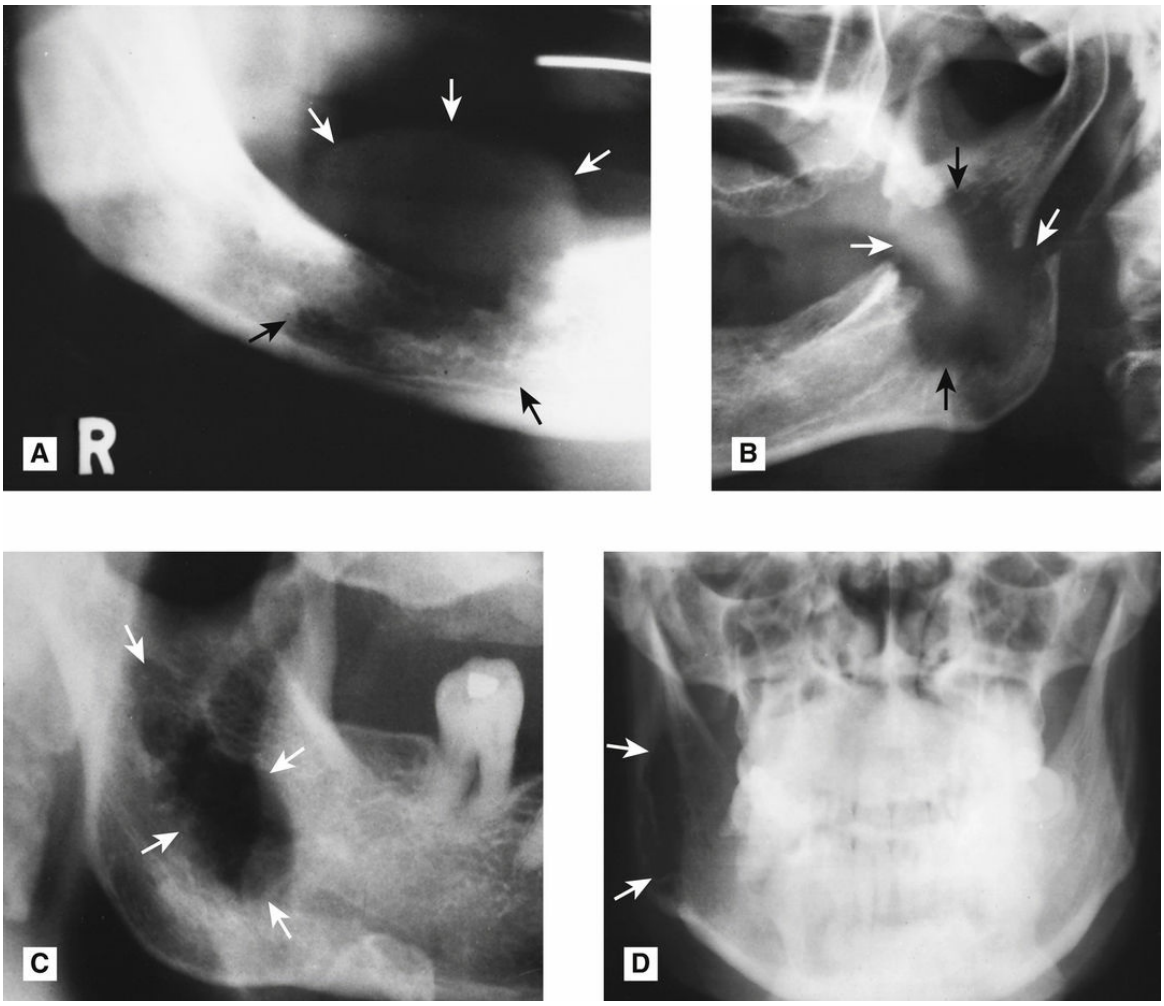


FIG. 26.20 **(A)** Right side of a panoramic radiograph showing the typical destructive, *moth-eaten* radiolucency of a malignant lesion (black arrows). Overlying soft tissue involvement is also evident (white arrows). Subsequent investigation showed this to be a secondary metastatic tumour from the breast. **(B)** Left side of a panoramic radiograph showing a large irregular destructive secondary metastatic tumour, from the prostate, in the ascending ramus (black arrows). There is an associated pathological fracture (white arrows). **(C)** Right side of a panoramic radiograph and **(D)** posteroanterior jaws of the same patient showing a poorly defined radiolucent secondary metastatic deposit, from the lung, presenting centrally in the ramus (arrowed).

Lymphoreticular Tumours of Bone

Multiple myeloma (Fig. 26.21A andB)

This is a multifocal proliferation of the plasma cell series within the bone marrow, resulting in overproduction of immunoglobulins.

- ***Age*** **:** Adults, middle-aged.
- ***Frequency*** **:** Uncommon.
- ***Site*** **:** Multiple lesions affecting
  - – Skull vault
  - –Posterior parts of the mandible
  - – Other parts of the skeleton.
- ***Size*** **:** Variable, individual lesions may be several centimetres in diameter.
- ***Shape*** **:** – Round
  - – Unilocular, though multifocal.
- ***Outline*** **:** – Punched-out
  - – Well-defined, not corticated.
- ***Radiodensity*** **:** Radiolucent.
- ***Effects*** **:** Enlargement and/or coalescence of lesions may lead to pathological fracture.

Others

- Large cell (anaplastic) lymphoma – adults under 40 years.
- Burkitt's (African) lymphoma – children (see Fig. 26.21C).
- Ewing's tumour – adults under 40 years.

These lymphoreticular tumours are rare and apart from the age group predilection (shown above), they present in a similar, relatively non-specific manner. Radiographically they usually present as expansile, destructive, poorly defined, radiolucent areas – suggestive of malignant disease.

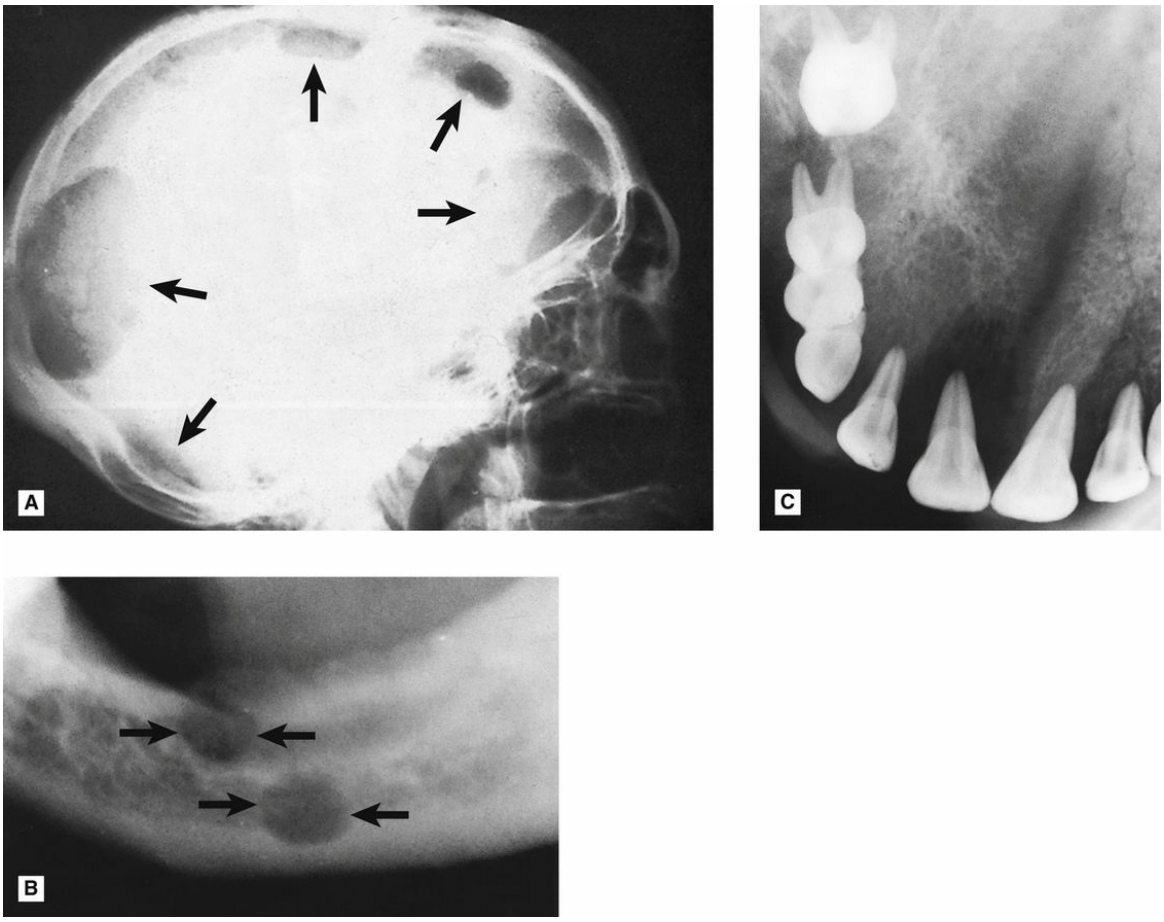


FIG. 26.21 **(A)** True lateral skull showing the typical multiple punched-out lesions (arrowed) of the skull vault of multiple myeloma. **(B)** Oblique lateral of the left side showing two similar lesions in the mandible (arrowed). **(C)** Upper oblique occlusal showing the typical appearance of destructive malignancy of Burkitt's lymphoma. Almost all normal anatomical structures have been destroyed.

Langerhans Cell Histiocytosis (see Fig. 26.22)

Langerhans cell histiocytosis is used as the over-arching terminology to describe three different clinical manifestations of the same disease. All three manifestations produce tumour-like lesions in bone, caused by proliferation of Langerhans cells and eosinophilic leucocytes:

- *Solitary eosinophilic granuloma* – localized to the skeleton, affecting adolescents and young adults (see Fig. 26.18)

- *Multifocal eosinophilic granuloma* (Hand-Schüller-Christian disease) – chronic and widespread, begins in childhood but may not be fully developed until early adulthood, 20–30 years
- *Letterer-Siwe disease* – acute or subacute and widespread, affecting children under 3 years old

Radiographically, the bone lesions (in whatever parts of the skeleton are affected) are similar in all three diseases.

- ***Frequency*** **:** Rare.
- ***Site*** **:** Multiple lesions (in multifocal eosinophilic granuloma and Letterer-Siwe disease only) throughout the skeleton, occasionally solitary lesion, affecting:
  - Skull vault
  - Mandible or maxilla, posteriorly in the alveolar process.
- ***Size*** **:** Small, 1–2 cm in diameter.
- ***Shape*** **:** – Unilocular
  - Round.
- ***Outline*** **:** – Smooth
  - Relatively well-defined
  - Not corticated, appears punched-out.
- ***Radiodensity*** **:** Radiolucent.
- ***Effects*** **:** – Adjacent teeth – not resorbed, but the periodontal bone support is sometimes destroyed so that they appear to be *floating* or *standing in space*
  - No expansion of the surrounding bone.

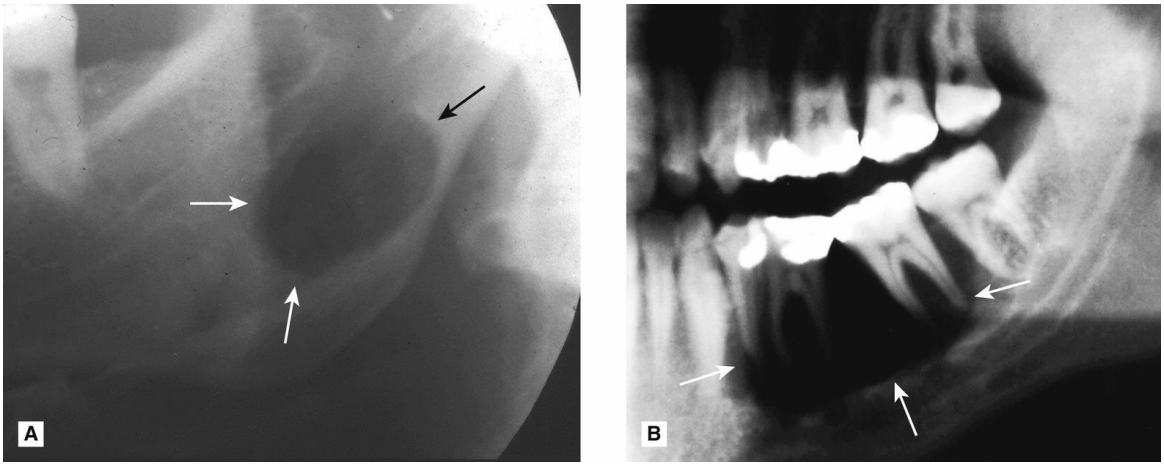


FIG. 26.22 **(A)** Oblique lateral of the left side of the mandible showing a well-defined, unilocular, punched-out, radiolucency (arrowed) beneath the inferior dental canal and therefore non-odontogenic, which proved to be an eosinophilic granuloma. **(B)** Left side of a panoramic radiograph showing an extensive punched-out destructive eosinophilic granuloma (arrowed) causing the 67 to seem to be *floating in space.*
Courtesy of Dr J. Luker.

Typical Radiographic Features of Allied Lesions

Giant Cell Lesions and Bone Cysts

Central Giant Cell Granuloma (see Fig. 26.23)

A central giant cell granuloma is a relatively rare localized, benign but sometimes aggressive osteolytic proliferation consisting histologically of fibrous tissue with haemorrhage and haemosiderin deposits, presence of osteoclast-like giant cells and reactive bone formation producing an expansile radiolucent lesion.

- *Age* **:** All ages can be affected but usually young adolescents and adults under 30 years old; one-third of cases reported in patients under 20.

- ***Frequency*** **:** Rare.
- ***Site*** **:** Mandible – all parts particularly the premolar/molar region and anteriorly often crossing the midline.
- ***Shape*** **:** Multilocular, may be unilocular in early stages.
- ***Outline*** **:** – Smooth and scalloped
  – Well-defined
  – Generally not well-corticated.
- ***Radiodensity*** **:** Radiolucent, larger lesions have thin internal septa or trabeculae producing the multilocular, or sometimes *honeycomb* appearance.
- ***Effects*** **:** –Adjacent teeth often displaced, sometimes resorbed
  – Surrounding buccal and lingual bone expanded unevenly producing the scalloped border.

Based on their clinical and radiological effects on adjacent structures, central giant cell lesions are sometimes subdivided into two categories:

- *Non-aggressive,* which exhibit slow-growing, benign behaviour
- *Aggressive,* which show the typical features of rapidly growing, destructive lesions.

NOTE: Central giant cell granulomas can rarely develop in hyperparathyroidism. Historically these lesions have been referred to as *brown tumours,* because of their brown colouration following surgical removal.

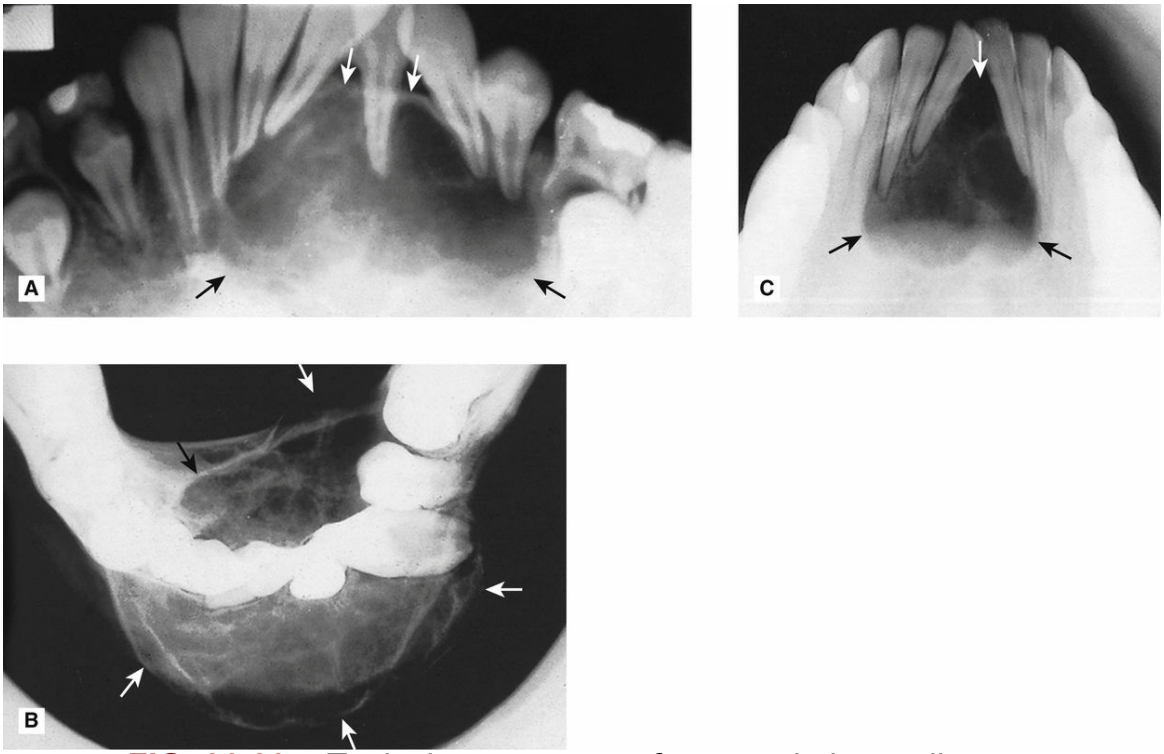


FIG. 26.23 Typical appearance of a central giant cell granuloma. **(A)** Anterior portion of a static panoramic showing the multilocular appearance, expansion (arrowed) and considerable displacement of the adjacent teeth. **(B)** Lower 90° occlusal of the same patient showing the gross buccal and lingual expansion (arrowed) and the scalloped cortical border. **(C)** Lower 45° occlusal of another patient showing the appearance of a similar but much smaller central giant cell granuloma (arrowed).

Cherubism (see Fig. 26.24)

This rare disease of the jaws is inherited, usually as an autosomal dominant, but some cases appear spontaneously. Radiologically the lesions resemble closely other giant cell-containing lesions.

- ***Age*** **:** Children, 2–6 years old.
- ***Frequency*** **:** Rare.
- ***Site*** **:** – Angle/posterior mandible – bilateral– Occasionally posterior maxilla – also bilateral.
- ***Size*** **:** Variable, up to several centimetres in diameter, and may

fill the whole jaw.

- ***Shape*** **:** – Multilocular
  – Bilateral lesions typically symmetrical.
- ***Outline*** **:** – Smooth
  – Well-defined
  – Well-corticated.
- ***Radiodensity*** **:** Radiolucent with internal radiopaque septa producing a multilocular appearance.
- ***Effects*** **:** – Adjacent teeth – gross displacement of deciduous and permanent teeth, occasionally resorbed, deciduous teeth sometimes exfoliated early
  – Extensive buccal/lingual expansion
  – Encroachment on the antra by maxillary lesions.

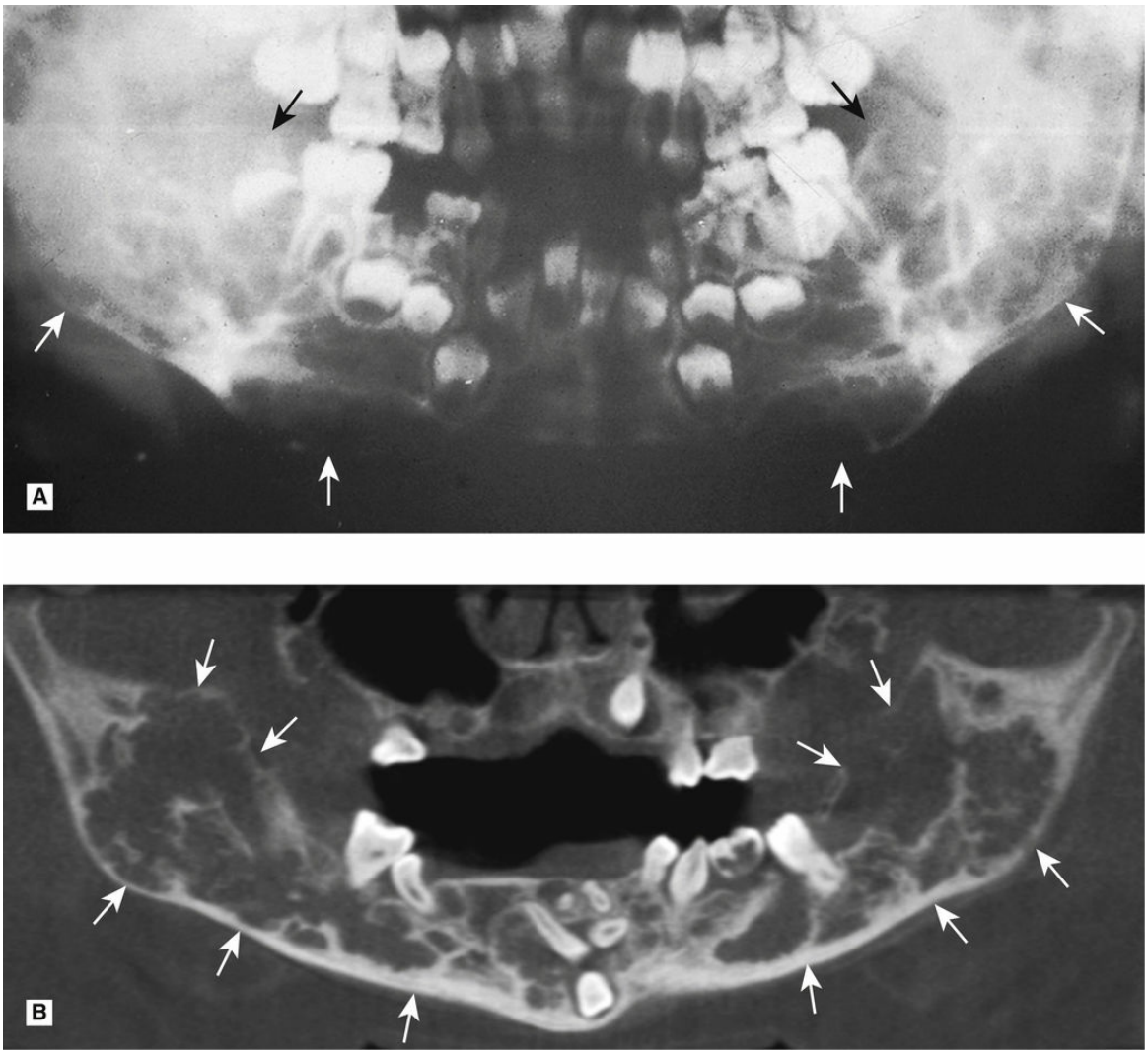


FIG. 26.24 **(A)** Panoramic radiograph of a 5-year-old boy showing the typical bilateral multilocular lesions of cherubism affecting the mandible (arrowed). **(B)** CBCT reconstructed panoramic image showing widespread multiple multilocular lesions of cherubism (arrowed).

Aneurysmal Bone Cyst (see Fig. 26.25)

As stated, despite its name this rare lesion is categorized as a *giant cell lesion* and is defined as an expansile osteolytic lesion, often multilocular with histologically blood-filled spaces separated by fibrous septa containing osteoclast-type giant cells and reactive bone.

- *Age* **:** Adolescents and young adults under 30 years old; the

peak incidence is in the second decade.

- ***Frequency*** **:** Rare.
- ***Site*** **:** – Body/posterior mandible including the ramus but very rarely the condyle
  – Maxilla occasionally.
- ***Shape*** **:** – Unilocular or multilocular
  – Faint internal trabeculation may produce a *soap-bubble* appearance.
- ***Outline*** **:** – Smooth
  – Moderately well-defined
  – Peripheral cortex usually retained even when large.
- ***Radiodensity*** **:** Radiolucent with evidence of faint, random internal trabeculations.
- ***Effects*** **:** – Adjacent teeth – displaced, rarely resorbed
  – Buccal and lingual expansion of the cortex, often marked and described as *ballooning* or *blow-out*
  – Rarely cortical perforation.

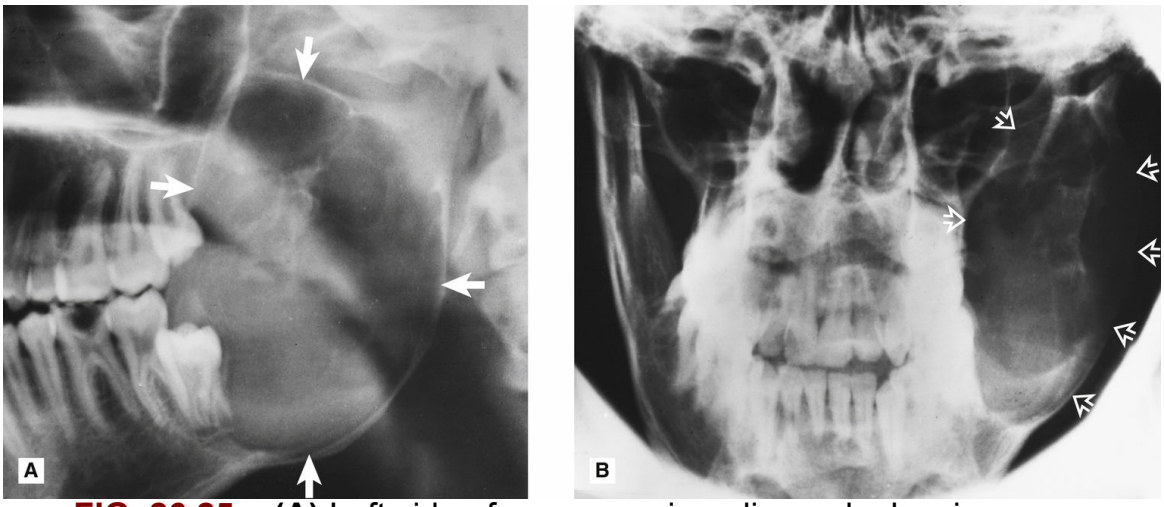


FIG. 26.25 **(A)** Left side of a panoramic radiograph showing a very large multilocular aneurysmal bone cyst in the ramus (arrowed). Note the marked expansion and the displacement of . **(B)** PA jaws of the same patient showing *ballooning* expansion (arrowed).

Simple Bone Cyst (see Fig. 26.26)

Despite their name, *simple* or *solitary bone cysts* are not true cysts in that they are usually devoid of an epithelial lining and are either empty or filled with serous or sanguineous fluid. Their aetiology is unknown.

- ***Age*** **:** Children or young adults, peak incidence in second decade.
- ***Frequency*** **:** Rare.
- ***Site*** **:** Mandible, particularly anteriorly and in the premolar/molar region.
- ***Size*** **:** Variable, up to several centimetres in diameter.
- ***Shape*** **:** – Unilocular
  – Irregular, but the upper border arches up between the roots of the teeth.
- ***Outline*** **:** – Smooth and undulating
  – Moderately well-defined
  – Moderately well or poorly corticated.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – Adjacent teeth – minimal or no displacement, very rarely resorbed
  – Minimal or no expansion of the jaw.

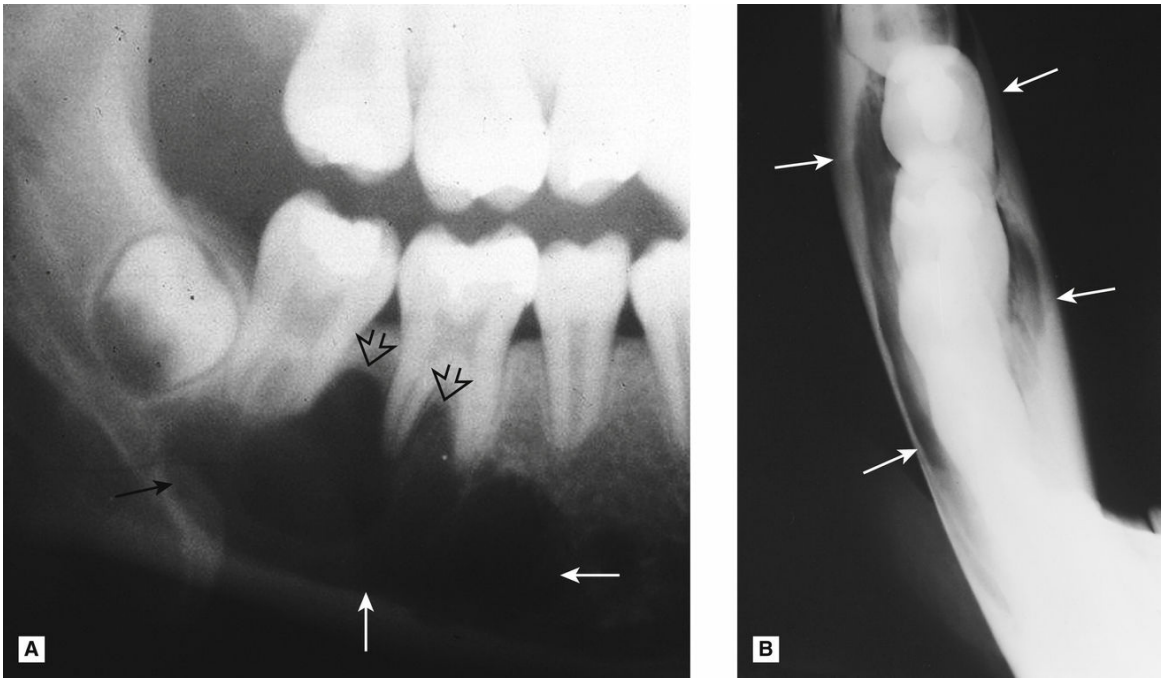


FIG. 26.26 **(A)** Oblique lateral of the right side of the mandible of a teenager showing a typical solitary bone cyst (solid arrows) in the body of the mandible. Note the upper border arching up between the roots of the molar teeth (open arrows). **(B)** Lower oblique occlusal of the same patient showing no apparent buccolingual expansion (arrowed).

Fibro-osseous Lesions

The 2017 WHO classification (see Table 26.1) categorises a number of conditions under the heading of fibro-osseous lesions. These include:

- Cemento-ossifying fibroma
- Fibrous dysplasia
- Cemento-osseous dysplasia, including:
  - Periapical cemento-osseous dysplasia
  - Focal cemento-osseous dysplasia
  - Florid cemento-osseous dysplasia

They are all skeletal disorders in which bone is replaced by fibrous tissue which in turn is replaced by bone or mineralized tissue to a

varying degree as the lesions age. Thus, in their early stages all the osseous dysplasias can present as cyst-like radiolucencies, although they are only sometimes seen clinically at this stage. It is more common to see them in their later stages when they present as mixed radiolucent/radiopaque lesions with varying degrees of opacity. Relatively radiolucent examples are shown and more radiopaque examples are discussed and illustrated in Chapter 27 .

Cemento-Ossifying Fibroma (see Fig. 26.27)

Ossifying fibromas are described in the 2017 WHO classification as benign fibro-osseous neoplasms affecting the jaws and the craniofacial skeleton. The *cemento-ossifying fibroma* is a distinct type of ossifying fibroma that occurs in the tooth-bearing areas of the jaws and is believed to be of odontogenic origin.

- ***Age*** **:** Variable, but usually in the second to fourth decades (particularly women).
- ***Frequency*** **:** Rare.
- ***Site*** **:** Usually posterior mandible, but different variants can affect the maxilla and paranasal sinuses.
- ***Size*** **:** Variable, may grow to several centimetres in diameter and cause facial asymmetry.
- ***Shape*** **:** – Round
  – Unilocular.
- ***Outline*** **:** – Smooth, well-defined
  – When opaque, usually surrounded by a thin encapsulating radiolucent line
  – Usually corticated and circumscribed.
- ***Radiodensit*** **y:** – Early stage – radiolucent
  – Intermediate stage – radiolucent with gradually increasing internal radiopaque calcified patches
  – Late stage – radiopaque zones coalesce to form a densely radiopaque mass with or without a radiolucent periphery.
- ***Effects*** **:** – Adjacent teeth:

* often displaced
* occasionally resorbed

– Expansion of the surrounding bone in all dimensions often demonstrating a *downward bowing* of the mandibular lower border cortex.

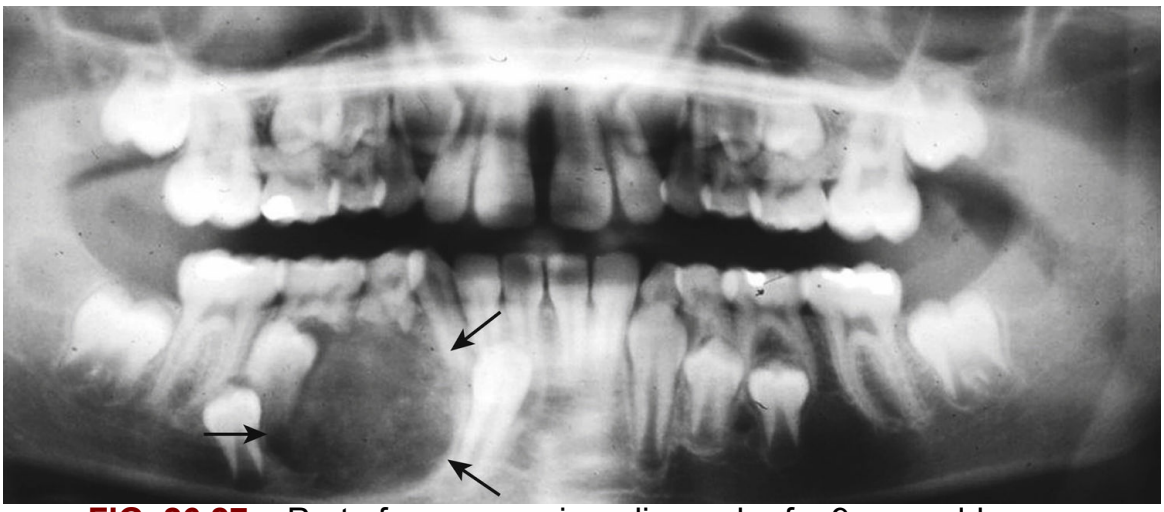


FIG. 26.27 Part of a panoramic radiograph of a 9-year-old child showing a relatively radiolucent cemento–ossifying fibroma in the right mandible (arrowed) with fine internal calcifications just becoming evident.

Fibrous Dysplasia (see Fig. 26.28)

Fibrous dysplasia is described by the WHO as a fibro-osseous skeletal anomaly in which normal bone is replaced and distorted by poorly organized and inadequately mineralized immature bone and fibrous tissue. It may involve a single bone or multiple bones. The jaws and other bones in the skull can be affected as well as other bones in the skeleton. The more general radiological features of fibrous dysplasia are covered in Chapter 28 .

The radiographic features of jaw lesions include:

- ***Age*** **:** 10 to 20-year-old adolescents.
- ***Site*** **:** Maxilla – usually posteriorly, more commonly than the

mandible; maxillary lesions may spread to involve adjacent bones such as the zygoma, sphenoid, occiput and base of skull.

- ***Size*** **:** Variable and difficult to define.
- ***Shape*** **:** Round.
- ***Outline*** **:** – Poorly defined, with the margins merging imperceptibly with adjacent normal bone
  – Not corticated.
- ***Radiodensity*** **:** – Initially radiolucent (but rarely seen clinically at this stage)
  – Gradually becomes opaque to produce the typical ground glass, orange peel and finger print appearances resulting from superimposition of many fine, poorly calcified bone trabeculae arranged in a disorganized fashion
  – Continuing to become more opaque with age.
- ***Effects*** **:** – Adjacent teeth:
  * sometimes displaced but rarely resorbed
  * loss of associated lamina dura
  – Buccal and lingual alveolar expansion
  – Encroachment on, or obliteration of, the antrum
  – Involvement of adjacent bones including the base of the skull.

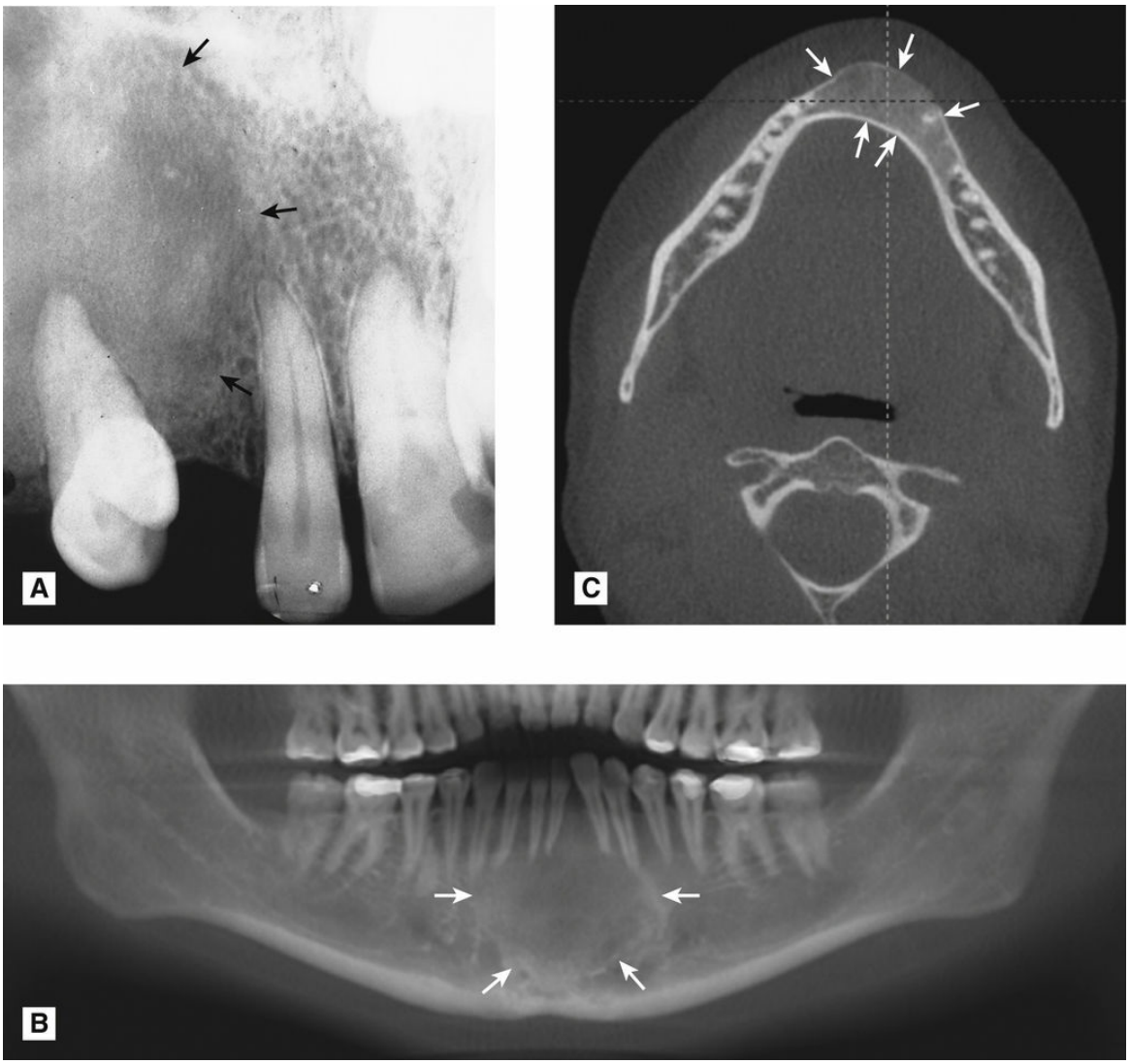


FIG. 26.28 **(A)** Periapical of the right maxilla showing a generalized radiolucent lesion of fibrous dysplasia (arrowed). There is evidence of fine internal trabeculation giving a *ground glass* appearance and the margin merges almost imperceptibly with the adjacent normal bone. **(B)** Reconstructed CBCT panoramic showing another generalized radiolucent lesion of fibrous dysplasia in the anterior mandible (arrowed). **(C)** Axial CBCT of the same patient showing the expansion of the anterior part of the mandible (arrowed).

Cemento-osseous Dysplasia

Cemento-osseous dysplasia is defined by the WHO as a non-neoplastic fibro-osseous lesion of the jaws.

Periapical cemento-osseous dysplasia (Fig. 26.29)

- ***Age*** **:** Middle-aged adults (typically black women).
- ***Frequency*** **:** Rare.
- ***Site*** **:** Apices of vital lower incisor teeth.
- ***Size*** **:** Small, usually only up to 5–6 mm in diameter.
- ***Shape*** **:** – Round, unilocular
  – Often multiple.
- ***Outline*** **:** – Variable but usually poorly defined
  – Not corticated.
- ***Radiodensity*** **:** – Early stage – radiolucent
  – Intermediate stage – radiolucent with patchy opacity within the radiolucency
  – Late stage – densely radiopaque but surrounded by a thin radiolucent line.
- ***Effects*** **:** – Adjacent teeth – not displaced, not resorbed, typically vital, with intact periodontal ligament space, but lamina dura may be discontinuous
  – No expansion of the jaw.

Florid cemento-osseous dysplasia (see Fig. 26.30)

- ***Age*** **:** Middle-aged adults (typically black women).
- ***Frequency*** **:** Rare.
- ***Site*** **:** Widespread, often in all four quadrants (dentulous and edentulous) but associated with the apices of the teeth if present.
- ***Size*** **:** Variable, but individual lesions up to 2 cm in diameter.
- ***Shape*** **:** – Multiple
  – Round, but frequently coalesce.
- ***Outline*** **:** – Smooth but lobular
  – Moderately well-defined but irregular
  – Occasionally corticated.

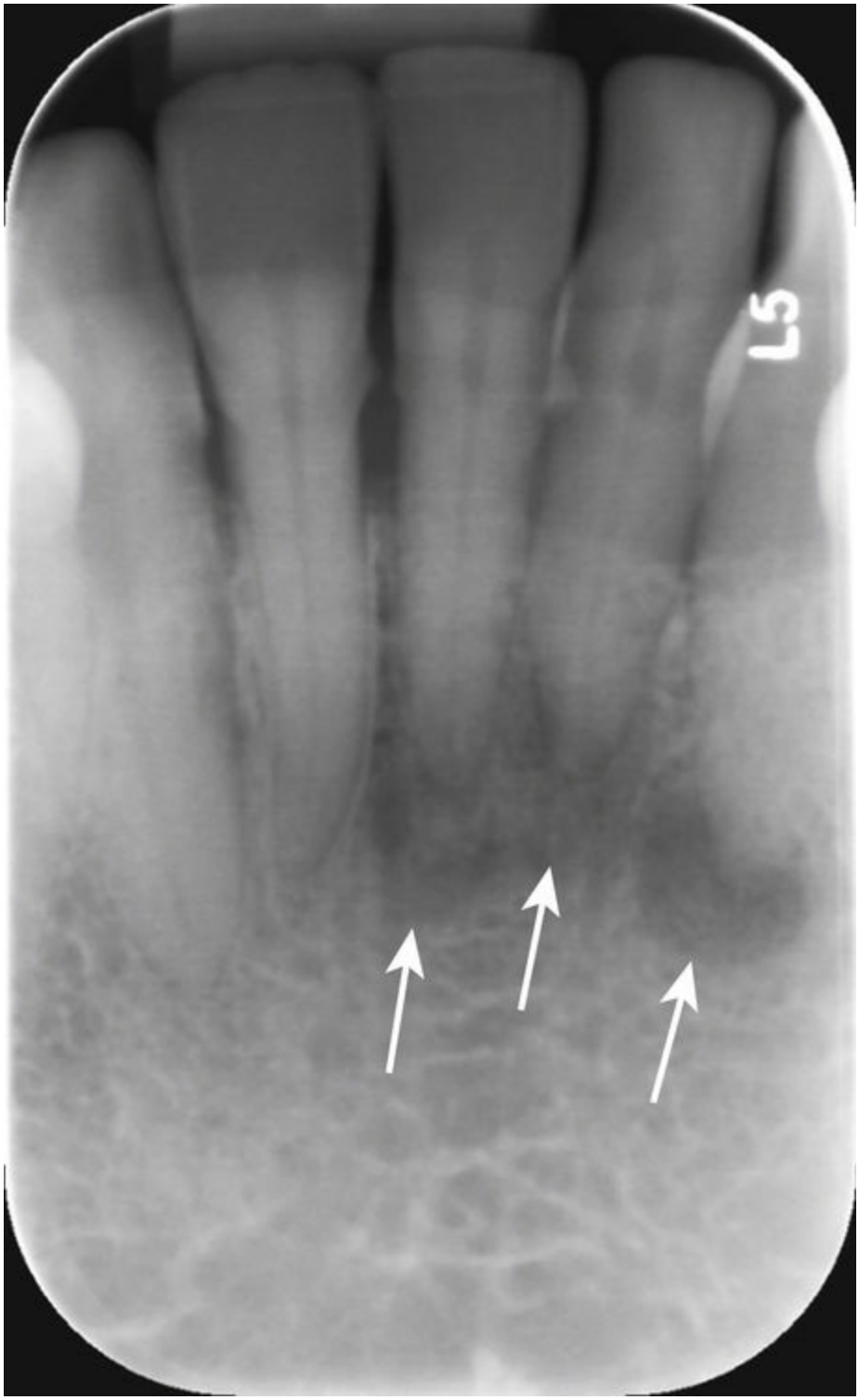


FIG. 26.29 Periapical of the lower incisors showing the early radiolucent lesions of periapical cemento-osseous dysplasia. Small discrete radiolucencies are evident at the apices of $\overline{123}$ (arrowed)

- ***Radiodensity*** **:** –Early stage – multiple radiolucencies
  – Intermediate stage – multiple radiolucencies with gradually increasing patchy internal opacities
  – Late stage – multiple irregular dense radiopacities with individual lesions, sometimes surrounded by a thin radiolucent line.
- ***Effects*** **:** – Adjacent teeth – not displaced, not resorbed, typically vital
  – Occasionally may cause expansion or enlargement of the affected jaw
  – Can be associated with low grade osteo-myelitis.

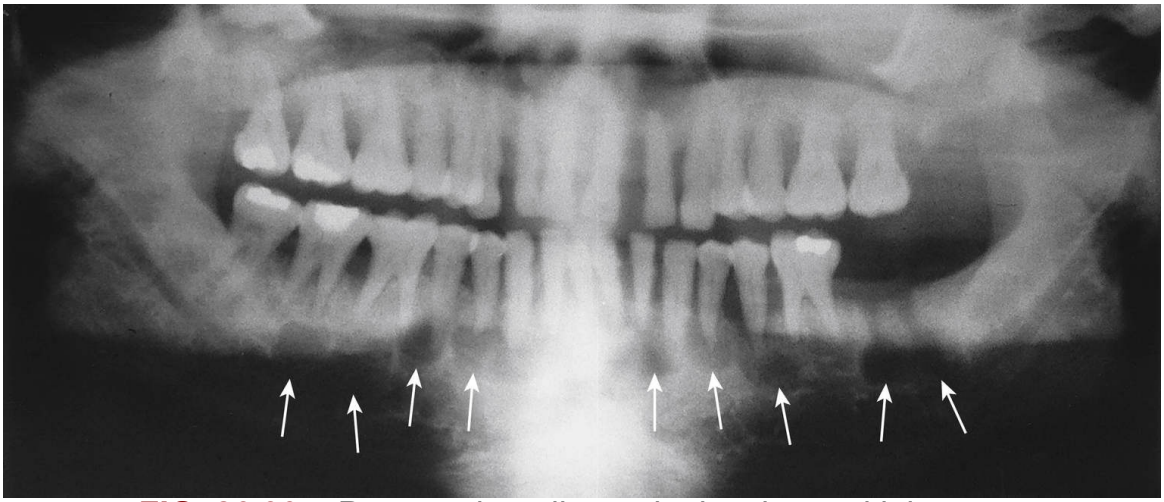


FIG. 26.30 Panoramic radiograph showing multiple radiolucent lesions (arrowed) in the mandible of early stage florid cemento-osseous dysplasia.

Stafne's idiopathic bone cavity (see Fig. 26.31)

A bone cavity or depression on the lingual aspect of the mandible near the lower border, frequently said to contain aberrant salivary gland tissue.

- ***Age*** **:** Adults.
- ***Frequency*** **:** Rare.

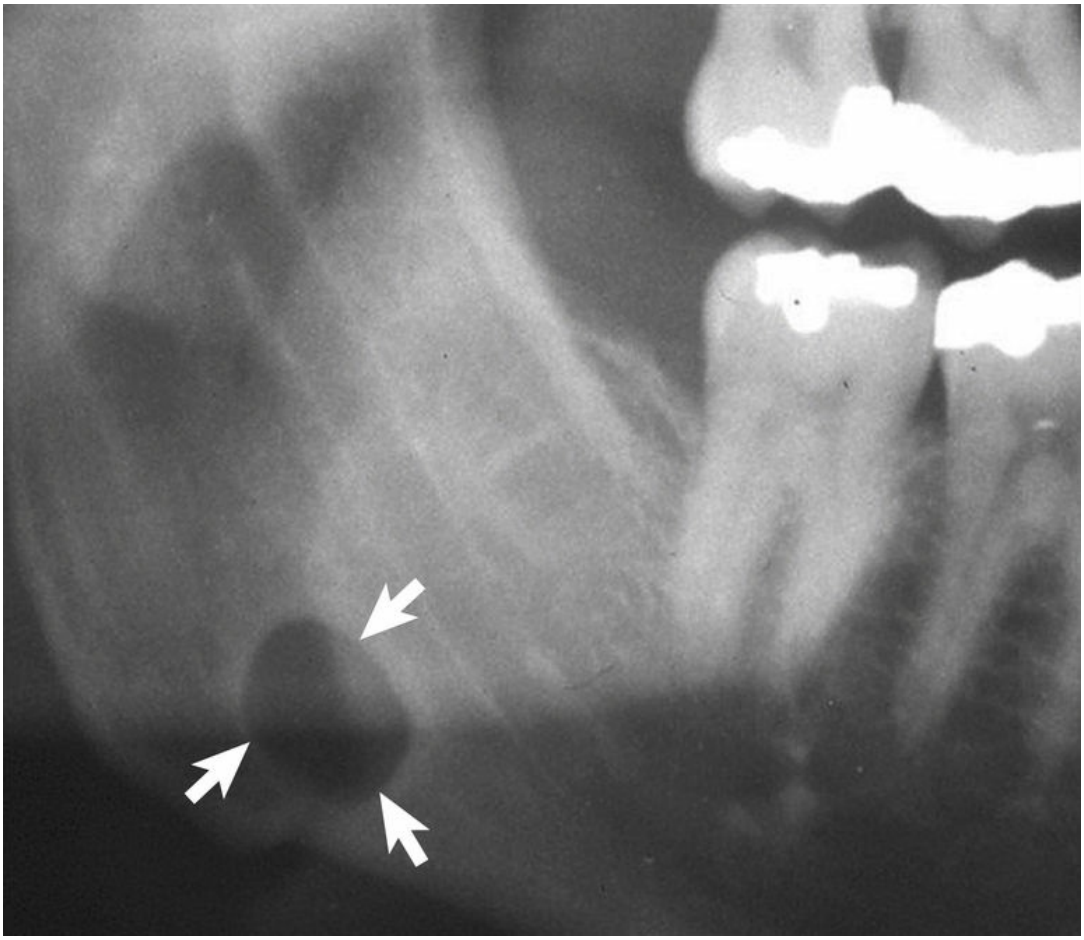


FIG. 26.31 Right side of a panoramic radiograph showing the typical cyst-like appearance of Stafne's idiopathic bone cavity at the angle of the mandible, below the inferior dental canal (arrowed).

- ***Site*** **:** Angle of the mandible, below the inferior dental canal but above or involving the lower border.
- ***Size*** **:** 1–2 cm in diameter, size does not usually alter with age.
- ***Shape*** **:** – Round
  – Unilocular.
- ***Outline*** **:** – Well-defined
  – Variable cortication.
- ***Radiodensity*** **:** Uniformly radiolucent.
- ***Effects*** **:** – No effect on nearby teeth – no expansion
  – Lingual depression not usually detectable clinically.

Footnote

In view of this large number of radiolucent conditions, an ordered, systematic approach when producing a differential diagnosis is essential. Although the old adage that common things are commonly seen applies aptly to radiology, clinicians always have to be prepared for the possibility that they may be dealing with one of the rare, and perhaps sinister conditions.

For review purposes, Table 26.2 summarizes those lesions that present typically as unilocular or multilocular radiolucencies.

TABLE 26.2

Summary of the main unilocular and multilocular radiolucent lesions of the jaws

Disease category	Typically unilocular lesions	Typically multilocular lesions
Cysts	Radicular cyst Residual cyst Inflammatory collateral cyst Dentigerous cyst Lateral periodontal cyst Calcifying odontogenic cyst Nasopalatine duct cyst	Odontogenic keratocyst Botyroid odontogenic cyst Glandular odontogenic cyst
Odontogenic tumours	Unicystic ameloblastoma Adenomatoid odontogenic tumour Odontogenic fibroma	Ameloblastoma Ameloblastic fibroma Calcifying epithelial odontogenic tumour Odontogenic myxoma
Non-odontogenic tumours	Chondroma Fibroma Neuroma Secondary metastatic tumours Multiple myeloma Eosinophilic granuloma	Haemangioma
Allied lesions	Simple bone cyst Cemento-ossifying fibroma Fibrous dysplasia Cemento-osseous dysplasia	Central giant cell granuloma Cherubism Aneurysmal bone cyst

	Stafne's idiopathic bone cavity	

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

27

Differential Diagnosis of Lesions of Variable Radiopacity in the Jaws

As explained in Chapter 25 , a variety of conditions that can affect the jaws are *radiopaque* relative to the surrounding bone, although the degree of opacity can be very variable. A step-by-step guide, similar to that suggested for radiolucent lesions in Chapter 26 , is outlined to emphasize the importance of a methodical approach when producing a differential diagnosis. The suggested approach is summarized in Fig. 27.1 . Although most lesions are still detected using plain radiographs, this process can be greatly facilitated in many cases if advanced imaging modalities, described in Chapters 16 and 18 , such as computed tomography (CT), cone beam computed tomography (CBCT) or magnetic resonance imaging (MRI) are available.

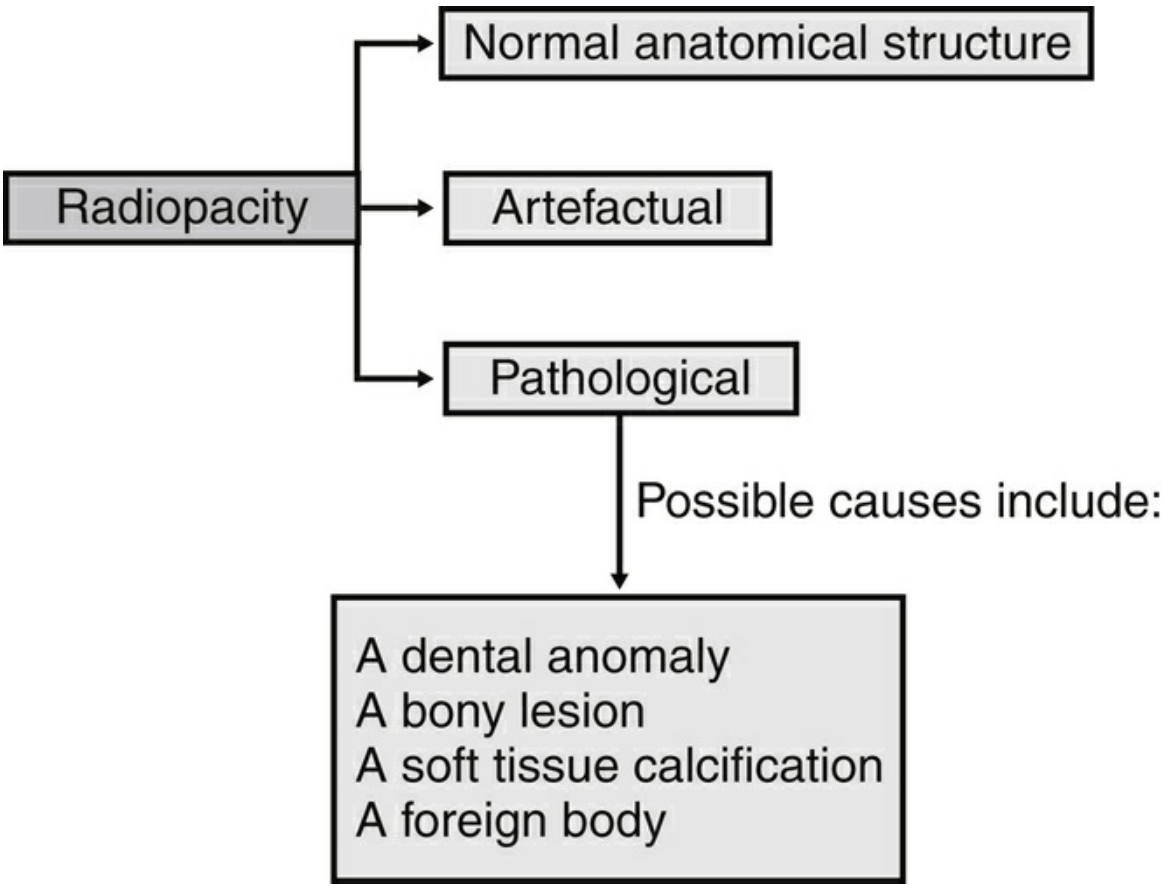


FIG. 27.1 Step-by-step guide to the differential diagnosis of radiopacities.

STEP I

Describe the variable radiopacity, noting in particular:

- Site or anatomical position – is the opacity actually within bone or is it within the surrounding soft tissues and thus superimposed on the bone? To localize the opacity, two radiographs are usually required, ideally at right angles to one another.
- Size.
- Shape.
- Outline or periphery – a particularly useful differentiating feature; if the opacity is surrounded by a thin radiolucent line,

it is invariably of dental tissue origin.
- Relative radiodensity.
- Effects on adjacent surrounding structures.
- Time present, if known.

STEP II

Decide whether the variable radiopacity is:

1. *A normal anatomical feature*
   - In the mandible, e.g.:
     - An area of dense bone sometimes referred to as a dense bone island
     - A bony prominence such as the external oblique ridge, mylohyoid line or genial tubercles
     - Another overlying bone such as the hyoid bone.
   - In the maxilla, e.g.:
     - Another overlying bone such as the zygoma or anterior nasal spine
     - Another overlying structure such as the nasal cartilages or soft palate.
2. *Artefactual*

These depend largely on the type of radiograph, but examples include:

- Real or ghost earring shadows – seen on panoramic radiographs (see Chapter 15)
- Scratches/debris on phosphor plates
- Light fogged phosphor plates
- Fixer solution splashes on a film
- Objects or scratches on intensifying screens.

3. *Pathological*

STEP III

If the radiopacity is *pathological,* decide within which of the following major categories it should be placed:

- Abnormalities of the teeth
- Conditions affecting the bone
- Superimposed soft tissue calcifications
- Foreign bodies.

STEP IV

Consider the subdivisions of these pathological categories. A typical list is shown in Table 27.1 .

STEP V

Compare the radiological features of the unknown opacity with the typical radiological features of these possible conditions. Then construct a list showing, in order of likelihood, all the conditions that the lesion might be. As mentioned in Chapter 26 , this list forms the *radiological differential diagnosis.*

The typical radiographic features of the important radiopacities are described below using a similar style to that adopted in Chapter 26 . It must be emphasized that this is a **simplified** approach and that most lesions can produce a variety of appearances.

TABLE 27.1

Classification of the more common lesions that can present as variable radiopacities in the jaws

Abnormalities of the teeth	
Unerupted and misplaced teeth including supernumeraries Odontomes • Compound • Complex (see odontogenic tumours) Root remnants	
Conditions of variable opacity affecting the bone	
Developmental anomalies	Exostoses including tori – mandibular or palatal
Inflammatory conditions	Low-grade chronic infection • Sclerosing osteitis Osteomyelitis • Sequestra and/or involucrum formation
Cysts	Calcifying odontogenic cyst (late stage)
Odontogenic tumours (late stages)	Calcifying epithelial odontogenic tumour (CEOT) Adenomatoid odontogenic tumour (AOT) Cementoblastoma Odontomes • Compound • Complex
Non-odontogenic tumours	Benign • Osteoma • Chondroma Malignant • Osteosarcoma • Osteogenic metastases
Fibro-osseous lesions (late stages)	Cemento-ossifying fibroma Fibrous dysplasia Cemento-osseous dysplasias • Periapical cemento-osseous dysplasia • Focal cemento-osseous dysplasia • Florid cemento-osseous dysplasia
Bone diseases	Paget's disease of bone Osteopetrosis
Superimposed soft tissue calcifications	
Salivary calculi Calcified lymph nodes Calcified tonsils Phleboliths Calcified acne scars	
Foreign bodies	
Intra-bony Within the soft tissues On or overlying the skin	

Typical Radiographic Features of Abnormalities of the Teeth

Unerupted or Misplaced Teeth Including Supernumeraries (see Fig. 27.2)

Radiopacities caused by unerupted or misplaced teeth and supernumeraries are readily identifiable as such radiographically, by their characteristic shape and radiodensity.

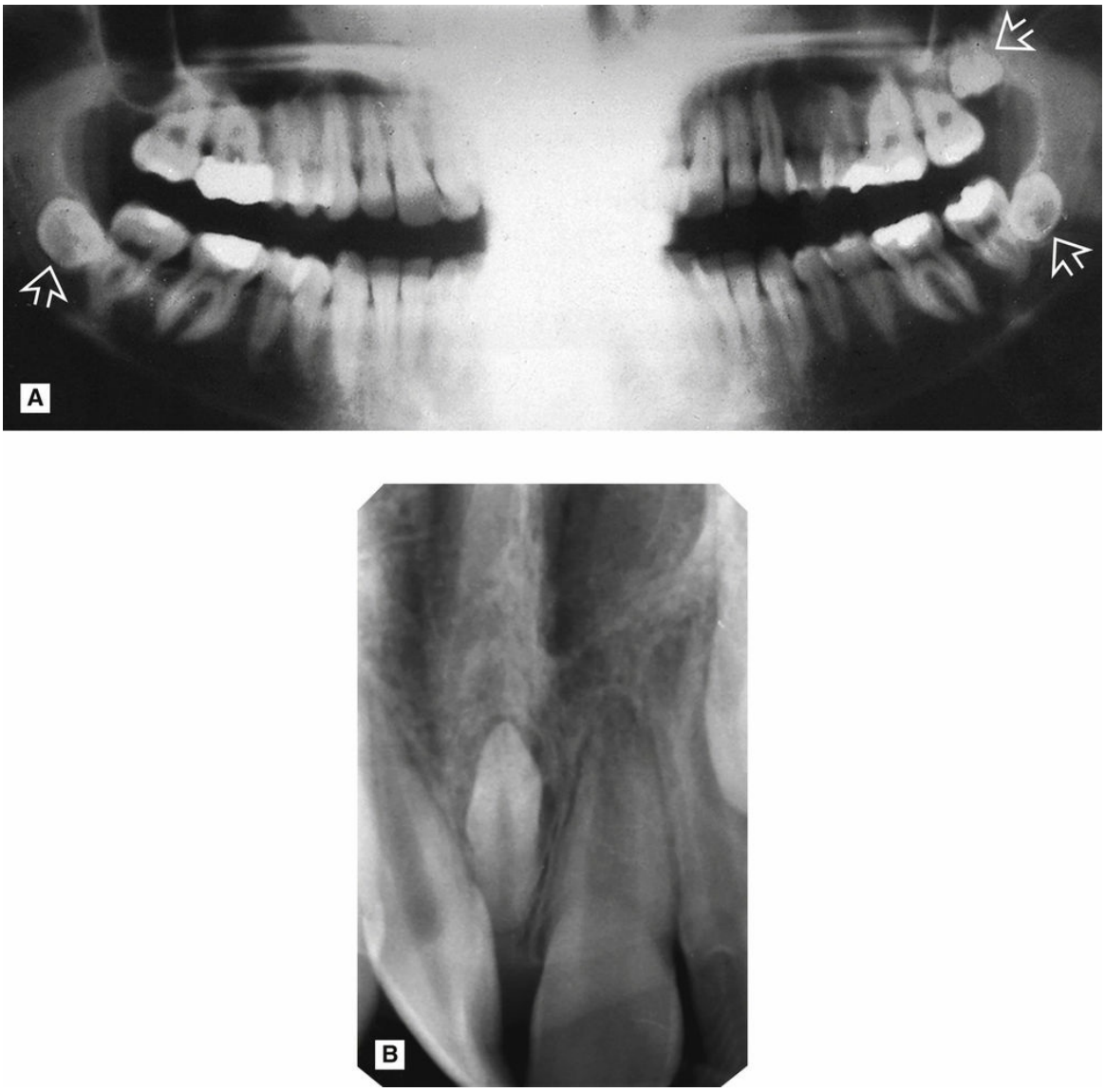
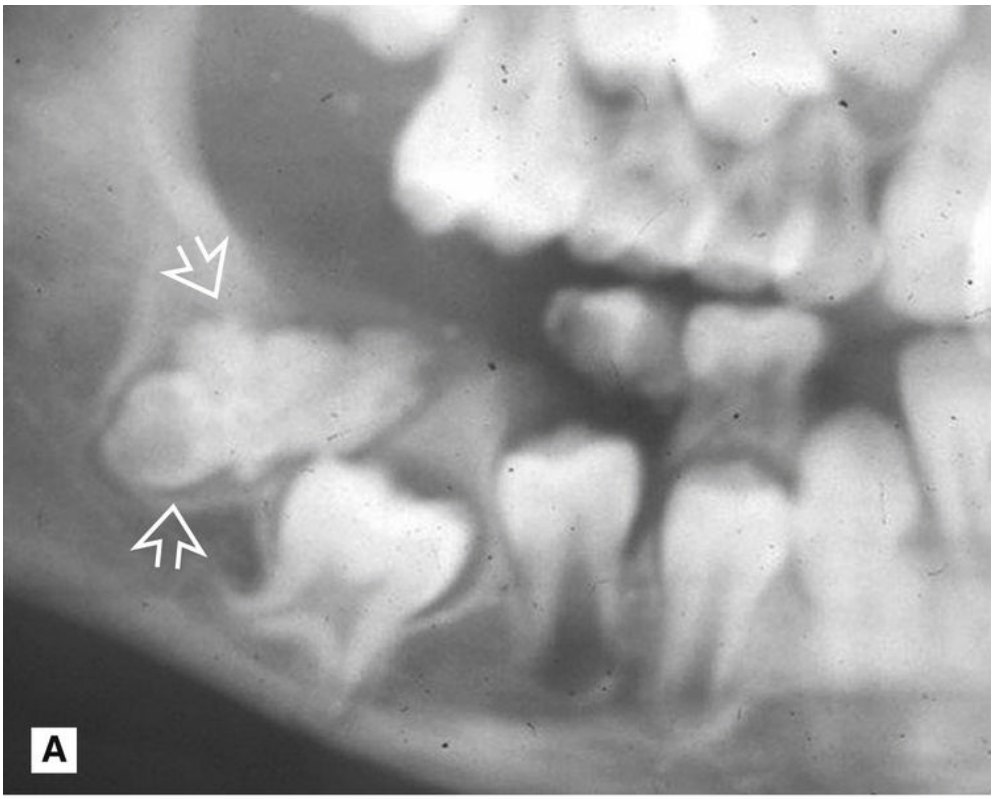


FIG. 27.2 Examples of opacities caused by unerupted teeth. **(A)** Panoramic radiograph showing the typical appearance of unerupted and misplaced wisdom teeth (arrowed) – $\overline{8}|\overline{8}$ are positioned transversely. **(B)** Periapical showing a conically shaped mesiodens (arrowed) between $\underline{1}|\underline{1}$. Density, shape and outline confirm that the opacity is composed of dental tissue.

Odontomes

Odontomes are classified by the World Health Organization (WHO) (2017) as mixed epithelial odontogenic tumours. They are subdivided into two types – compound or complex. The previously described

entities of ameloblastic fibro-odontomas and ameloblastic fibro-dentinomas are now classified by the WHO as developing odontomes. All the odontomes exhibit a degree of *histo-differentiation* resulting in the formation of recognizable dental tissues. The compound odontomes also exhibit a degree of *morpho-differentiation* such that they resemble the shape of teeth. As a result odontomes are also often described as dental developmental anomalies (see Chapter 24).


A

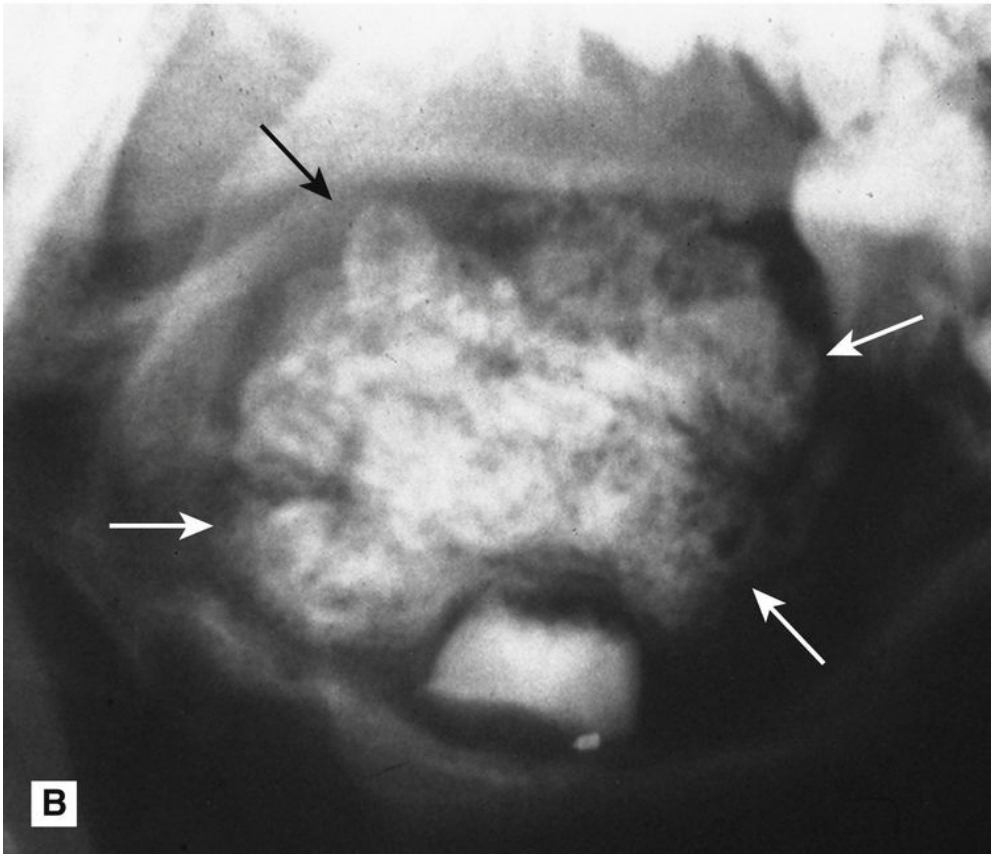

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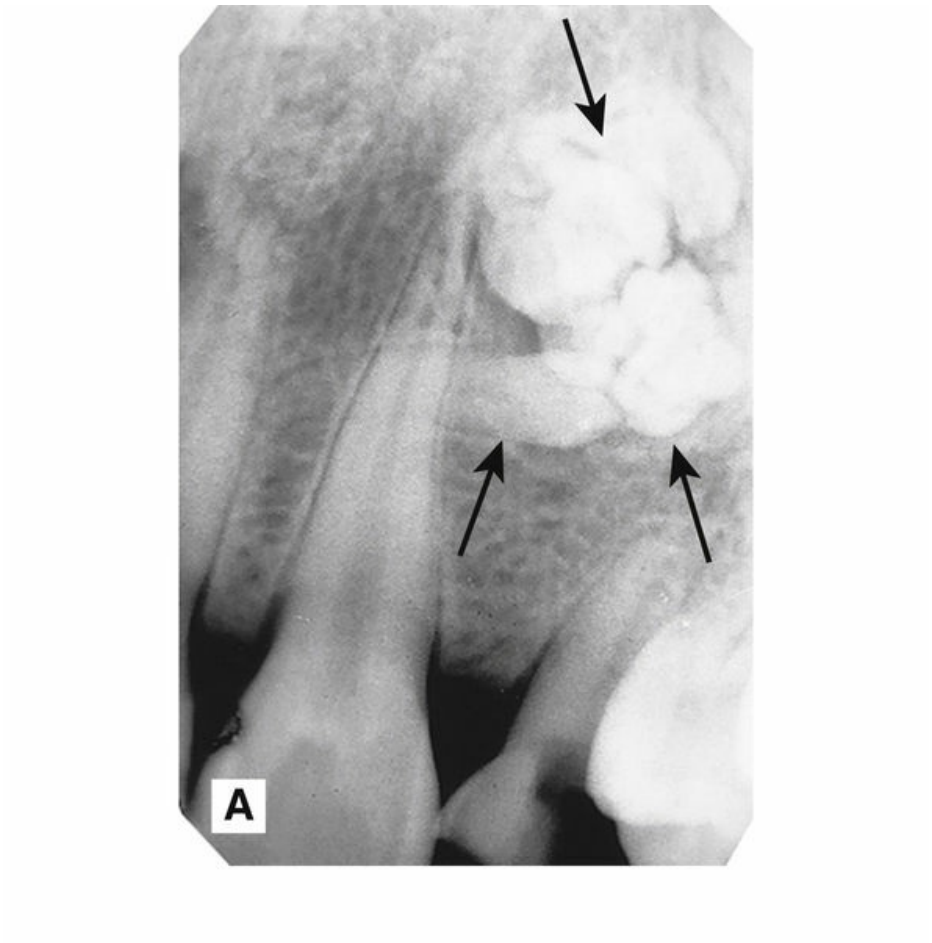
FIG. 27.3 (A) Right side of a panoramic radiograph showing the typical irregular, densely radiopaque mass of a complex odontome, surrounded by a radiolucent line, in the position of $\overline{7}$ (arrowed). (B) Oblique lateral showing a large developing radiopaque complex odontome (arrowed) in the mandible of a 5-year-old child.

Complex Odontomes (see Fig. 27.3)

Complex odontomes exhibit a degree of histo-differentiation and are made up of an irregular, confused mass of dental tissues bearing no resemblance in shape to recognizable teeth. The enamel content provides the dense radiopacity, suggestive of dental tissue, which is typically surrounded by a radiolucent line.

Compound Odontomes (see Fig. 27.4)

Compound odontomes have undergone histo-differentiation into dental tissue and exhibit a degree of morpho-differentiation. As a result, they are typically made up of several small tooth-like denticles. The miniature tooth shapes are of dental tissue radiodensity, with a surrounding radiolucent line.


A

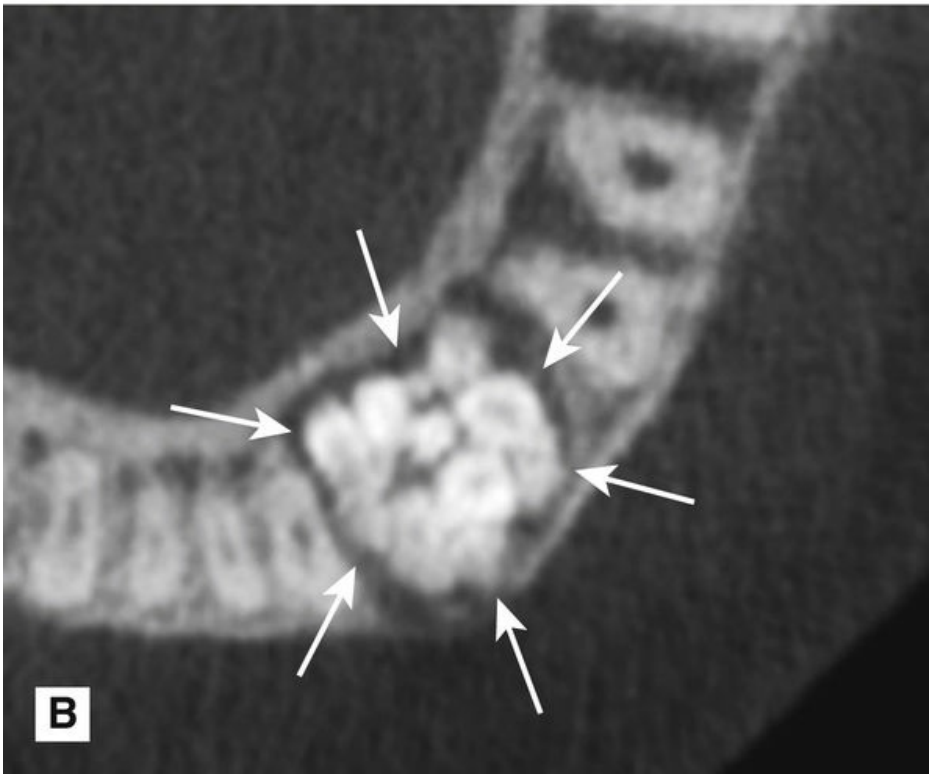

B

FIG. 27.4 (A) Periapical of the 12 region showing a radiopaque compound odontome (arrowed), consisting of small denticles. (B) Axial CBCT scan showing another compound odontome in the 3 region (arrowed).

Root Remnants (see Fig. 27.5)

Deciduous and permanent root remnants remaining in the alveolar bone, after attempted extraction, are common. The site, shape and density make radiographic identification relatively simple. Additional diagnostic radiographic features include the surrounding radiolucent line of the periodontal ligament shadow and sometimes evidence of a root canal.

Typical Radiographic Features of Conditions of Variable Opacity Affecting Bone

Developmental Anomalies

Exostoses, including Tori (Mandibular or Palatal) (see Fig. 27.6)

Exostoses are small, irregular overgrowths of bone sometimes developing on the surface of the alveolar bone. They consist primarily of compact bone and produce an ill-defined radiopacity when superimposed over the bulk of the alveolar bone. Usually two views are required to establish the exact site.

Specific exostoses develop in particular sites and are often bilateral:

- *Torus mandibularis* – lingual aspects of the mandible, in the premolar/molar region
- *Torus palatinus* – either side of the midline towards the posterior part of the hard palate.

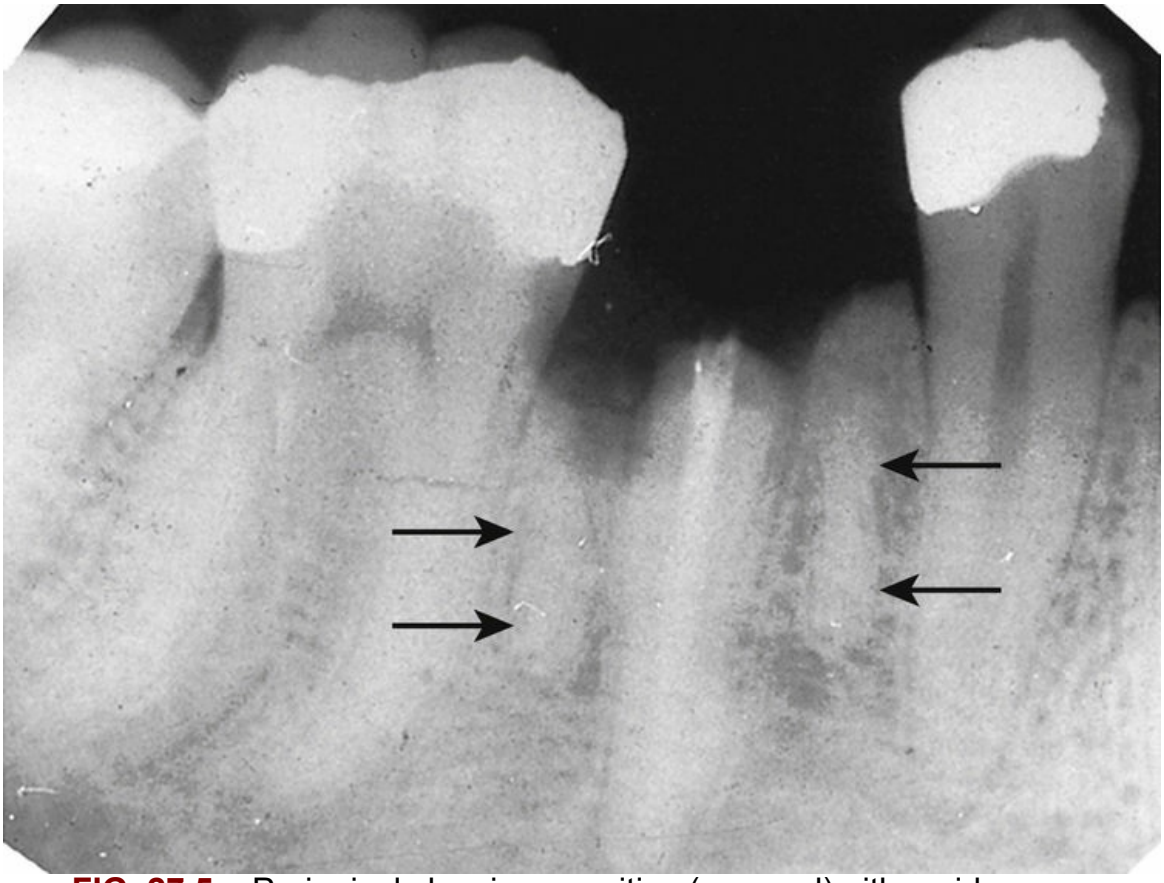


FIG. 27.5 Periapical showing opacities (arrowed) either side of $\overline{5}$| root caused by the root remnants of the deciduous $\overline{E}$|.

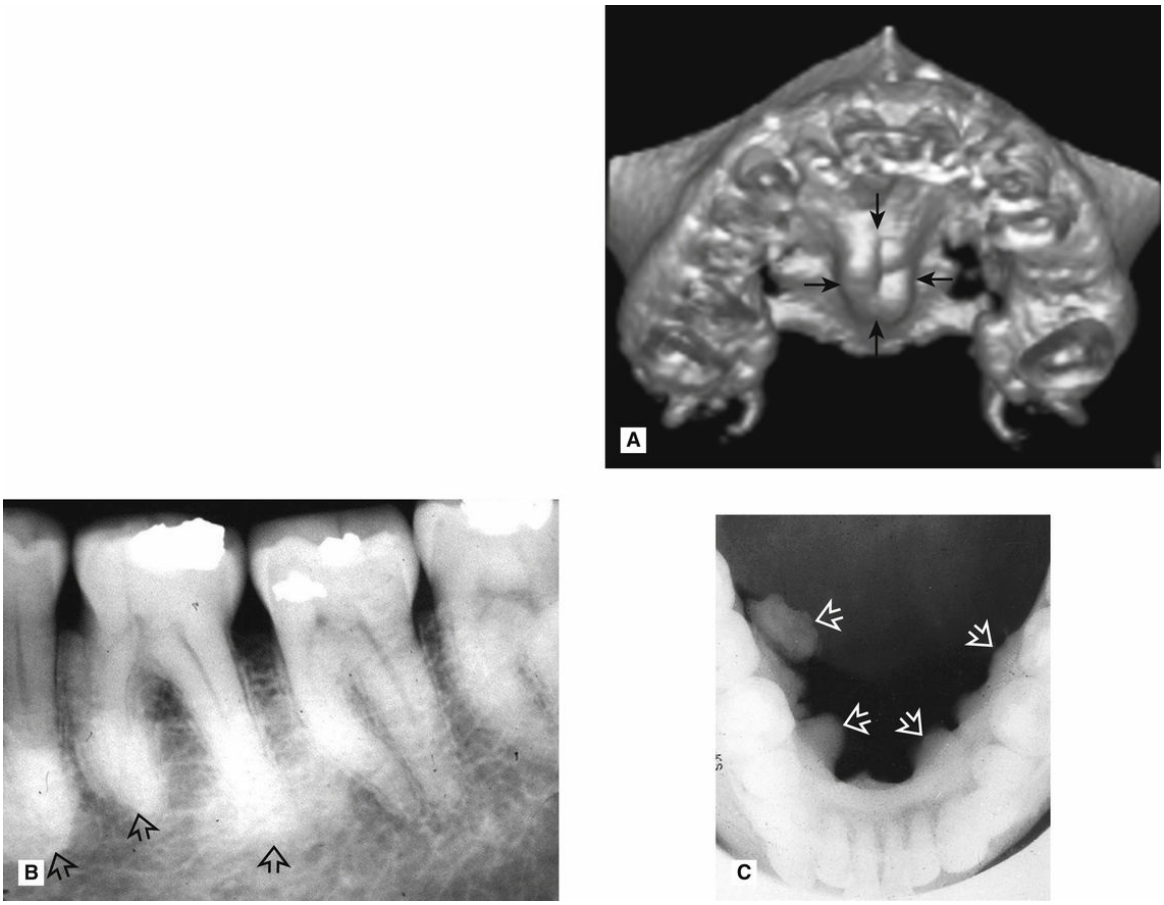


FIG. 27.6 (A) A 3-D volume-rendered CBCT image showing a large palatal exostosis (palatal torus) (arrowed). (B) Periapical of 5678 showing ill-defined areas of radiopacity (arrowed) overlying the teeth. (C) Lower 90° occlusal of the same patient showing the large irregular exostoses (mandibular tori) on the lingual aspect of the mandible (arrowed).

Inflammatory Conditions

Sclerosing Osteitis (see Fig. 27.7)

As described in Chapter 21 , periapical inflammatory changes often result from low-grade chronic infection causing resorption of apical alveolar bone and the formation of a periapical granuloma. The body's defence systems respond to, and try to confine, the spread of infection and radiopaque, sclerotic, dense bone is laid down around the area of resorption.

Cysts

Calcifying Odontogenic Cyst (see Fig. 27.8)

As mentioned in Chapter 26 , in the 2017 WHO classification the calcifying odontogenic cyst or Gorlin's cyst is reclassified as a cyst, rather than a tumour, and is defined as a simple cyst lined by ameloblastoma-like epithelium which contains focal accumulations of ghost cells. Unlike other odontogenic cysts, as this lesion matures a variable amount of calcified material, of tooth-like density, becomes evident scattered throughout the radiolucency. The opacities can range from small flecks to large masses.

- ***Age*** **:** Variable, reported in patients between 5 and 92 years old.
- ***Frequency*** **:** Rare.
- ***Site*** **:** Mandible or maxilla – anterior or premolar regions, one-third are associated with an unerupted tooth or odontome.
- ***Size*** **:** Usually small, up to 4 cm in diameter.

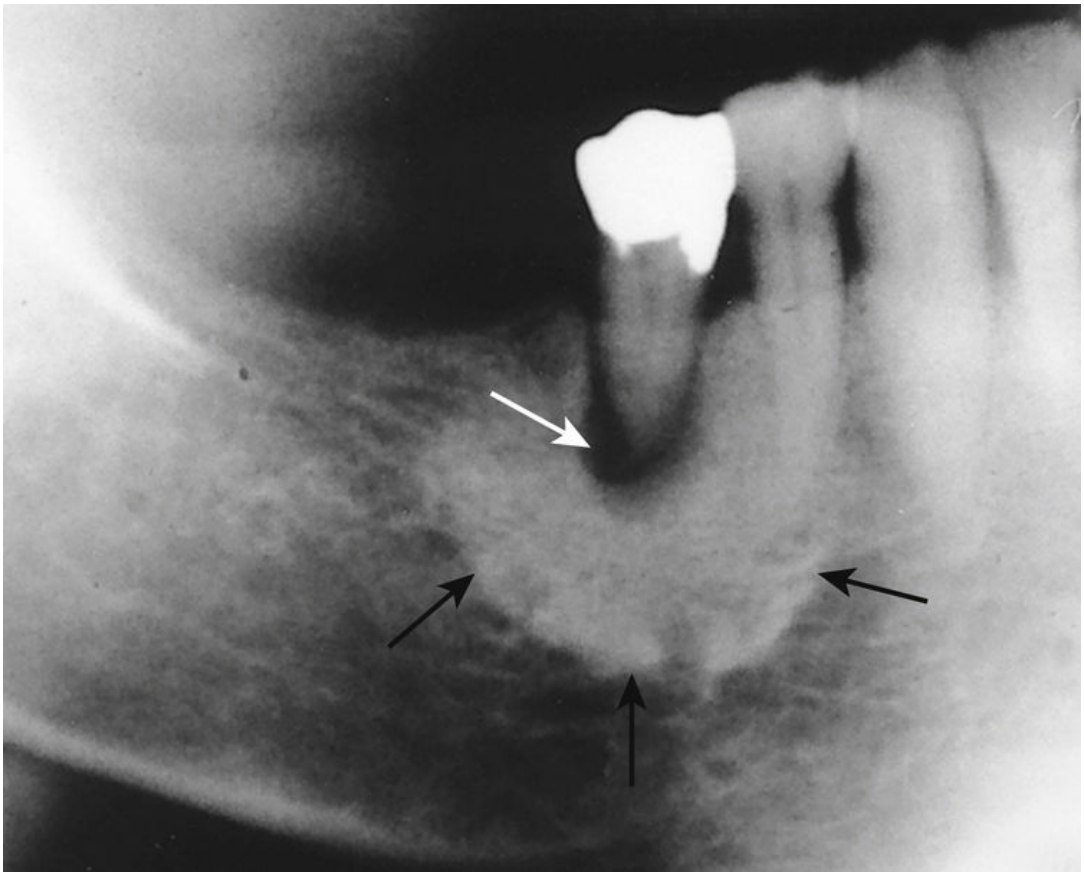


FIG. 27.7 Part of a panoramic radiograph showing the appearance of low grade chronic infection associated with $\overline{5}|$ resulting in a radiolucent periapical granuloma (white arrow), surrounded by radiopaque chronic inflammatory sclerosing osteitis (black arrows).

- ***Shape*** **:** Variable, but usually unilocular.
- ***Outline*** **:** – Smooth, well-defined
  – Well-corticated.
- ***Radiodensity*** **:** Initially radiolucent but in more advanced stages contains a variable amount of calcified radiopaque material of tooth-like density.
- ***Effects*** **:** – Adjacent teeth usually displaced, causing root divergence, and/or resorbed
  – Bony expansion.

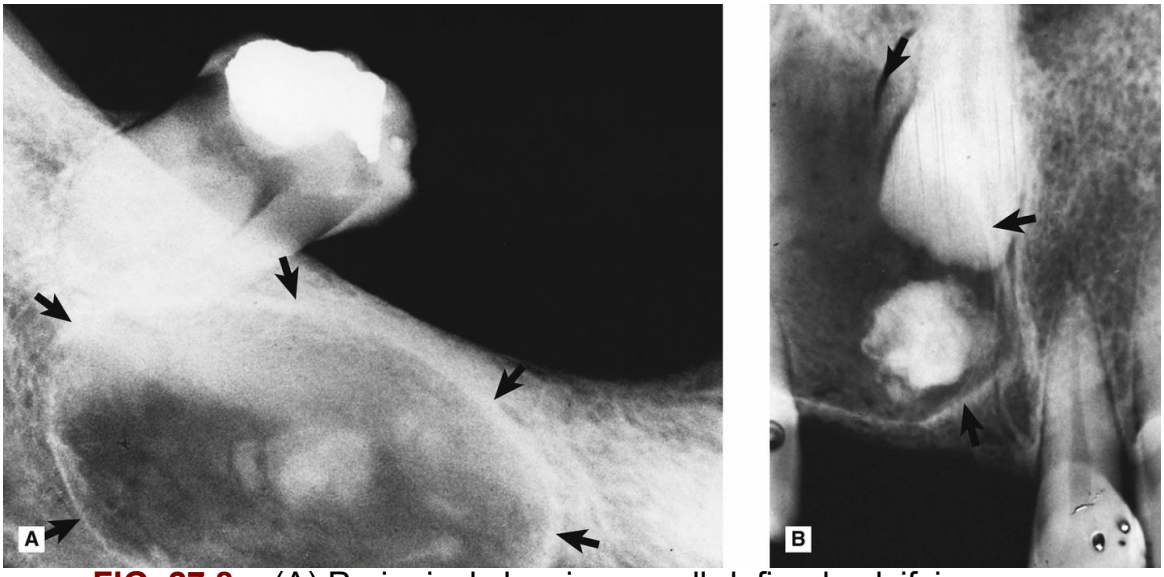


FIG. 27.8 (A) Periapical showing a well-defined calcifying odontogenic cyst (arrowed) in the mandible with obvious areas of internal calcification. (B) Periapical showing a calcifying odontogenic cyst (arrowed) in the anterior maxilla. The central incisor is unerupted and there is internal calcification of tooth-like density.

Odontogenic Tumours

Calcifying Epithelial Odontogenic Tumour (CEOT or Pindborg tumour) (see Fig. 27.9)

Defined by the WHO as a locally invasive epithelial odontogenic neoplasm, characterized histologically by amyloid material that may become calcified.

- ***Age*** **:** 20 to 60-year-old adults.
- ***Frequency*** **:** Rare – approximately 1% of all odontogenic tumours.
- ***Site*** **:** – Molar/premolar region of the mandible
  – Maxilla occasionally.
- ***Shape*** **:** – Unilocular or multilocular
  – Usually round
  – Often associated with an unerupted tooth,

particularly $\overline{8}|\overline{8}$.

- ***Outline*** **:** – Variable definition, frequently scalloped
  – Variable cortication.
- ***Radiodensity*** **:** – Radiolucent in early stages then numerous scattered radiopacities usually become evident within the lesion, often most prominent around the crown of any associated unerupted tooth
  – This appearance is sometimes described as *driven snow* .
- ***Effects*** **:** – Adjacent teeth sometimes displaced, sometimes resorbed
  – Expansion of the cortical bone.

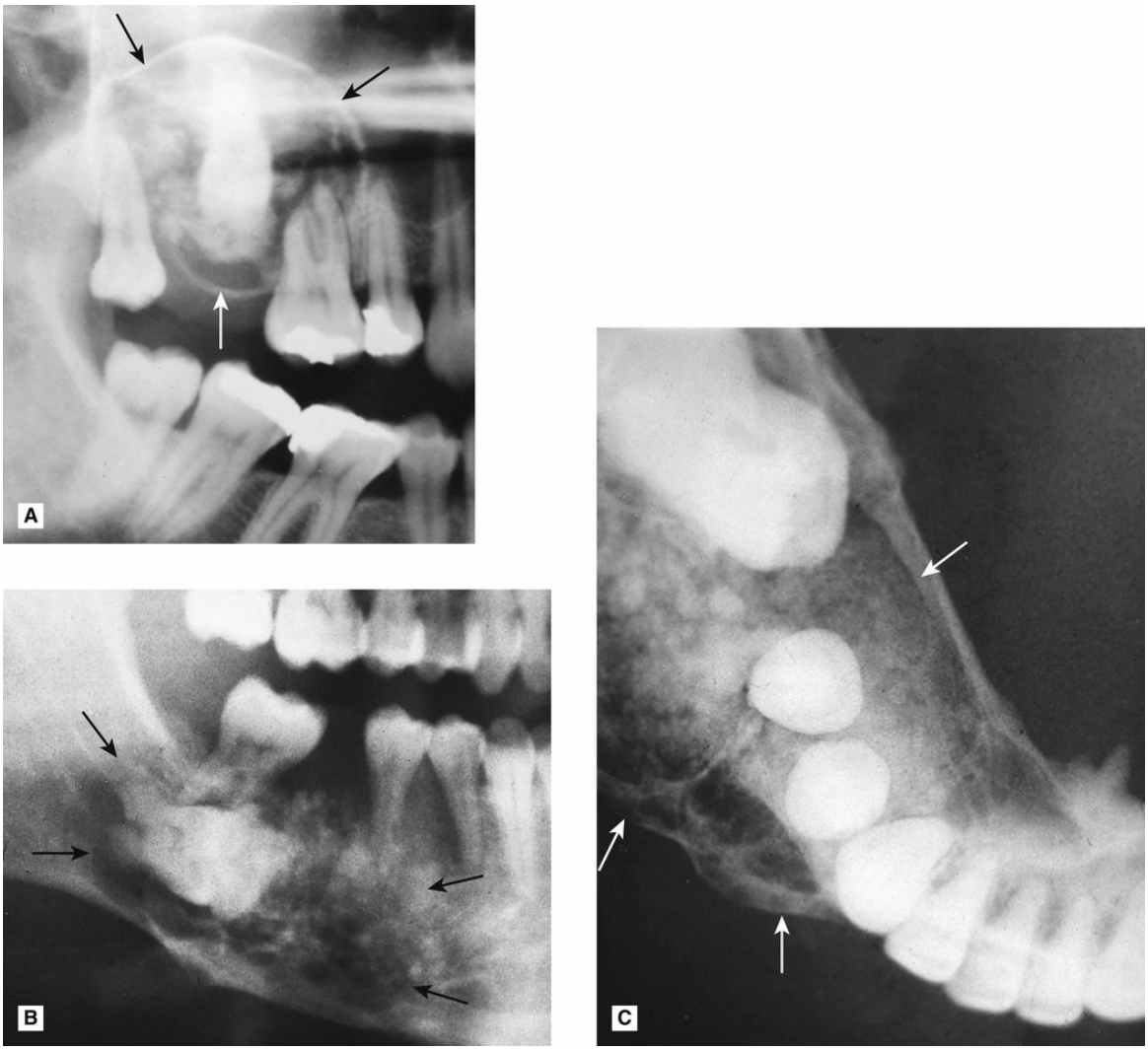


FIG. 27.9 (A) Right side of a panoramic radiograph showing a calcifying epithelial odontogenic tumour in the maxilla (arrowed) associated with the unerupted 7. There are obvious areas of calcification within the lesion. (B) Right side of a panoramic radiograph showing a poorly defined calcifying epithelial odontogenic tumour (arrowed) associated with the unerupted molar. (C) Lower 90° occlusal of the same patient showing the expansive, multilocular nature of the lesion and the discrete internal calcifications.

Adenomatoid Odontogenic Tumour (AOT) (see Fig. 27.10)

Described by the WHO as being composed of odontogenic epithelium

embedded in a mature connective tissue stroma and characterized by slow but progressive growth (see also Fig. 26.13).

- ***Age*** **:** Variable, but 90% develop before the age of 30 with most diagnosed in the second decade.
- ***Frequency*** **:** Rare – approximately 2%–7% of all odontogenic tumours.
- ***Site*** **:** – Anterior maxilla – incisor/canine region
  – Occasionally anterior mandible.
- ***Shape*** **:** – Unilocular
  – Usually round or oval
  – Often surrounds an entire unerupted tooth.
- ***Outline*** **:** – Smooth and well-defined
  – Well-corticated.
- ***Radiodensity*** **:** – Initially radiolucent
  – Small opacities (*snowflakes*) within the central radiolucency may be seen peripherally as the lesion matures.
- ***Effects*** **:** – Adjacent teeth displaced, rarely resorbed
  – Associated tooth often unerupted
  – Buccal/palatal expansion.

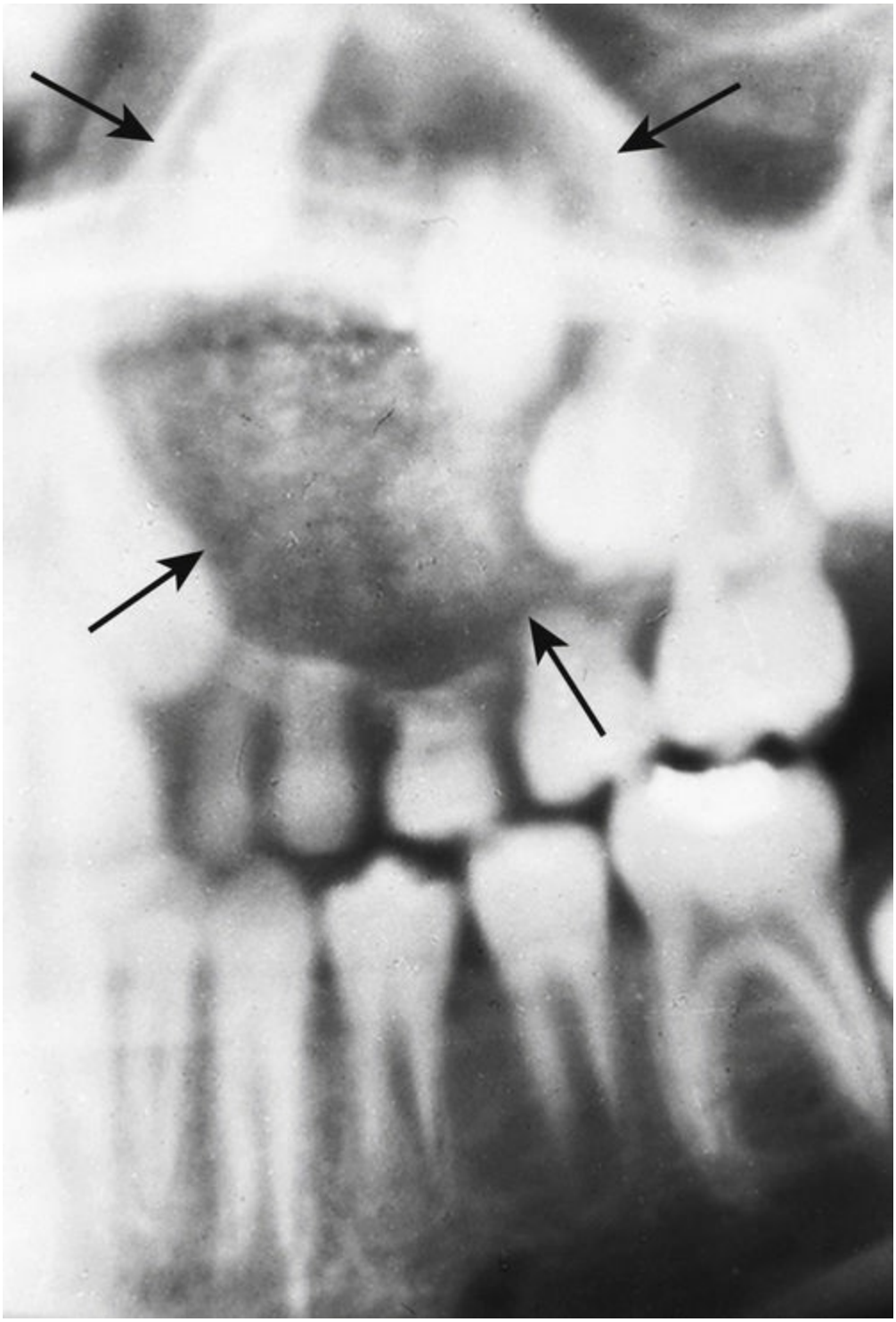


FIG. 27.10 Part of a panoramic radiograph showing a unilocular adenomatoid odontogenic tumour with internal calcification in the anterior maxilla (arrowed) surrounding the unerupted and displaced 3.

Cementoblastoma (see Fig. 27.11)

Classified by the WHO in 2017 as a benign odontogenic tumour of mesenchymal origin characterized by the formation of cementum-like tissue in connection with the root of a tooth.

- ***Age*** **:** Reported in patients between 8 and 44 years old, with a mean age of 20 years.
- ***Frequency*** **:** Rare.
- ***Site*** **:** Apex of mandibular first permanent molars, occasionally premolars. Exceptionally associated with the primary dentition.
- ***Size*** **:** Variable, but up to 2–3 cm in diameter.
- ***Shape*** **:** – Round or irregular, sometimes described as resembling a *golf ball*
  – Attached to a tooth root.
- ***Outline*** **:** Well-defined.
- ***Radiodensity*** **:** – Radiopaque but often surrounded by a thin radiolucent line

– Often surrounded by a diffuse area of sclerotic bone.

- ***Effects*** **:** – Root resorbed with mass fused and attached to the tooth
  – If large, may cause localized expansion of the cortical plates.

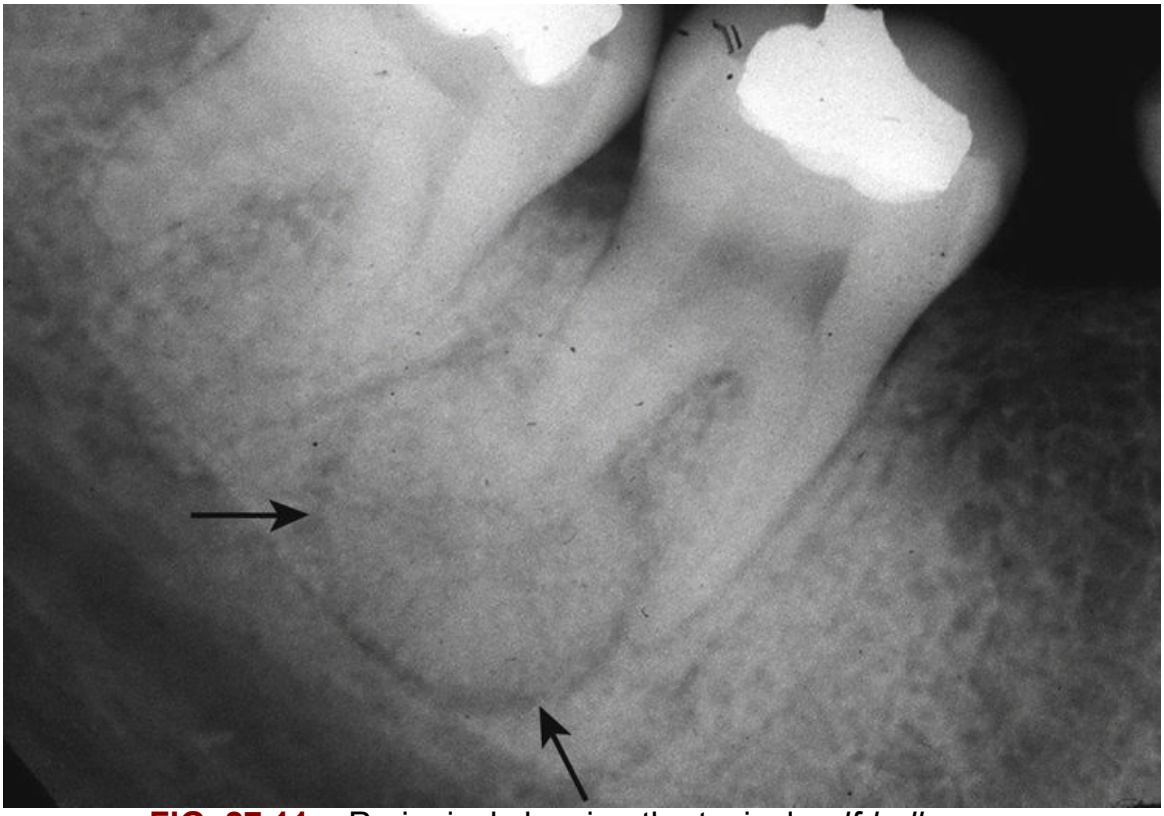


FIG. 27.11 Periapical showing the typical *golf-ball* radiopaque mass of a cementoblastoma attached to the distal root of $\overline{6}|$ (arrowed).

Non-odontogenic Tumours

Osteoma (see Fig. 27.12)

Osteomas of the jaws may be located in the medullary bone (*endosteal osteoma*) or arise on the surface of the bone as a pedunculated mass (*periosteal osteoma*). They are usually detected in young adults and are typically asymptomatic, solitary lesions. Multiple jaw osteomas are a feature of the rare inherited condition *Gardner's syndrome.*

There are two main types:

- Compact – consisting of dense lamellae of bone and including the so-called *ivory osteoma* occasionally seen in the frontal sinus (see Chapter 31)
- Cancellous – consisting of trabeculae of bone.

Both tumours are uncommon. The type of bone making up the tumour determines the degree of radiopacity.

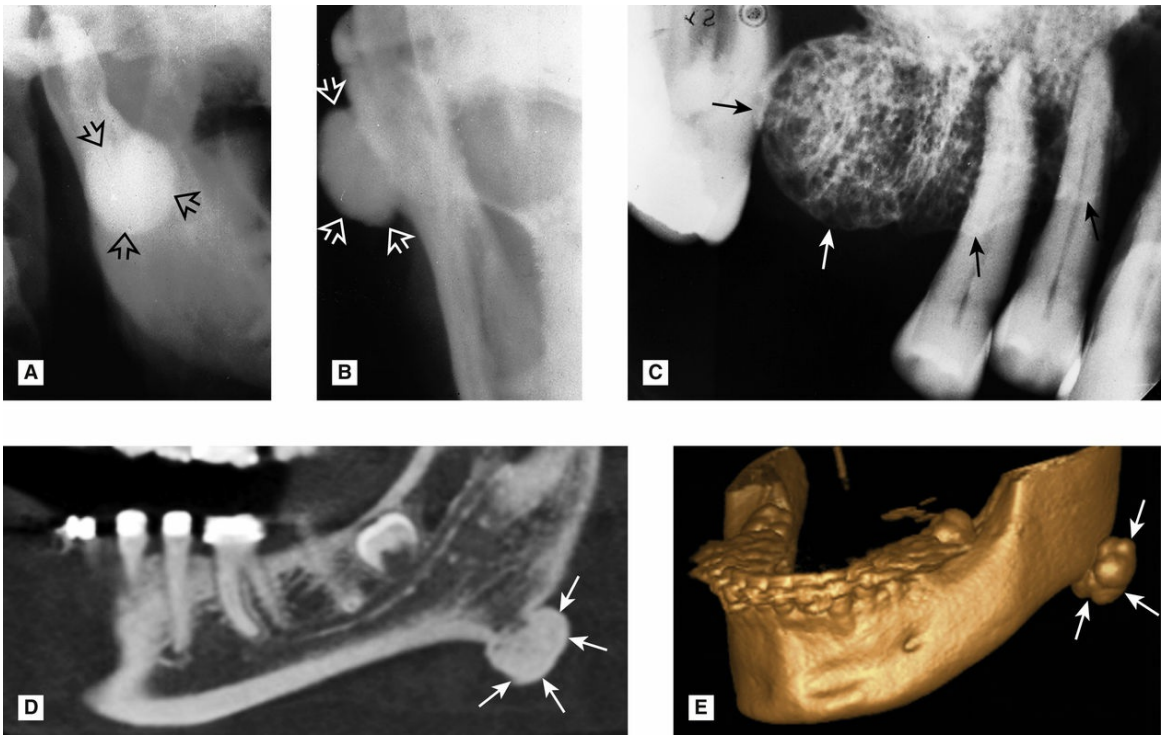


FIG. 27.12 (A) Oblique lateral of right ramus of the mandible showing a round radiopaque compact osteoma (arrowed). (B) Part of a PA jaws of the same patient showing the lesion (arrowed) arising from the lateral surface of the mandible confirming a periosteal osteoma. (C) Periapical showing a periosteal cancellous osteoma (arrowed). (D) Sagittal CBCT image showing a pedunculated osteoma at the angle of the mandible. (E) Volume-rendered 3-D CBCT image of the same osteoma.

Osteosarcoma (see Fig. 27.13)

An osteosarcoma is a rare, rapidly destructive, malignant tumour of bone. From a radiological viewpoint, there are three main types:

- Osteolytic – no neoplastic bone formation
- Osteogenic/osteosclerotic – neoplastic osteoid and bone

formed
- Mixed lytic and sclerotic – patches of neoplastic bone formed.

Early features

- Non-specific, poorly defined radiolucent area around one or more teeth
- Widening of the periodontal ligament space.

Later features

- Osteolytic lesion:
  - Unilocular, ragged area of radiolucency
  - Poorly defined, *moth-eaten outline*
  - So-called *spiking* resorption and/or loosening of associated teeth.
- Osteogenic and mixed lesions:
  - Poorly defined radiolucent area
  - Variable internal radiopacity with obliteration of the normal trabecular pattern
  - Perforation and expansion of the cortical margins by stretching the periosteum, producing the classical, but rare, *sunray* or *sunburst* appearance.

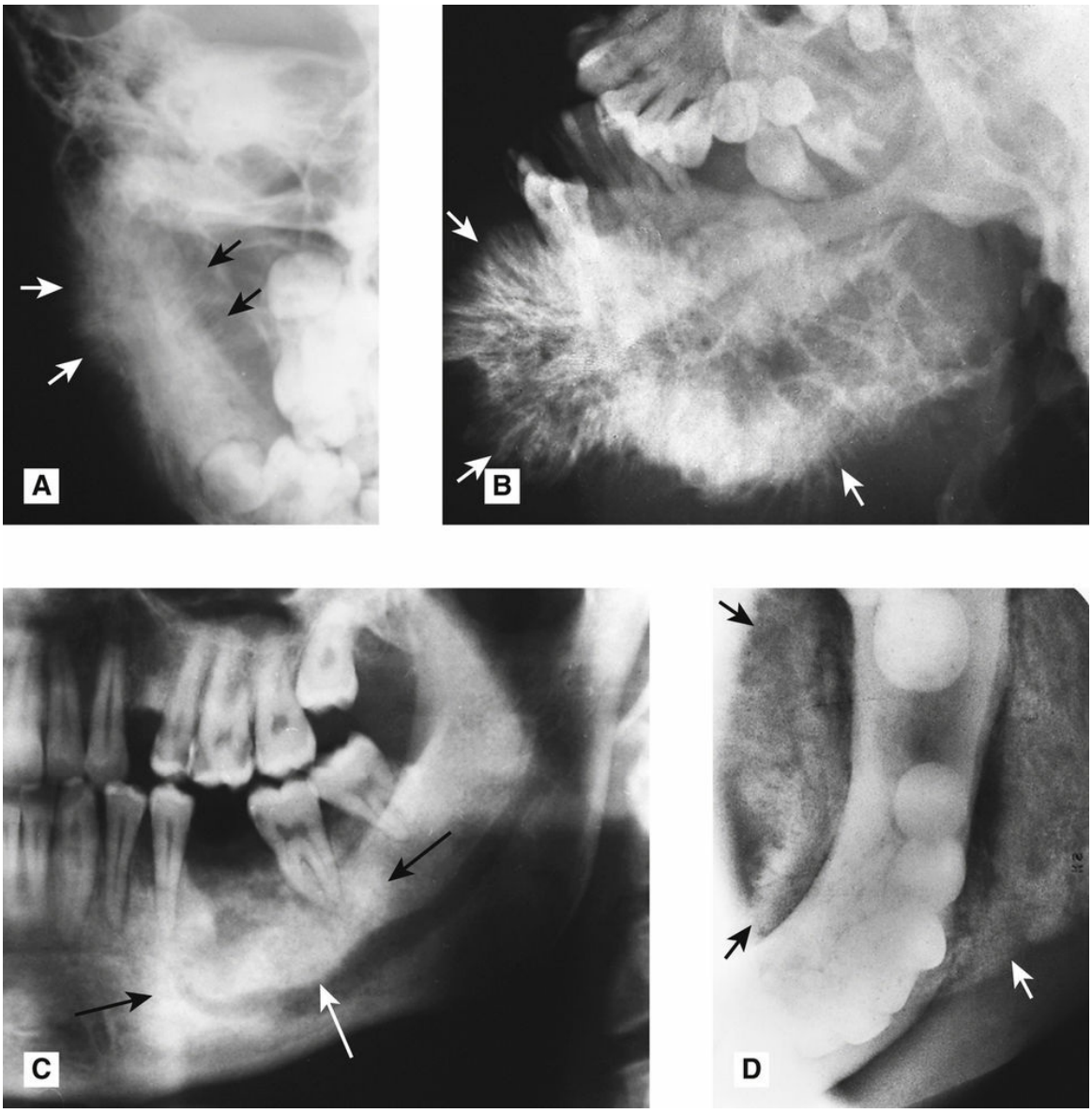


FIG. 27.13 (A) Right side of a PA jaws of a 7-year-old child showing an osteosarcoma in the ascending ramus of the mandible. The *sunray* or *sunburst* appearance is evident medially and laterally (arrowed). (B) Oblique lateral showing a very extensive osteogenic osteosarcoma of the mandible with obvious *sunray* or *sunburst* bone formation. (C) Left side of a panoramic radiograph showing an irregular, poorly defined area of radiopacity (arrowed) in the body of the mandible. (D) Lower 90° occlusal of the same patient showing extensive buccal and lingual abnormal bone formation (arrowed) of another osteogenic osteosarcoma.

Fibro-osseous Lesions

Cemento-ossifying Fibroma (see Fig. 27.14)

As mentioned in Chapter 26 , ossifying fibromas are described in the 2017 WHO classification as benign fibro-osseous neoplasms affecting the jaws and the craniofacial skeleton. The *cemento-ossifying fibroma* is a distinct type of ossifying fibroma that occurs in the tooth-bearing areas of the jaws and is believed to be of odontogenic origin.

- ***Age*** **:** Variable, but usually in the second to fourth decades (particularly in women).
- ***Frequency*** **:** Rare.
- ***Site:*** Usually posterior mandible, but different variants can affect the maxilla and paranasal sinuses.
- ***Size:*** Variable, may grow to several centimetres in diameter and cause facial asymmetry.
- ***Shape*** **:** –Round
  – Unilocular.
- ***Outline*** **:** – Smooth, well-defined
  – When opaque, usually surrounded by a thin encapsulating radiolucent line
  – Usually corticated and circumscribed.
- ***Radiodensity*** **:** –Early stage – radiolucent
  – Intermediate stage – radiolucent with gradually increasing internal radiopaque calcified patches
  – Late stage – radiopaque zones coalesce to form a densely radiopaque mass with or without a radiolucent periphery.
- ***Effects*** **:** – Adjacent teeth:
  * often displaced
  * occasionally resorbed
  – Expansion of the surrounding bone in all dimensions often demonstrating a *downward bowing* of the mandibular lower border cortex.

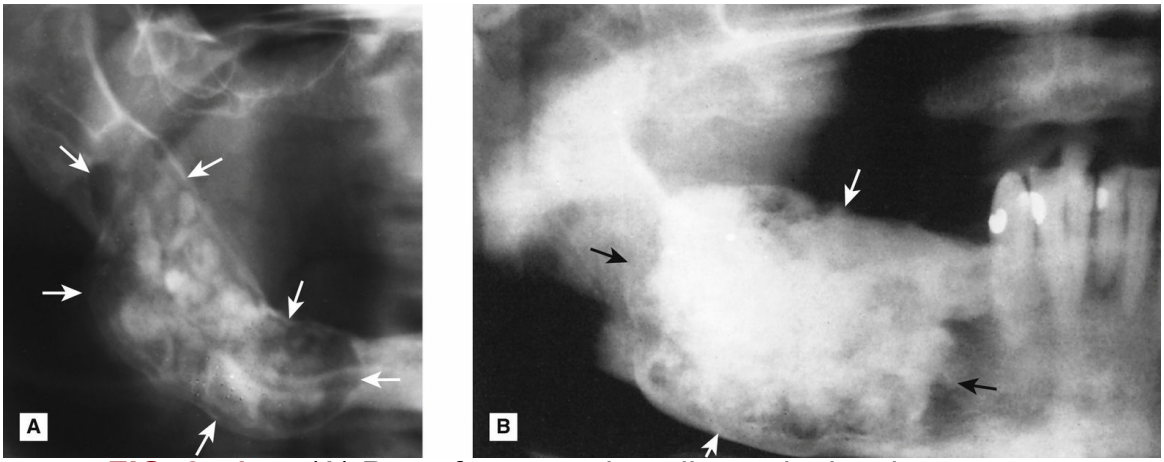


FIG. 27.14 (A) Part of panoramic radiograph showing a large cemento–ossifying fibroma (arrowed) occupying most of the body of the mandible with considerable internal calcification. (B) Right side of a panoramic radiograph showing a large mature radiopaque cemento–ossifying fibroma (arrowed).

Fibrous Dysplasia (see Fig. 27.15)

As mentioned in Chapter 26 , fibrous dysplasia is described by the WHO as a fibro-osseous skeletal anomaly in which normal bone is replaced and distorted by poorly organized and inadequately mineralized immature bone and fibrous tissue. It may involve a single bone or multiple bones. The jaws and other bones in the skull can be affected as well as other bones in the skeleton. In the early stages of the disease the lesions are more radiolucent (see Fig. 26.28), but then they gradually become more opaque. The more general radiological features of fibrous dysplasia are covered in Chapter 28 .

- ***Age*** **:** 10 to 20-year-old adolescents.
- ***Site*** **:** Maxilla – usually posteriorly, more commonly than the mandible; maxillary lesions may spread to involve adjacent bones such as the zygoma, sphenoid, occiput and the base of the skull.
- ***Size*** **:** Variable and difficult to define.
- ***Shape*** **:** Round.

- ***Outline*** **:** –Poorly defined, with the margins merging imperceptibly with adjacent normal bone
  – Not corticated.
- ***Radiodensity*** **:** –Initially radiolucent (but rarely seen clinically at this stage)
  – Gradually becomes opaque to produce the typical *ground glass, orange peel* and *finger print* appearances resulting from superimposition of many fine, poorly calcified bone trabeculae arranged in a disorganized fashion
  – Continuing to become more opaque with age.
- ***Effects*** **:** –Adjacent teeth:
  * sometimes displaced but rarely resorbed
  * loss of associated lamina dura
  – Buccal and lingual alveolar expansion
  – Encroachment on, or obliteration of, the antrum
  – Involvement of adjacent bones including the base of the skull.

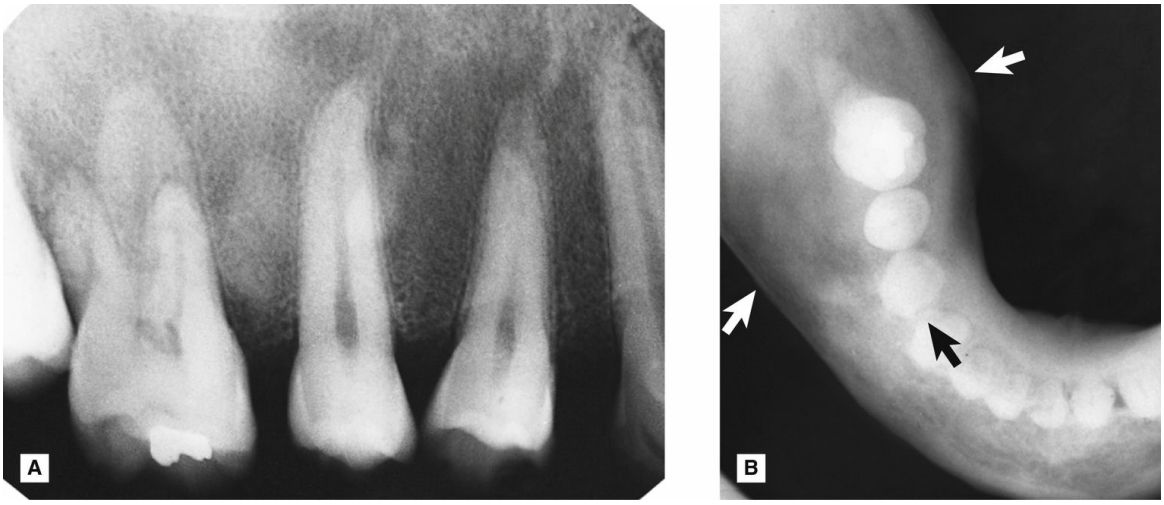


FIG. 27.15 (A) Periapical showing a mixed radiolucent/radiopaque lesion of fibrous dysplasia affecting the right maxilla, showing the overall fine opaque stippled trabecular pattern (*orange peel*), and loss of the lamina dura around 6. (B) Lower 90° occlusal centred on the right side of the mandible showing another lesion of fibrous dysplasia

demonstrating the opaque *ground glass* appearance and expansion in the molar and premolar region (arrowed).

Cemento-osseous Dysplasias

Periapical cemento-osseous dysplasia (see Fig. 27.16)

- ***Age*** **:** Middle-aged adults (typically black women).
- ***Frequency*** **:** Rare.
- ***Site*** **:** Apices of several lower incisor teeth.
- ***Size*** **:** Small, usually only up to 5–6 mm in diameter
- ***Shape*** **:** –Round, unilocular
  – Often multiple.
- ***Outline*** **:** Variable but usually poorly defined and not corticated.
- ***Radiodensity*** **:** –Early stage – radiolucent
  – Intermediate stage – radiolucent with patchy opacity within the radiolucency
  – Late stage – densely radiopaque but surrounded by a thin radiolucent line.
- ***Effects*** **:** –Adjacent teeth:
  * not displaced
  * not resorbed
  * typically vital, with intact periodontal ligament space, but lamina dura may be discontinuous
  – No expansion of the jaw.

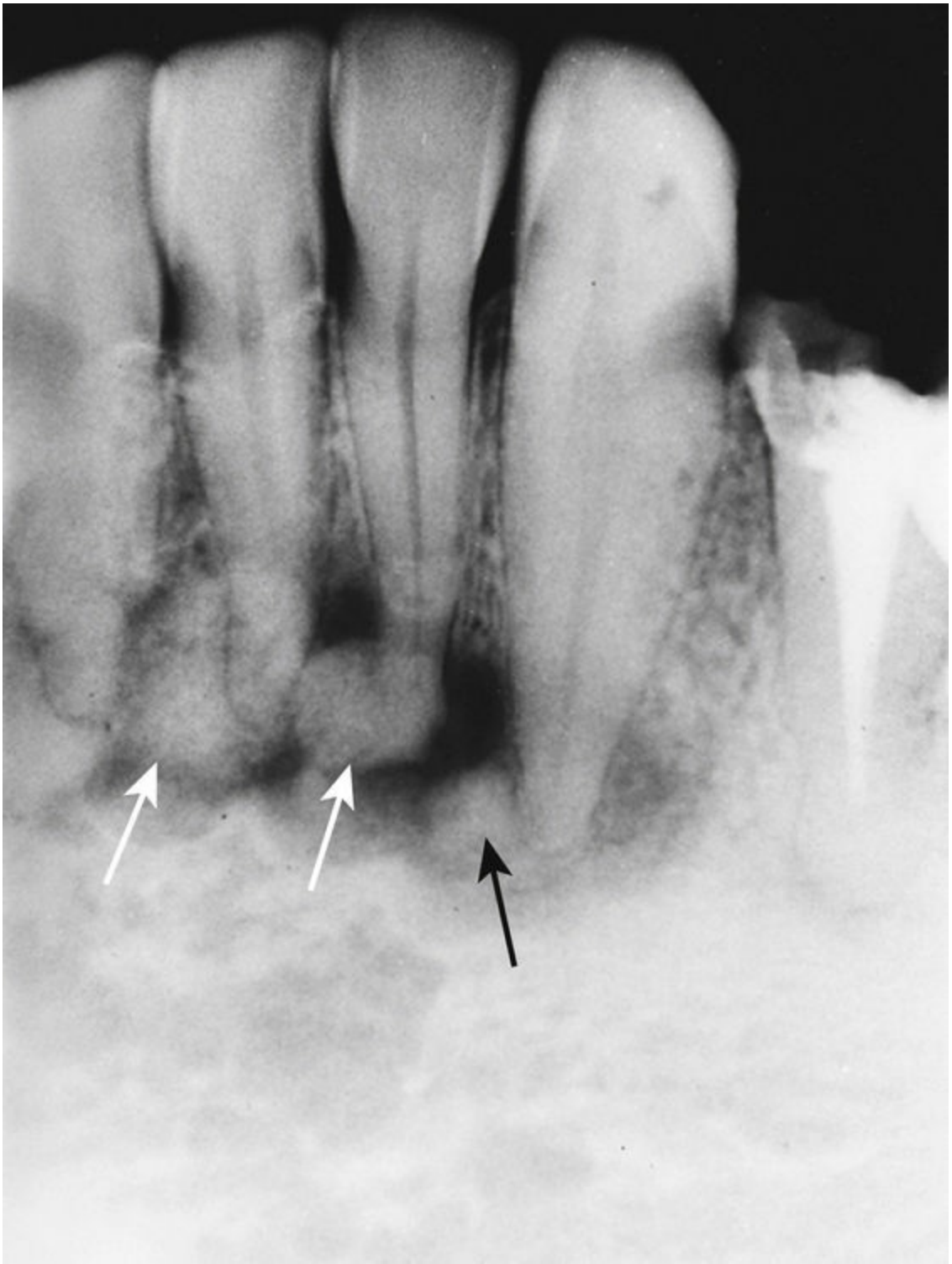


FIG. 27.16 Periapical showing the latter stage of periapical cemento–osseous dysplasia. The developing internal calcification is arrowed.

Focal cemento–osseous dysplasia (see Fig. 27.17)

This usually solitary fibrocemento-osseous lesion occupies a portion of the spectrum between the periapical and florid cemento-osseous dysplasias.

- ***Age*** **:** Adults between 40 and 50 years old (typically white women).
- ***Frequency*** **:** Uncommon.
- ***Site*** **:** Any areas of the jaws (dentulous or edentulous), but mainly posterior mandible, and often in extraction sites.
- ***Size*** **:** Small, less than 1.5 cm in diameter.
- ***Shape*** **:** Round, unilocular.
- ***Outline*** **:** –Well-defined but irregular
  – Not corticated.
- ***Radiodensity*** **:** –Early stage – radiolucent
  – Intermediate stage – radiolucent with patchy opacity within the radiolucency
  – Late stage – densely radiopaque but often surrounded by a thin radiolucent line.
- ***Effects*** **:** –Adjacent teeth:
  * not displaced
  * not resorbed
  * typically vital, with intact periodontal ligament space, but lamina dura may be discontinuous
  – No expansion of the jaw.

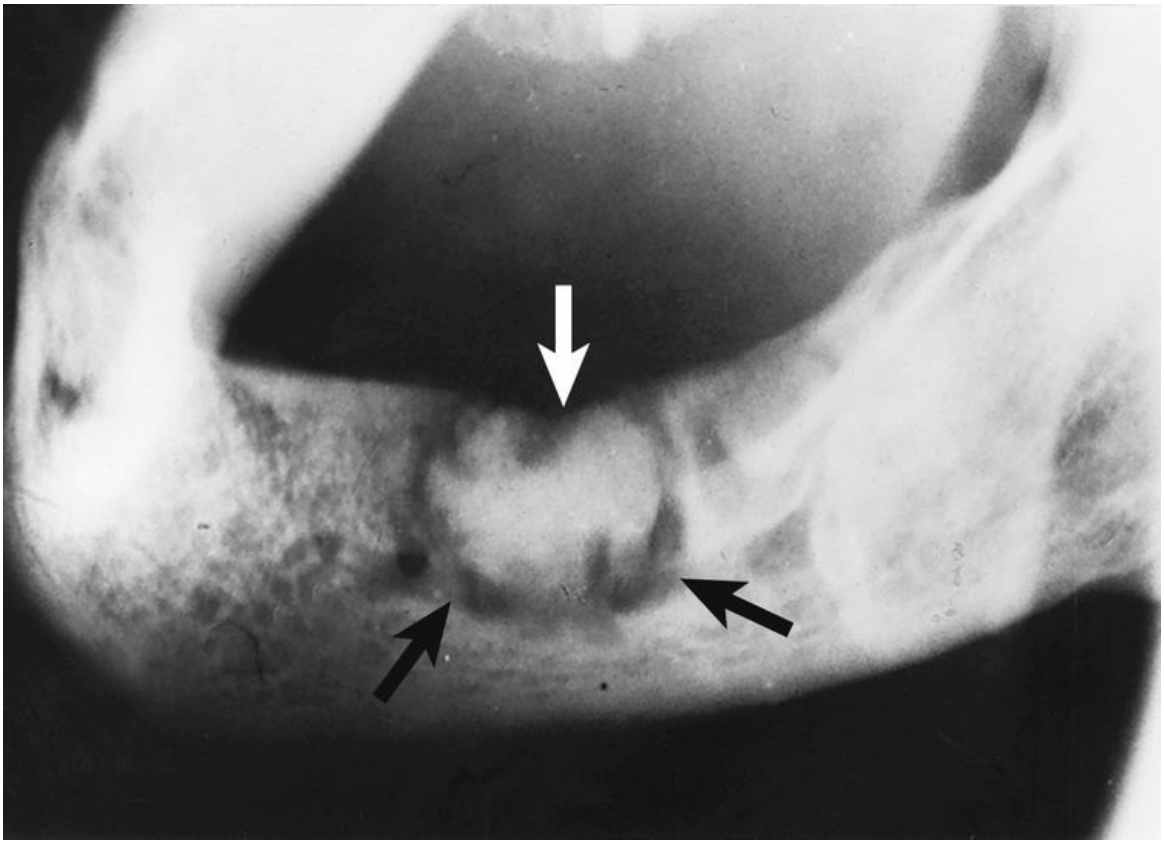


FIG. 27.17 Oblique lateral showing relatively late-stage focal cemento–osseous dysplasia in the region of the ⌊6 extraction site (arrowed). An appreciable amount of internal calcification is evident.

Florid cemento-osseous dysplasia (see Fig. 27.18)

- ***Age*** **:** Middle-aged adults (typically black women).
- ***Frequency:*** Rare.
- ***Site*** **:** Widespread, often in all four quadrants (dentulous and edentulous) but associated with the apices of the teeth if present.
- ***Size*** **:** Variable, but individual lesions up to 2–3 cm in diameter.
- ***Shape*** **:** –Multiple
  – Round, but frequently coalesce.
- ***Outline*** **:** –Smooth but lobular
  – Moderately well-defined but irregular

– Occasionally corticated.

- ***Radiodensity*** **:** –Early stage – multiple radiolucencies
  – Intermediate stage – multiple radiolucencies with gradually increasing patchy internal opacities
  – Late stage – multiple irregular dense radiopacities within individual lesions sometimes surrounded by a thin radiolucent line.
- ***Effects*** **:** –Adjacent teeth:
  * not displaced
  * not resorbed
  * typically vital
  – Occasionally may cause expansion or enlargement of the affected jaw
  – Can be associated with low grade sclerosing osteomyelitis.

Familial gigantiform cementoma

The WHO in 2017 described familial gigantiform cementoma as a rare form of fibro-osseous lesion of the jaws that is characterized by early onset of multifocal or multiquadrant, progressively expansive lesions that may be massive and cause remarkable facial deformity.

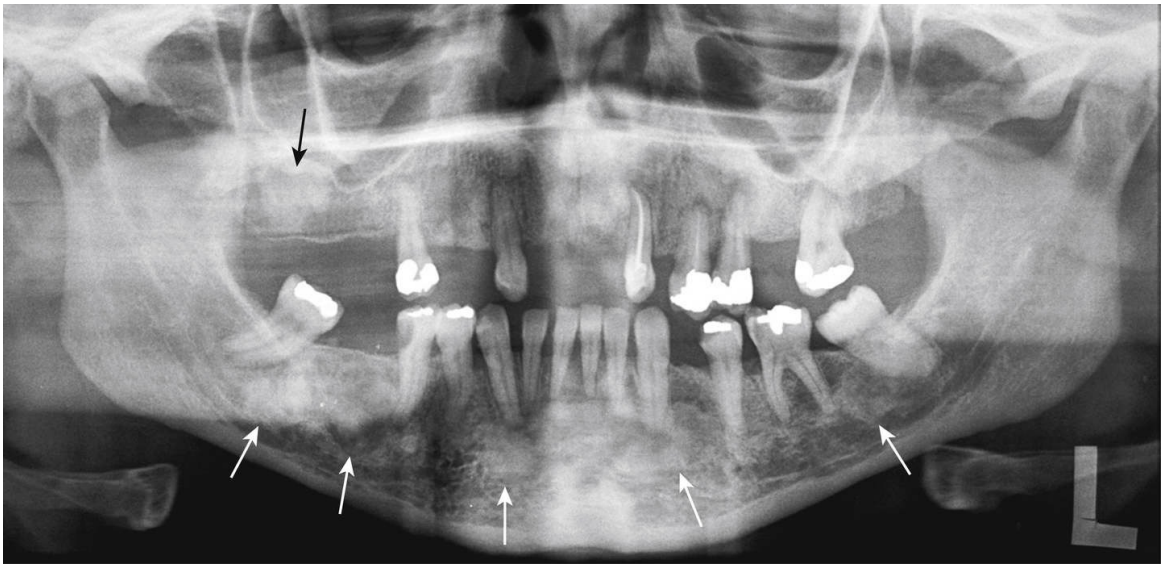


FIG. 27.18 Panoramic radiograph showing the multiple lesions (arrowed) of variable radiodensity of florid cemento–osseous dysplasia.

Other Important Bone Conditions

Paget's disease of bone and osteopetrosis, two generalized conditions that can cause an overall increase in bone radiopacity, are discussed in detail in Chapter 28 .

Summary

It is worth repeating that the radiodensity of many of the lesions mentioned in this chapter changes as they mature. During their early stages of development, there may be no evidence of internal calcification, making radiological differential diagnosis more difficult. For revision purposes, Table 27.2 summarizes the main lesions of variable radiodensity that can develop internal radiopaque calcifications and so present with mixed radiolucent/radiopaque appearances.

Typical Radiographic Features of Soft Tissue Calcifications

A variety of radiopaque calcifications within the overlying soft tissues can present radiographically. Differential diagnosis is relatively straightforward once the **site** of the opacity has been determined.

Radiopaque Salivary Calculi (see Fig. 27.19)

Submandibular salivary calculi are often radiopaque and develop within the main duct or in the gland itself (see Chapter 32). Those in the main duct can be superimposed on the alveolar bone producing an opacity apparently within the bone. Stones in the gland present

usually below the lower border of the mandible.

TABLE 27.2

Summary of the main lesions that can present with variable radiodensity by developing internal radiopaque calcifications

Cysts
Calcifying odontogenic cyst
Odontogenic tumours
Calcifying epithelial odontogenic tumour Adenomatoid odontogenic tumour Cementoblastoma Odontomes • Compound • Complex
Non-odontogenic tumours
Osteoma Chondroma Osteogenic osteosarcoma
Fibro-osseous lesions
Cemento-ossifying fibroma Fibrous dysplasia Cemento-osseous dysplasias • Periapical cemento-osseous dysplasia • Focal cemento-osseous dysplasia • Florid cemento-osseous dysplasia

Calcified Lymph Nodes (see Fig. 27.20)

Calcification of lymphoid tissue is relatively common after chronic infection (e.g. tuberculosis), especially in older patients.

- ***Nodes involved*** **:** Submandibular or cervical chain, single or multiple.
- ***Site*** **:** Behind or below the angle of the mandible.
- ***Appearance*** **:** Irregular heterogeneous opaque mass, said to

resemble a *mass of coral* .

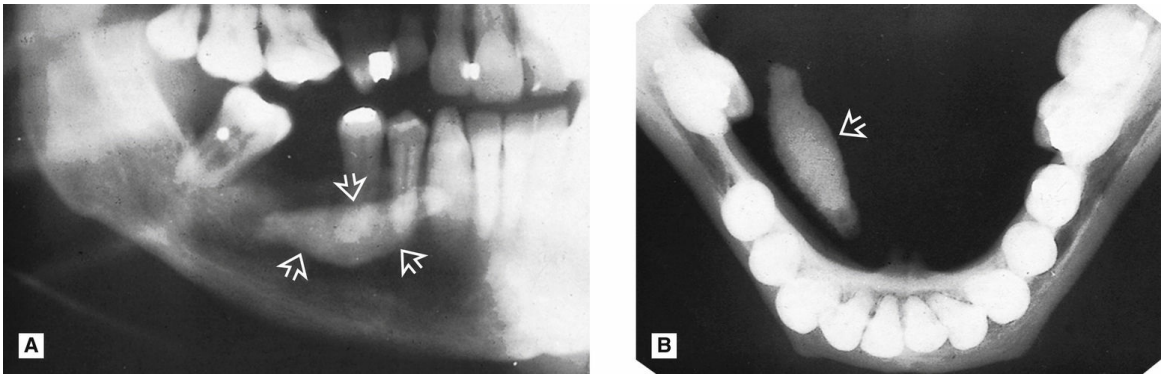


FIG. 27.19 (A) Right side of a panoramic radiograph showing a large radiopacity in the lower premolar region (arrowed). (B) Lower 90° occlusal of the same patient showing the opacity to be a large stone in the right submandibular duct.

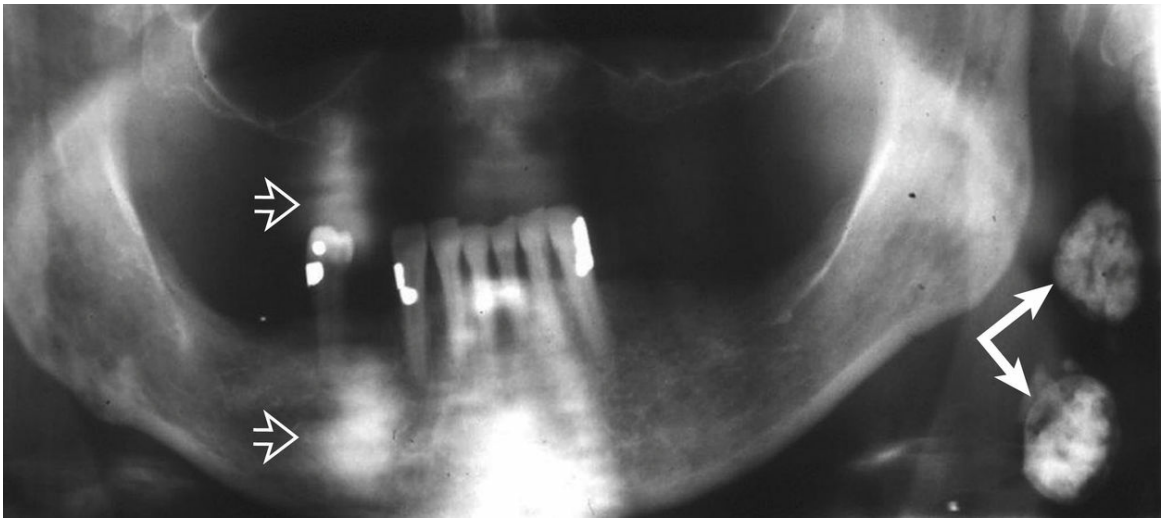


FIG. 27.20 Panoramic radiograph showing two calcified lymph nodes in the left cervical chain (solid arrows). Note also the *ghost* shadows of the lymph nodes on the right premolar/canine region (open arrows).

Calcified Tonsils (see Fig. 27.21)

Calcification of the tonsillar lymphoid tissue is sometimes seen as an incidental finding on panoramic radiographs, especially in elderly patients. Areas of calcification appear as small irregular opaque masses overlying the superior aspect of the ramus of the mandible; they are often bilateral.

Phleboliths (see Fig. 27.22)

Phleboliths are calcifications of thrombi within veins and are occasionally seen in vascular anomalies such as venous malformations.

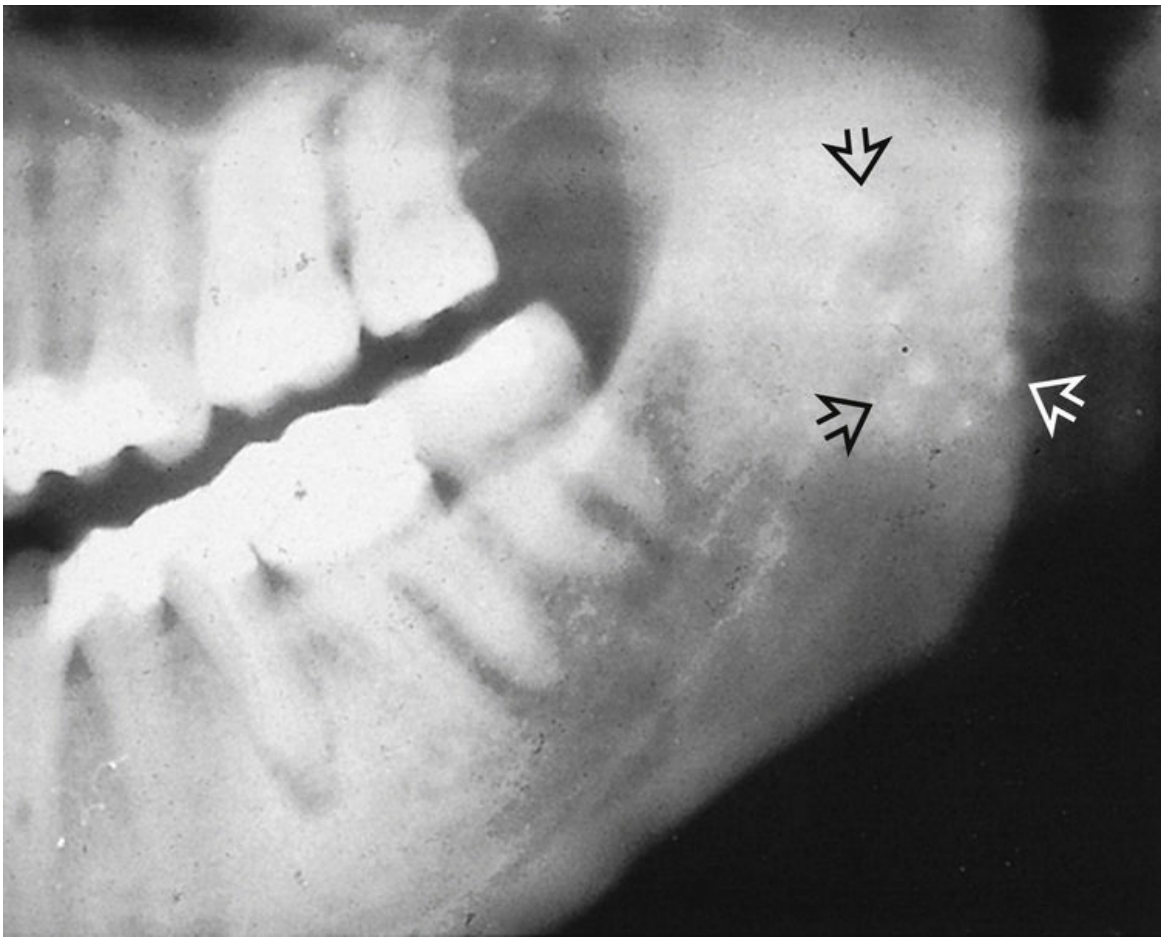


FIG. 27.21 Left side of a panoramic radiograph showing the typical appearance of tonsillar calcifications (arrowed) overlying the ramus of the mandible.

If the radiograph shows the calcified blood vessel end-on, the phlebolith has a characteristic *target* appearance – radiopaque around the periphery and radiolucent in the centre.

Calcified Acne Scars

Occasionally calcification can develop in the scars of severe acne producing multiple small radiopacities in the area involved. If acne calcification is suspected radiographically, the diagnosis can be confirmed by clinical examination.

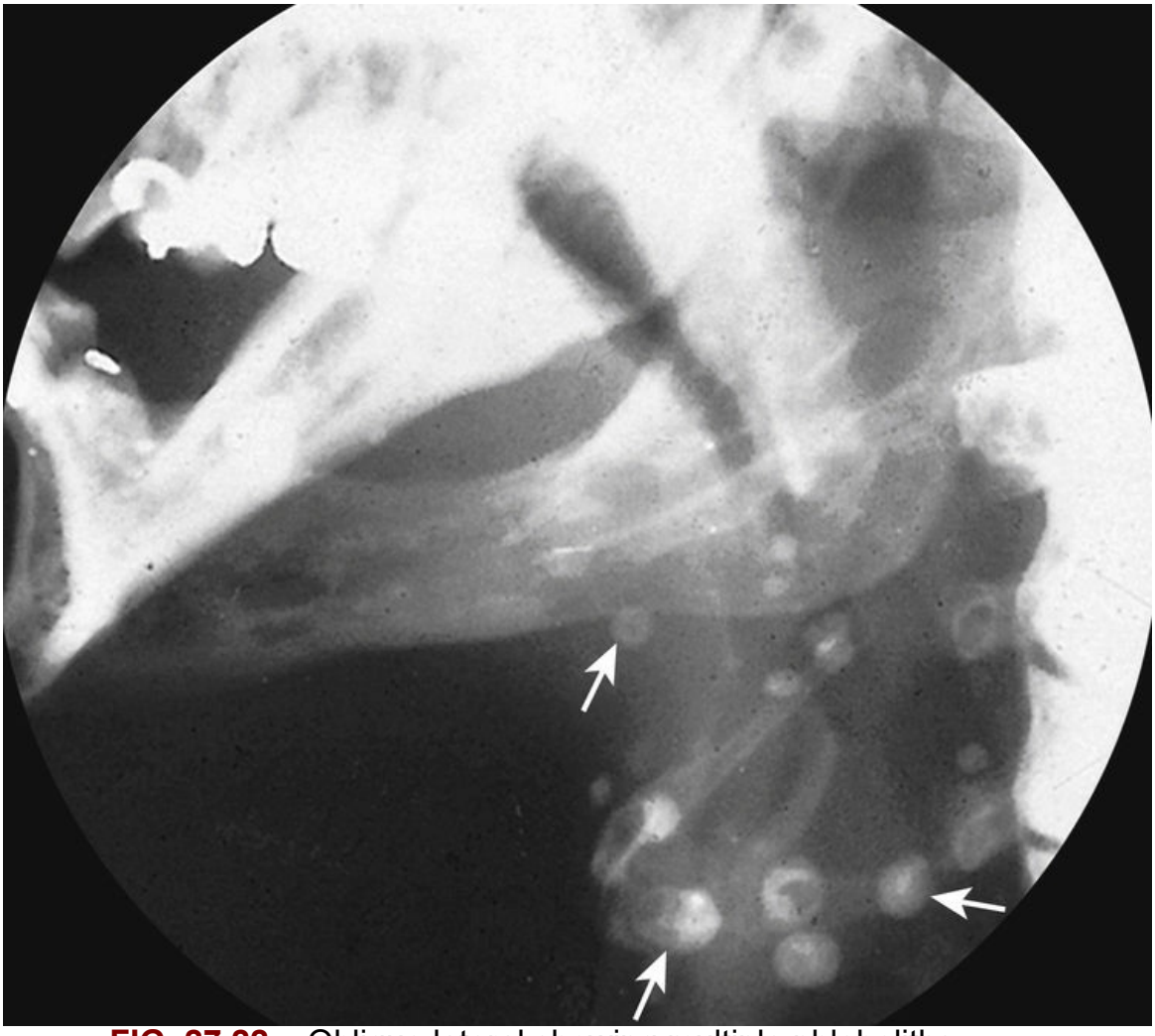


FIG. 27.22 Oblique lateral showing multiple phleboliths (arrowed) associated with a venous malformation. Note the typical *target* appearance of some of the calcifications.

Typical Radiographic Features of Foreign Bodies

A variety of foreign bodies can produce radiopacities. The appearance depends obviously on the nature of the foreign body, its density and its location. Fig. 27.23 shows a selection of foreign bodies.

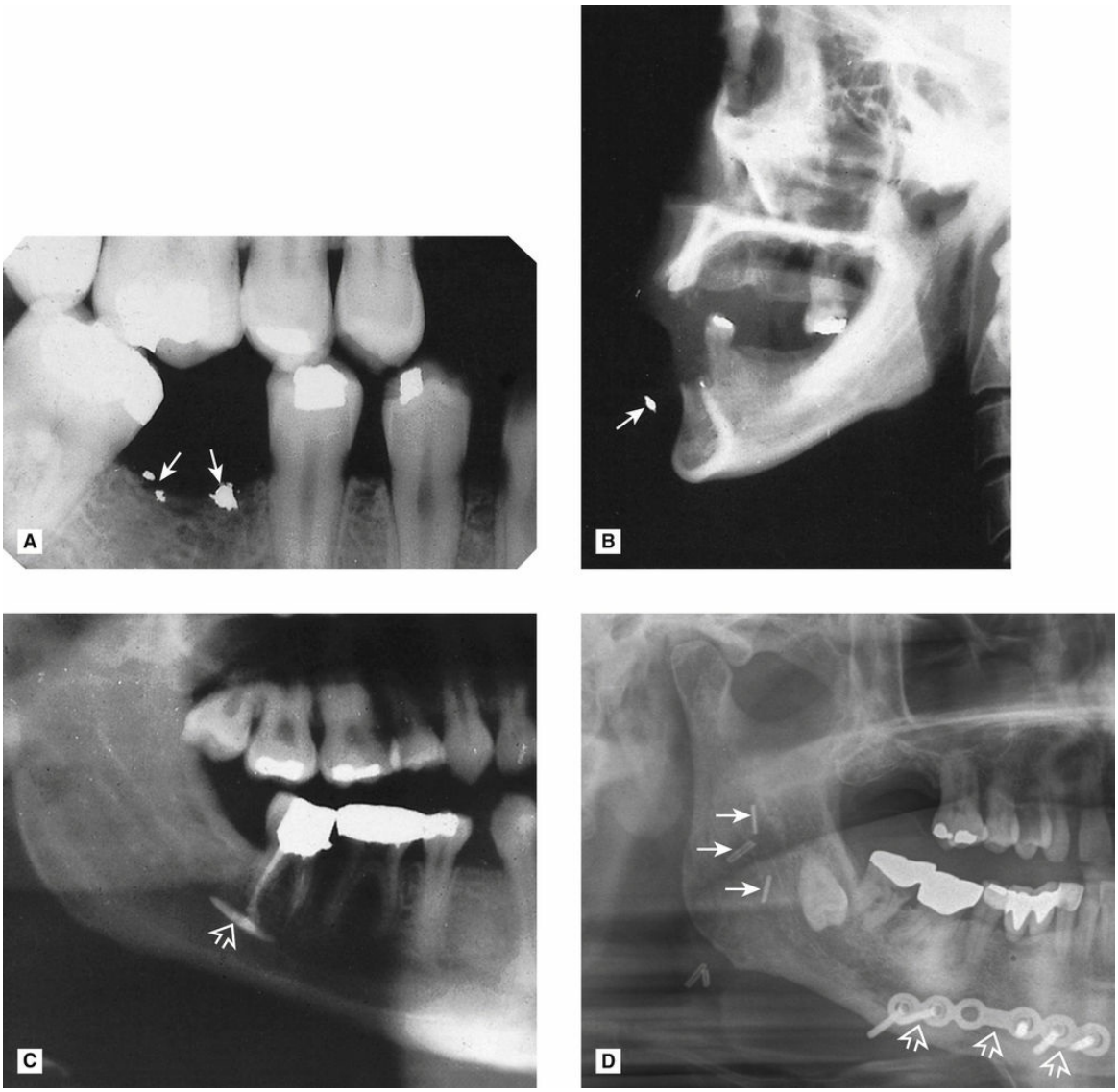


FIG. 27.23 (A) Bitewing showing amalgam remnants (arrowed), dislodged and left behind after an extraction. If evident clinically, they are referred to as *amalgam tattoos.* (B) True lateral skull showing a radiopaque foreign body (arrowed) in the lower lip. (C) Right side of a panoramic radiograph showing radiopaque root canal sealant (arrowed) in the inferior dental canal. (D) Right side of a panoramic radiograph showing radiopaque vascular clips (arrowed) and a bone plate (open arrows).

To access the self-assessment questions for this chapter, please go to http://evolve.elsevier.com/Whaites/essentials/

28

Bone Diseases of Radiological Importance

Introduction

There are many diseases and abnormalities of bone. Some are localized to the jaws while others can affect the whole skeleton. It is beyond the scope of this book to consider them all. This chapter summarizes a somewhat diverse, but important, group of bone conditions that can affect the facial skeleton and are of radiological importance.

Unfortunately, several of the bone diseases described, although totally different in nature, can present very similar appearances radiographically. To differentiate them, clinicians need to consider all relevant factors, including the age of the patient, the distribution of the disease (whether it is generalized or localized) and which bones are involved, as well as noting the specific radiographic features.

Using the *atlas* approach adopted in Chapter 24 , an example of each of the conditions is shown together with a summary of the main radiographic features seen in the skull and facial skeleton. It is worth remembering that bone is a constantly changing, dynamic tissue. Thus, diseases of bone can present a spectrum of radiographic appearances depending on the behaviour and maturity or stage of the disease and/or lesion(s). The examples shown represent only a small part of that spectrum.

The diseases of bone described include:

- Developmental or genetic disorders
  - Cleidocranial dysplasia

  - Osteopetrosis
- Infective or inflammatory conditions
  - Osteomyelitis
  - Osteoradionecrosis
  - Medication-related osteonecrosis of the jaw
- Hormone-related disorders
  - Hyperparathyroidism
  - Acromegaly
- Blood dyscrasias
  - Sickle cell anaemia
  - Thalassaemia
- Diseases of unknown cause
  - Fibrous dysplasia
  - Paget's disease of bone.

Developmental or Genetic Disorders

Cleidocranial Dysplasia (see Fig. 28.1)

Cleidocranial dysplasia is a rare developmental disturbance affecting the skull and clavicles. The abnormalities of dentition can be gross but usually affect only the permanent teeth. Examples are delayed eruption and multiple supernumeraries.

Main Radiographic Features

These can include:

- Aplasia or hypoplasia of the clavicles
- Evidence in the skull vault of:
  - A widened cranium
  - Delayed ossification of the fontanelles
  - A large number of wormian bones
  - Frontal and occipital bossing
  - Basilar invagination
- Evidence in the jaws of:

– Small, underdeveloped maxillae
– Delayed eruption of many permanent teeth, sometimes with associated cyst formation
– Multiple supernumerary teeth.

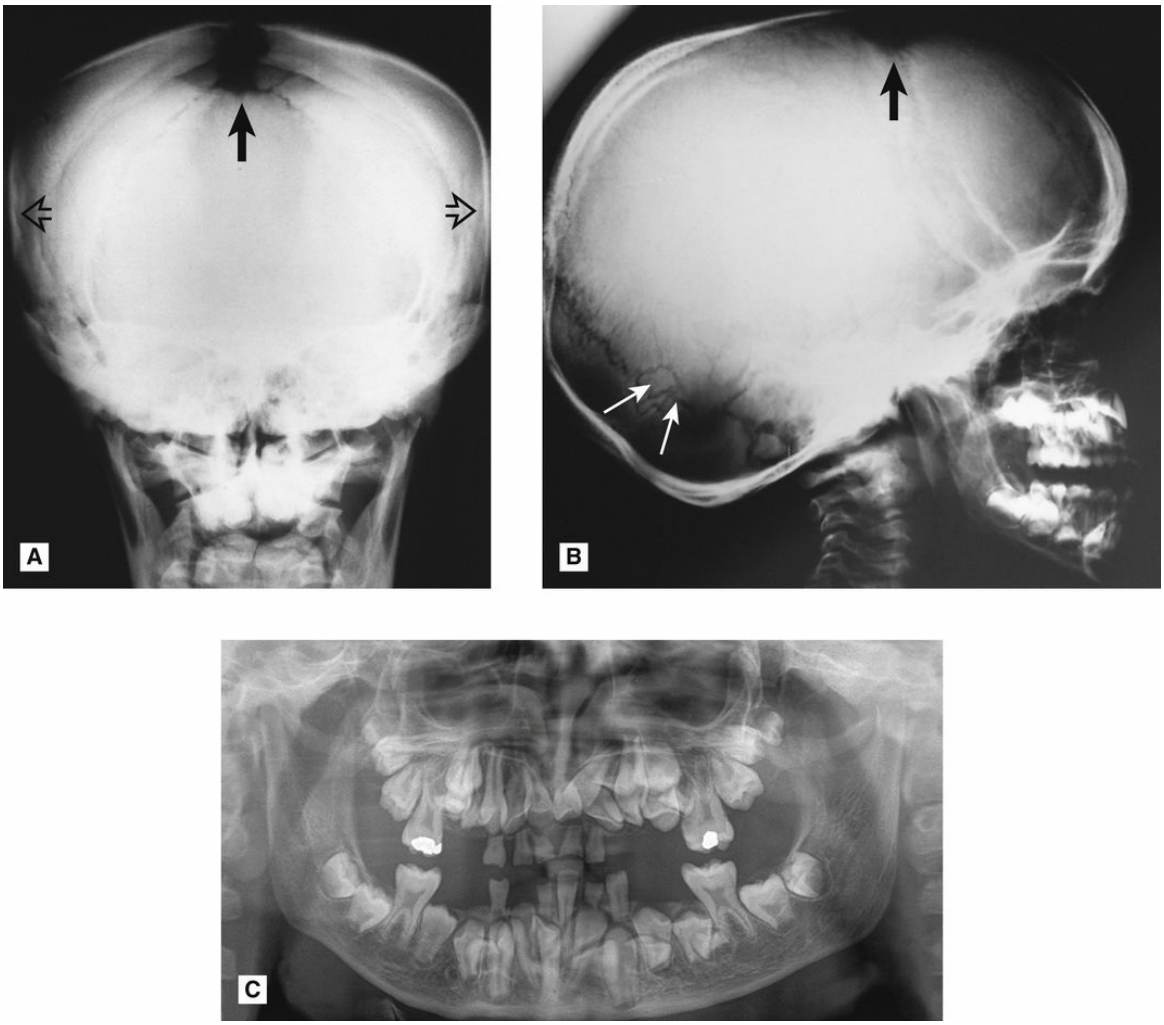


FIG. 28.1 Cleidocranial dysplasia. **(A)** PA skull showing the cranial features of widened cranium (open arrows) and open fontanelle (solid arrow). **(B)** True lateral skull of another patient also showing the open fontanelle (black arrow) and also small wormian bones (white arrows). The enlargement of the occiput is also obvious. **(C)** Panoramic radiograph showing the dental anomalies of delayed eruption and multiple supernumerary teeth in a 12-year-old child.

Osteopetrosis (Albers–Schönberg Disease) (see Fig. 28.2)

This hereditary disease is characterized by sclerosis of the skeleton (so-called *marble bones*), fragile bones and secondary anaemia. Bone formation is normal, but bone resorption is reduced, resulting in the

presence of excessive calcified tissue and a lack of marrow space. Cranial-base changes may produce compression of the cranial nerves.

Main Radiographic Features

These can include:

- Evidence in the skull of:
  - A uniformly dense and radiopaque skull vault
  - Loss of the normal skull markings and structure
  - Gross thickening and increased opacity of the cranial base with narrowing of the foramina
- Occasional involvement of the jaws. This involvement is always bilateral and includes:
  - Thickening of the lamina dura around the teeth in the early stages (an almost pathognomonic finding in adults)
  - Gradual thickening of the trabeculae and a decrease in the size of the marrow spaces, producing an overall increase in bone density
  - Usually normal teeth, but they may be deformed.

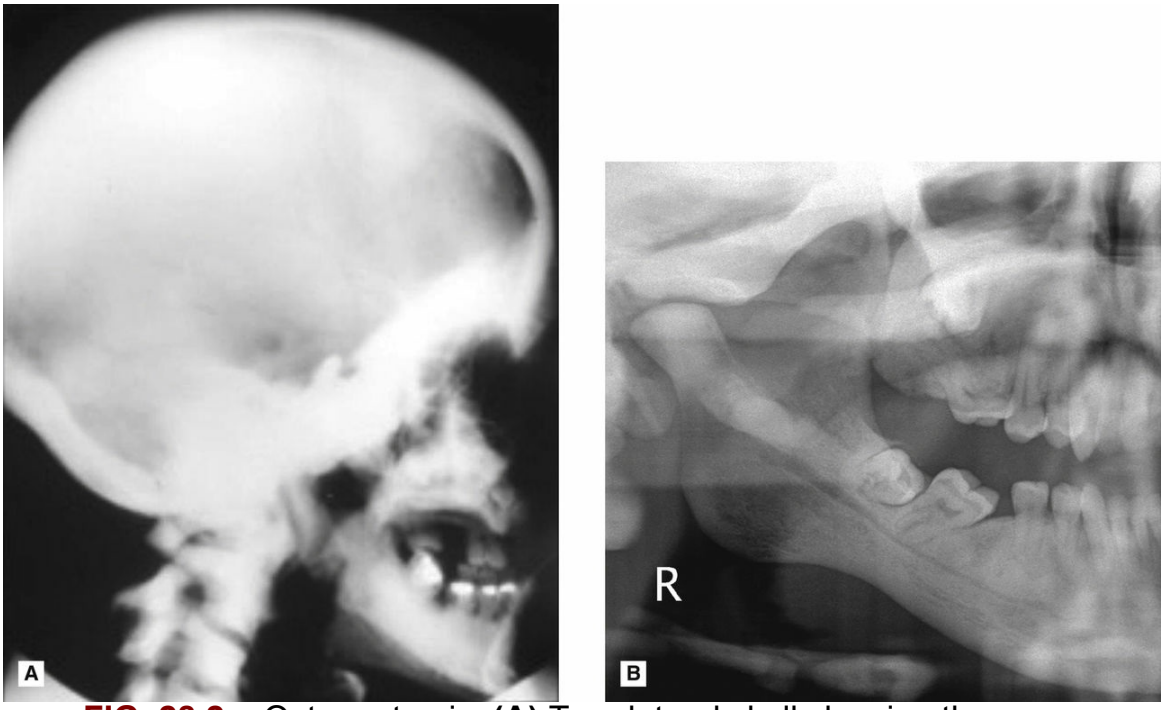


FIG. 28.2 Osteopetrosis. **(A)** True lateral skull showing the cranial features of radiopaque, dense vault and thickened base. **(B)** Right side of a panoramic radiograph showing loss of the normal trabecular pattern and replacement with dense thickened bone.

Infective or Inflammatory Conditions

Osteomyelitis (see Figs. 28.3 and 28.4)

Osteomyelitis is a spreading, progressive inflammation of bone and bone marrow that more frequently affects the mandible than the maxilla. It is caused usually by local factors such as periapical infection, pericoronitis, acute periodontal lesions, extractions or trauma. The inflammatory response may be acute or chronic depending on the virulence of the infecting organism and the resistance of the patient. It results ultimately in the destruction of the infected bone. The reaction of the surrounding bone and periosteum is very variable and often age related. There may be surrounding sclerosis of the bone forming poorly defined patchy opacity. Sequestra (small pieces of necrotic bone) can be exfoliated over a period of

several weeks. The periosteum around the affected area can lay down new bone (the so-called periosteal reaction). In children, this reaction can be pronounced and is described as *proliferative periostitis* . This typically affects the mandible in young girls, after apical or pericoronal infection associated with the lower first molar producing a nontender, bony, hard swelling of the lower border. Radiographically the proliferative periostitis results in a laminated, so-called *onion-skin* , appearance (see Fig. 28.5).

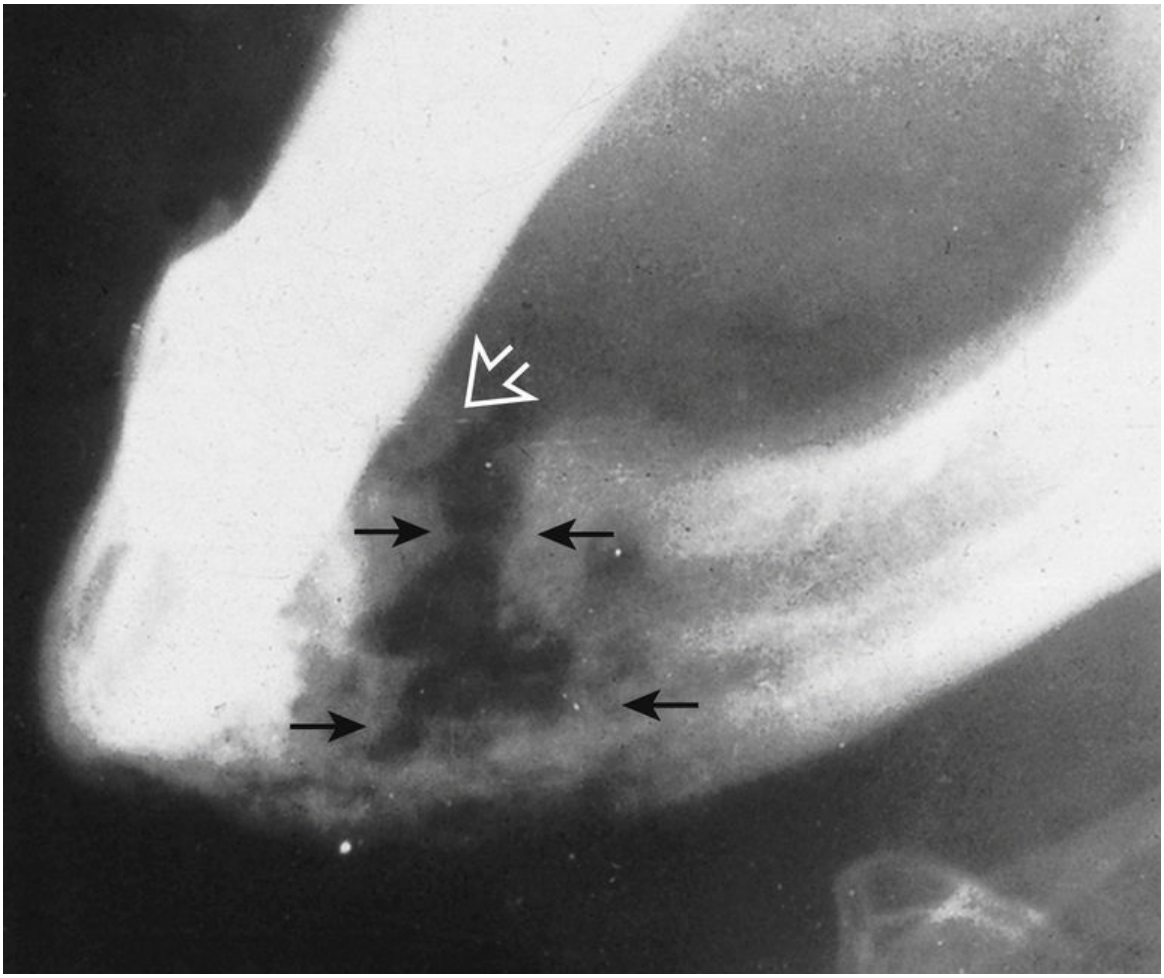


FIG. 28.3 Osteomyelitis. Oblique lateral of the mandible showing typical ragged or *moth-eaten* radiolucent areas of bone destruction (solid arrows) and a sequestrum of dead bone (open arrow).

Main Radiographic Features of Acute Osteomyelitis

These can include:

- Ragged, patchy or *moth-eaten* areas of radiolucency – the outline of the area of destruction is irregular and poorly defined
- Evidence of small radiopaque sequestra of dead bone occasionally within the radiolucency
- Evidence of new subperiosteal bone formation, usually beyond the area of necrosis, particularly along the lower border of the mandible.

Main Radiographic Features of Chronic Osteomyelitis

These can include:

- Localized patchy or *moth-eaten* areas of bone destruction
- Sclerosis of the surrounding bone
- Evidence of small radiopaque sequestra of dead bone sometimes within the area of bone destruction
- Evidence of an involucrum surrounding the area of destruction following extensive subperiosteal bone formation.

NOTE: The radiographic appearance of osteomyelitis varies considerably depending on the type of underlying inflammatory response and the age of the patient.

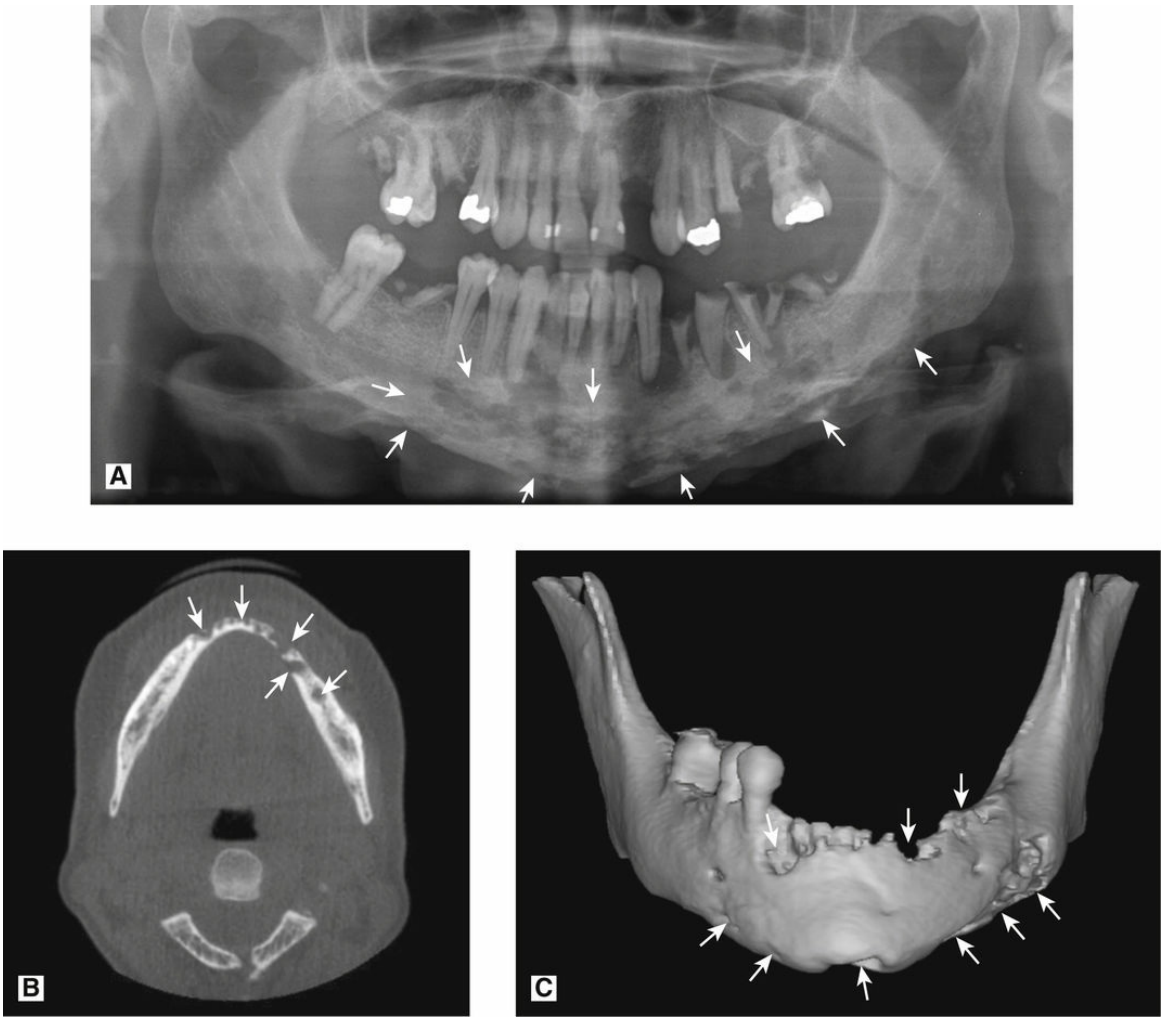


FIG. 28.4 Osteomyelitis. **(A)** Panoramic radiograph showing extensive destruction of the anterior and left side of the mandible (arrowed). **(B)** Axial CBCT scan showing the bone destruction. **(C)** A 3-D surface-rendered CBCT scan showing the destruction of the buccal cortex (arrowed).

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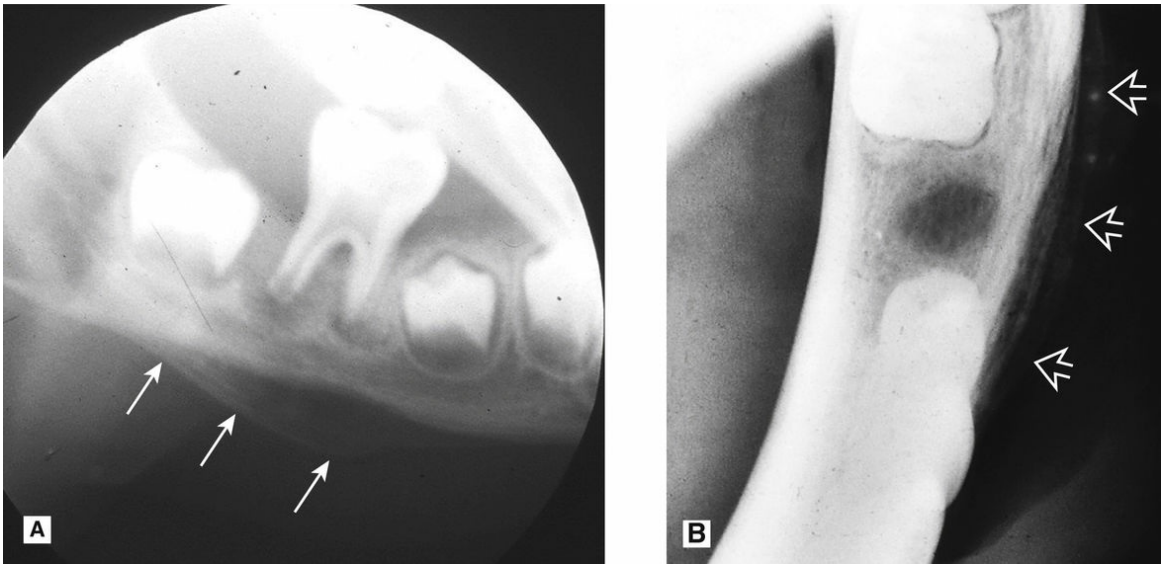


FIG. 28.5 **(A)** Proliferative periostitis. Oblique lateral of a 9-year-old girl showing bone destruction around the first molar and the *onion-skin* layering periosteal reaction affecting the lower border (arrowed). **(B)** Part of a lower occlusal showing another example of *onion-skin* layering periosteal new bone formation.

Osteoradionecrosis (see Fig. 28.6)

The high doses of radiation used in radiotherapy reduce drastically the vascularity and reparative powers of bone. The mandible is particularly susceptible. Subsequent trauma (e.g. tooth extraction) or infection may produce osteomyelitis with rapid destruction of the irradiated bone, sequestra formation and poor healing. Radiographically, osteoradionecrosis resembles other types of osteomyelitis, although the border between necrotic and normal bone may be more sharply defined and subperiosteal new bone formation is not usually evident. A history of radiotherapy enables the differential diagnosis to be made.

Main Radiographic Features

These can include:

- Ragged, patchy or *moth-eaten* radiolucent areas of bone destruction
- Occasional evidence of radiopaque sequestra of dead bone
- Little evidence of healing.

Medication-related Osteonecrosis of the Jaw (MRONJ) (see Fig. 28.7)

Medication-related osteonecrosis of the jaw is an avascular necrosis in patients who are currently being, or have previously been, treated with antiresorptive or antiangiogenic agents. In addition, for medication-related osteonecrosis of the jaw to be diagnosed the American Association of Oral and Maxillofacial Surgeons also stipulate that patients present with exposed bone or necrotic bone that can be probed through an intraoral or extraoral fistula in the maxillofacial region that has persisted for more than 8 weeks and where there is no history of radiotherapy to the jaws or obvious metastatic disease to the jaws.

Main Radiographic Features

These can include:

- Diffuse sclerosis of the bone
- Thickening of the lamina dura
- Loss of alveolar bone not attributable to periodontal disease
- Poor or no healing or dense bone at extraction sites
- Irregularity of the cortical bone
- Ill-defined radiolucency with sequestra of bone
- Periosteal reaction
- Pathological fracture in late stages.

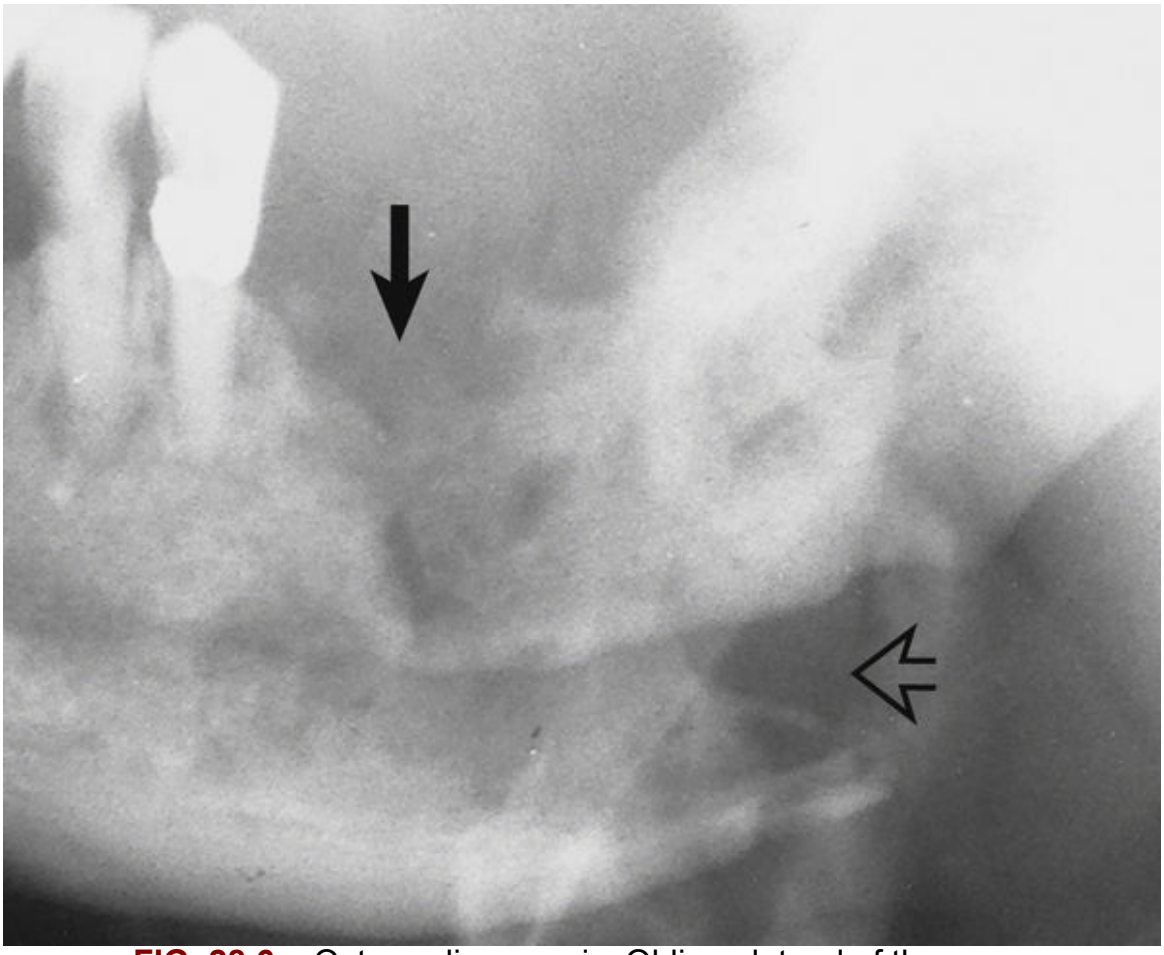


FIG. 28.6 Osteoradionecrosis. Oblique lateral of the mandible following the extraction of $\overline{6}$, showing the typical destructive appearance (solid arrow), which has resulted in a pathological fracture (open arrow). Radiotherapy had been given several years previously.

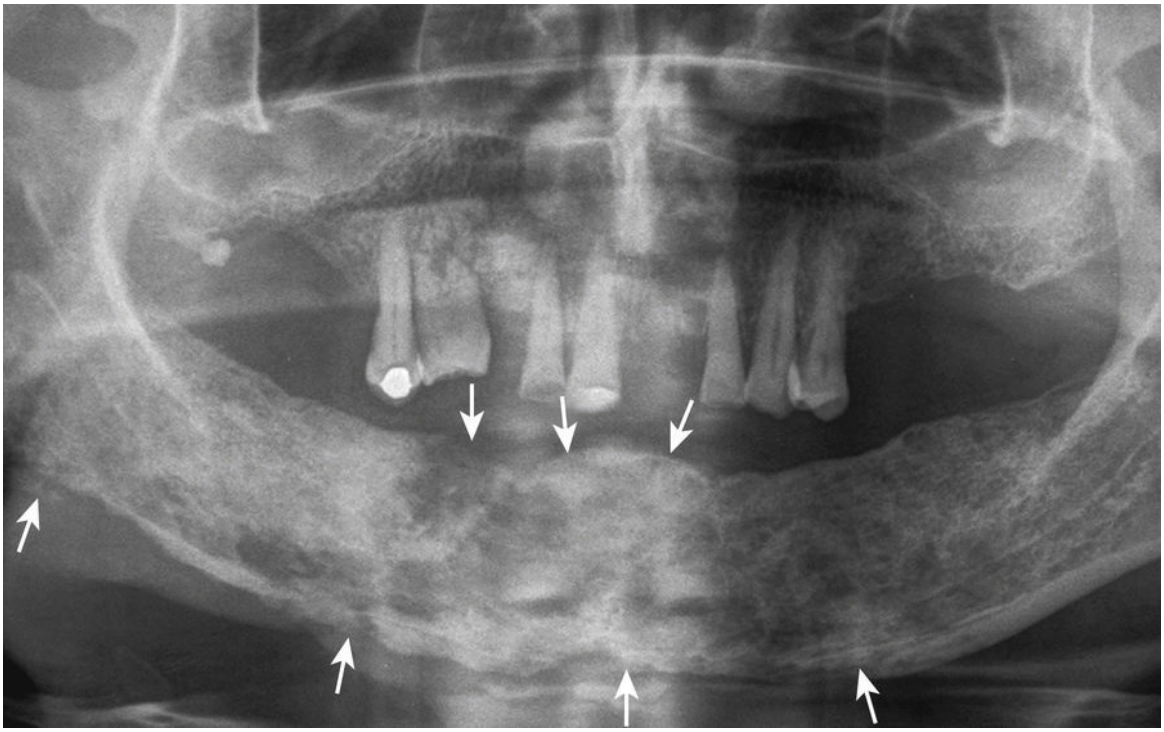


FIG. 28.7 Panoramic radiograph showing extensive medication-related osteonecrosis of the jaw (MRONJ) affecting the mandible. There is an ill-defined radiolucency of the anterior mandible, with destruction of the cortex that extends from the right angle to the left body of the mandible (arrowed). There is also some sclerosis of the right body of the mandible.

Hormone-Related Diseases

Hyperparathyroidism (see Fig. 28.8)

Primary hyperparathyroidism, caused by either hyperplasia or an adenoma of the parathyroids, or secondary hyperparathyroidism caused by kidney disease, results in increased secretion of parathormone. This causes generalized skeletal bone resorption leading to osteopenia (generalized decrease in bone density), bone pain or even pathological fracture and increases the plasma calcium levels. Localized cyst-like central giant cell granulomas (historically referred to as *brown tumours*) can also develop in the jaws and long

bones. The term *osteitis fibrosa cystica* is used to describe severe chronic skeletal hyperparathyroidism after brown tumour degeneration and fibrosis.

Main Radiographic Features

These can include:

- Evidence in the skull vault of osteopenia producing a fine overall stippled pattern to the bone – hence the description *pepper-pot* skull
- Evidence in the jaws of:
  - Osteopenia (in mandible and maxilla) producing a very fine trabecular pattern, often described as *ground glass*
  - Loss of the lamina dura surrounding all the teeth and thinning or loss of the normal thick cortical bone of the lower border of the mandible
  - Occasional localized radiolucent cyst-like central giant cell granulomas (see Chapter 26)
  - Usually normal teeth.

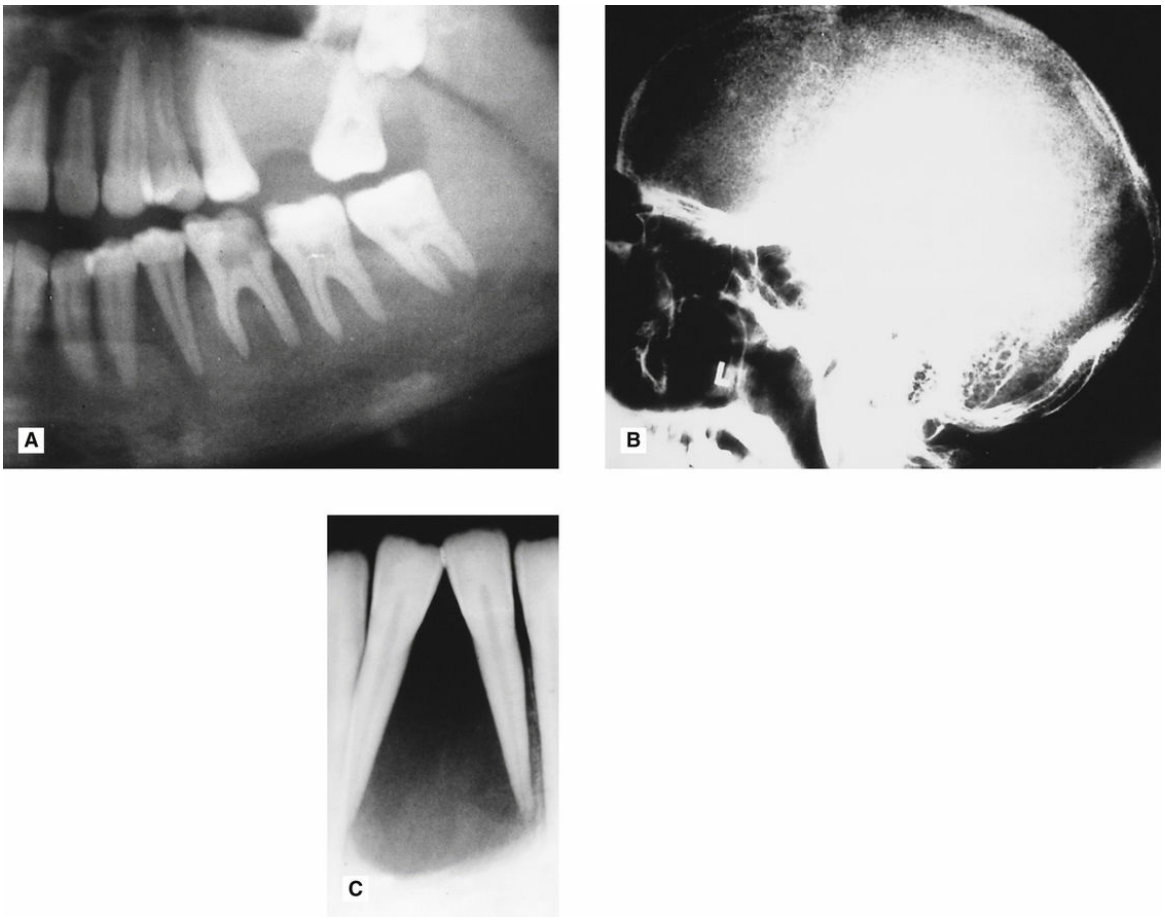


FIG. 28.8 Hyperparathyroidism. **(A)** Left side of a panoramic radiograph showing the typical bone changes including loss of the lamina dura, fine *ground glass* trabecular pattern and thinning of the cortical bone of the lower border and inferior dental canal. **(B)** True lateral skull showing the *pepper-pot* appearance in the skull vault. **(C)** Periapical showing a radiolucent central giant cell granuloma (*brown tumour*) between the lower incisors, which have been displaced but not apparently resorbed.

Acromegaly (see Fig. 28.9)

Acromegaly is a disturbance of bone growth caused by hypersecretion of growth hormone (GH) usually as the result of a pituitary adenoma developing after puberty. Characteristic features include renewed growth of certain bones, particularly the jaws, hands and feet, and overgrowth of some soft tissues.

Main Radiographic Features

These can include:

- Evidence in the skull of:
  - Thickening of the bones of the skull vault, which become enlarged and deformed
  - Enlargement and distortion of the pituitary fossa
- Evidence in the jaws of:
  - Enlargement of the mandible – the length of the horizontal and ascending rami are both increased, causing it to become prognathic with an increased obliquity of the angle and with loss of the antegonial notch
  - The body of the mandible may also be bent or bowed downwards anterior to the angle
  - Enlargement of the inferior dental canal
  - Thickening and enlargement of the alveolar bone with spacing and fanning out of the teeth, particularly anteriorly, resulting in an open bite.

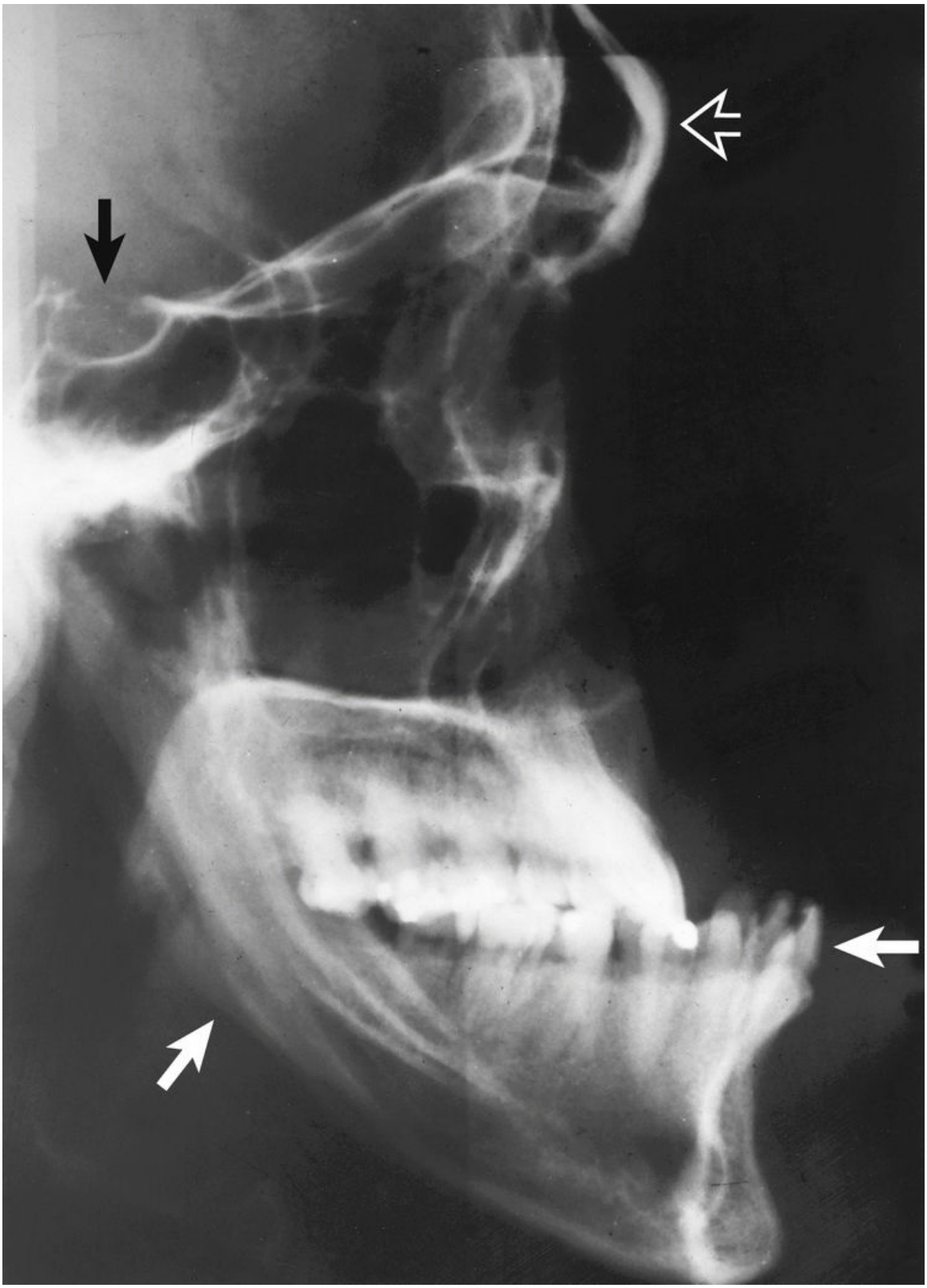


FIG. 28.9 Acromegaly. True lateral skull showing frontal bossing (open white arrow), enlarged pituitary fossa (black

arrow), grossly enlarged and prognathic mandible with increased obliquity of the angle (solid white arrows).

Blood Dyscrasias

Sickle Cell Anaemia (see Fig. 28.10)

This hereditary, chronic, haemolytic blood disorder affects principally black populations. It is characterized by abnormal haemoglobin, which results in fragile erythrocytes that become sickle shaped under conditions of hypoxia. These abnormal red blood cells have a decreased capacity to carry oxygen and are destroyed rapidly, producing anaemia.

In homozygotes, the radiographic changes reflect the haemopoietic system's response to the anaemia, including:

- Increased production of red blood cells and hyperplasia of the bone marrow at the expense of the cancellous bone
- Bone infarcts.

Main Radiographic Features

These can include:

- Evidence in the skull vault of:
  - Thickening of the frontal and parietal bones
  - Widening of the diploic space
  - Thinning of the inner and outer tables
  - Generalized osteoporosis
  - The *hair-on-end* appearance (rare)
- Evidence in the jaws of:
  - A generalized coarse trabecular pattern; fewer trabeculae are evident and the spaces between them seems to be larger
  - The remaining trabeculae between the roots of the

teeth can become aligned horizontally to produce a *step ladder* appearance
– Enlargement of the maxillae, with protrusion and separation of the upper anterior teeth
– Osteosclerotic areas resulting from the infarcts
– Usually normal teeth with normal lamina dura.

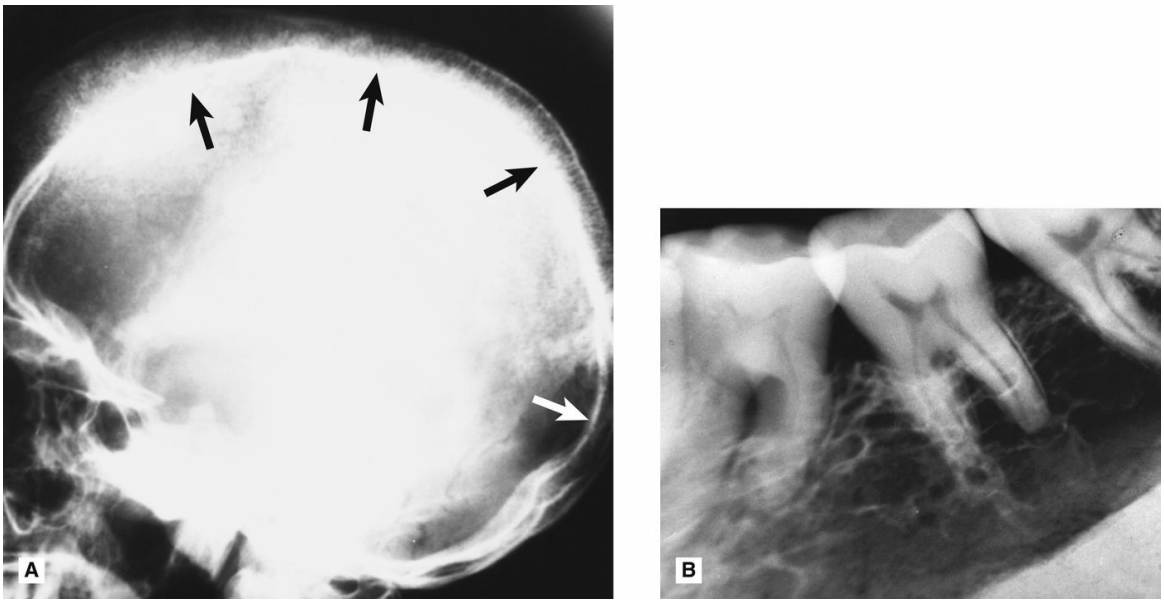


FIG. 28.10 Sickle cell anaemia. **(A)** True lateral skull showing widening of the diploic space and thinning of the inner and outer tables and early *hair-on-end* appearance anteriorly (arrowed). **(B)** Periapical showing the generalized coarse trabecular pattern in the mandible.

Thalassaemia (Cooley's Anaemia) (see Fig. 28.11)

Thalassaemia is a hereditary haemoglobinopathy characterized by chronic haemolytic anaemia and mainly affects people from the Mediterranean area. The defect lies in an inability to make enough normal globin chains, thus creating abnormal red blood cells, which have a shortened life expectancy. Again, the radiographic features result from the bone marrow proliferation required to produce more red blood cells with subsequent remodelling of all affected bones.

Main Radiographic Features

These can include:

- Evidence in the skull vault of:
  - Widening of the diploic space
  - Thinning of the inner and outer tables
  - Remodelling of the trabeculae to give sparse lines, which may radiate outwards from the inner table producing the *hair-on-end* appearance
- Evidence in the jaws of:
  - Generalized coarse trabecular pattern with very large marrow spaces
  - Expansion, which may lead to encroachment on, and subsequent obliteration of, the maxillary antra
  - Thinning of all cortical structures, most noticeably the lower border of the mandible
  - Apparent spike-shaped or shortened tooth roots
  - No evidence of bone infarcts.

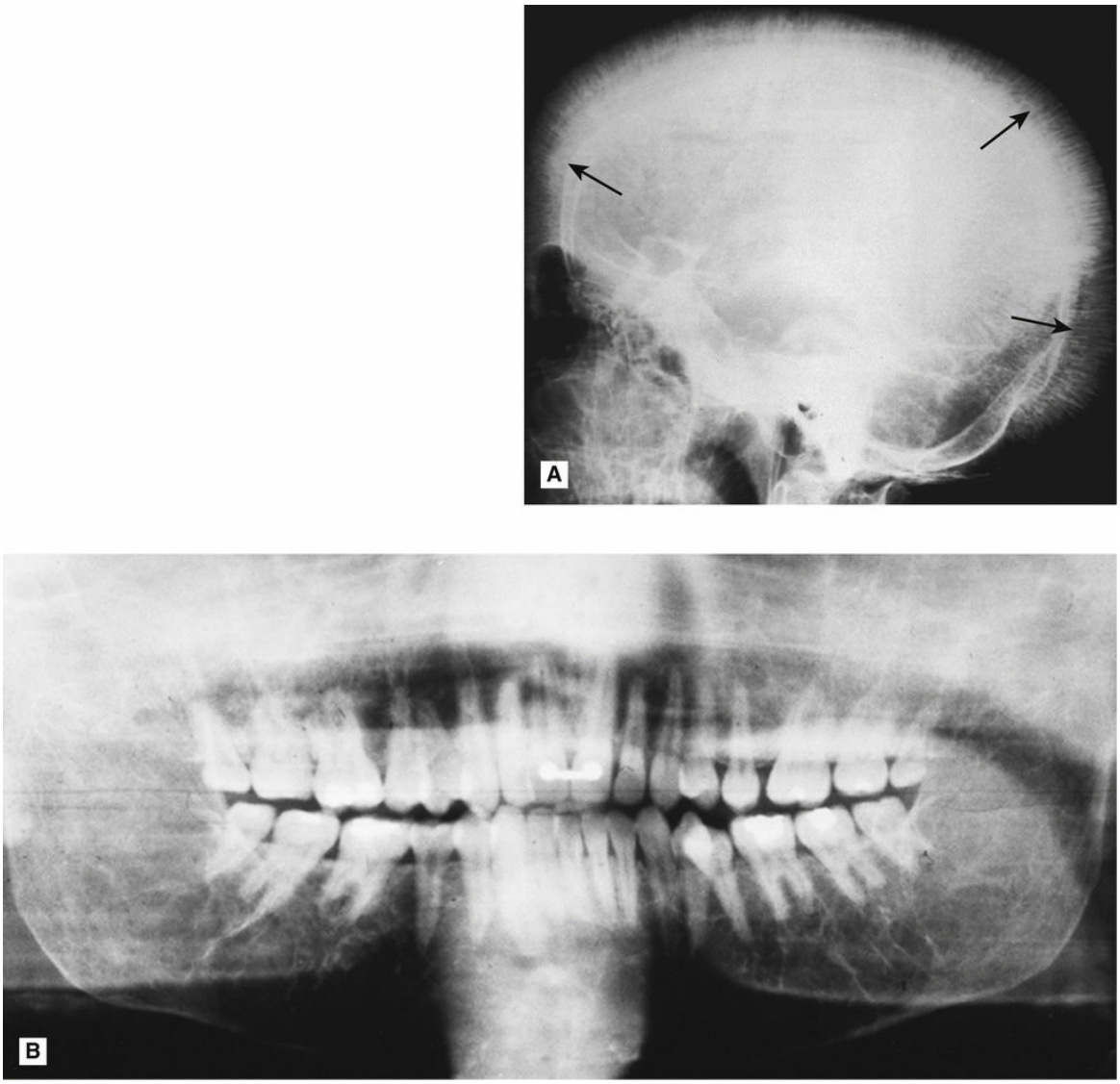


FIG. 28.11 Thalassaemia. **(A)** True lateral skull showing pronounced *hair-on-end* appearance (black arrows) and involvement of the maxilla with obliteration of the antra. **(B)** Panoramic radiograph showing the altered trabecular pattern throughout the mandible and maxilla with very large marrow spaces, obliteration of the antra and thinning of the lower border cortex.
Courtesy of Mrs J.E. Brown.

Diseases of Unknown Cause

Fibrous Dysplasia (see Fig. 28.12)

As mentioned in Chapters 26 and 27 , fibrous dysplasia was classified by the World Health Organization in 2017 as a fibro-osseous skeletal anomaly in which normal bone is replaced and distorted by poorly organized and inadequately mineralized immature bone and fibrous tissue. It may involve a single bone or multiple bones. It usually develops in childhood and is manifest before the age of ten. Clinical varieties include:

- *Monostotic fibrous dysplasia* , characterized by a lesion affecting a single bone, including the jaws, particularly the posterior part of the maxilla.
- *Polystotic fibrous dysplasia* , characterized by multiple bone lesions and subdivided into:
  - *Jaffe type* , with skin pigmentation but without endocrine disturbances
  - *McCune–Albright syndrome* , with endocrine disturbances and skin pigmentation.

Main Radiographic Features of Monostotic Fibrous Dysplasia Affecting the Jaws

- A localized rounded zone of relative radiolucency containing a variety of fine trabecular patterns, described as *ground glass* , *fingerprint* and *orange peel.* The more mature the lesion the more radiopaque it appears
- Poor definition of the edge of the lesion, which merges imperceptibly with the surrounding normal bone (see Fig. 26.28).
- Loss of the lamina dura with thinning of the periodontal ligament shadow
- Enlargement of the affected bone
- In the maxilla encroachment on, or obliteration of, the antrum and spread into particularly the zygoma and sphenoid bones of the cranial base
- Associated teeth occasionally displaced, but rarely resorbed.

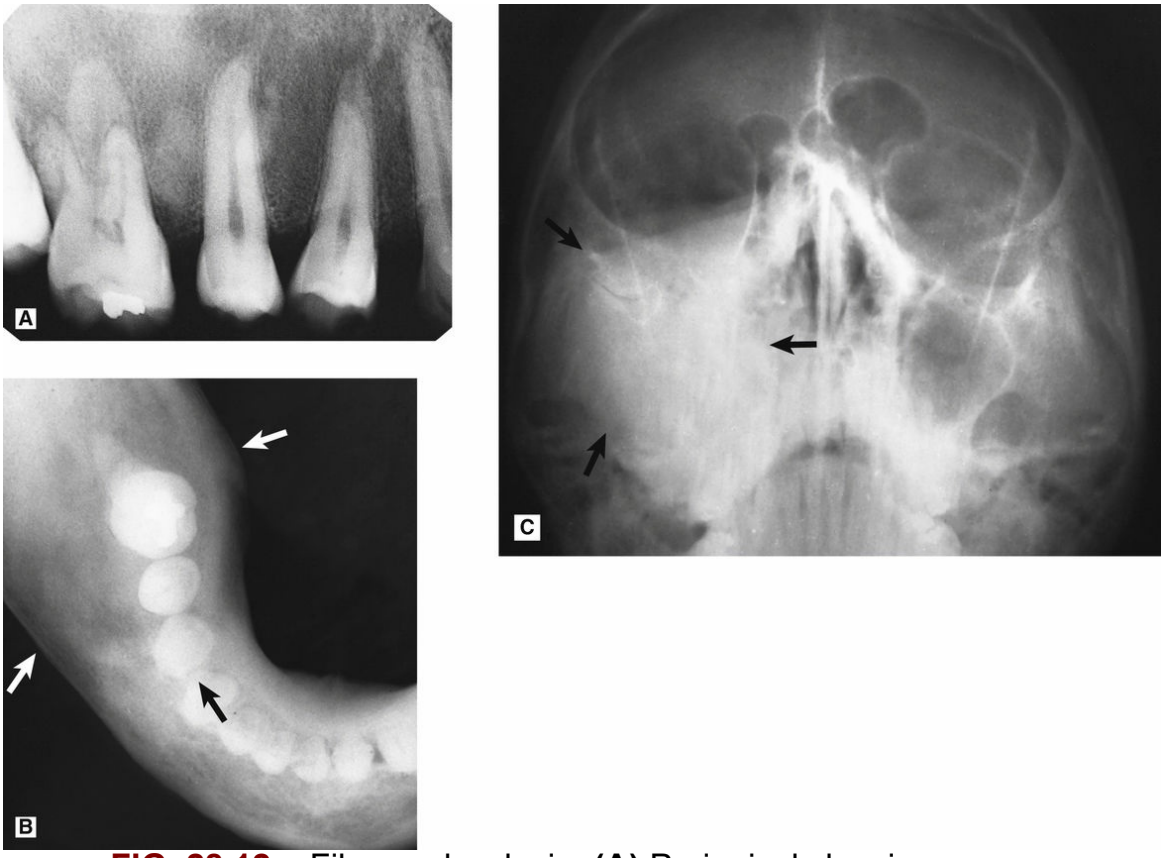


FIG. 28.12 Fibrous dysplasia. **(A)** Periapical showing a lesion of fibrous dysplasia affecting the right maxilla. The overall fine opaque stippled trabecular pattern (*orange peel*), and loss of the lamina dura around the 6| are evident. **(B)** Lower 90° occlusal centred on the right side of the mandible showing another lesion of fibrous dysplasia demonstrating the opaque *ground glass* appearance and expansion in the molar and premolar region (arrowed). **(C)** A 0° occipitomental showing fibrous dysplasia causing expansion of the right maxilla, spread into the zygoma and total obliteration of the right antrum (arrowed).

Paget's Disease of Bone (*Osteitis Deformans*) (see Figs. 28.13 and 28.14)

In this disease of the elderly, the normal processes of bone deposition and resorption are disturbed severely, but only in certain bones and usually symmetrically. The main features are an enlarged head and thickening of the affected long bones, which bend under stress.

Typically the early stages of the disease are characterized by bone resorption and the later stages by bone deposition, although there is no clear-cut distinction between the two stages.

Main Radiographic Features of Early-stage Paget's Disease of Bone

- In the skull vault, scalloped, circumscribed zones of osteoporosis spreading gradually across the calvarium, described as *osteoporosis circumscripta*
- Involvement of the maxilla and/or the mandible. If either is involved, the whole of the bone concerned shows radiographic changes, which include:
  - Generalized osteoporosis of the affected bones producing a fine trabecular pattern, described as *ground glass*

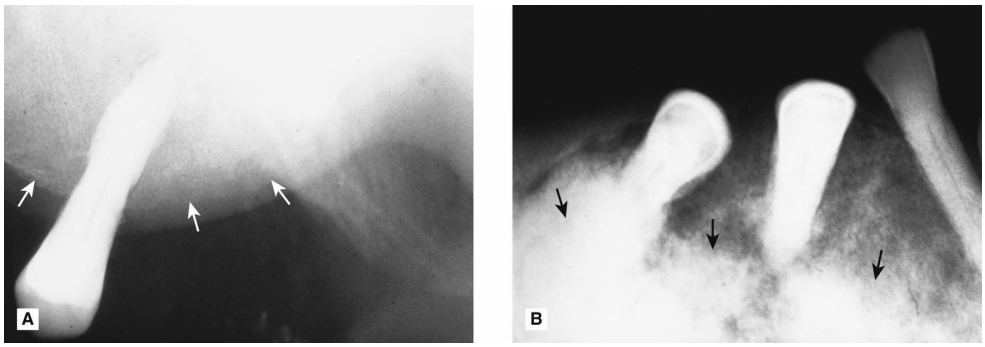


FIG. 28.13 Paget's disease of bone. **(A)** Periapical showing the early porotic stage in the maxilla; note the overall fine trabecular pattern (*ground glass*), loss of the lamina dura and enlargement of the maxilla (arrowed). **(B)** Periapical showing the typical late stage in the mandible. Note the *cotton wool* patches of sclerotic bone (arrowed), loss of the lamina dura, enlargement of the bone, malposition of the teeth and the associated hypercementosis.

  - Enlargement of the affected bone
  - Loss of the lamina dura surrounding all the teeth.

Main Radiographic Features of Late-stage Paget's Disease of Bone

- Evidence in the skull vault of:
  - Haphazard deposition of sclerotic bone in the earlier zones of osteoporosis producing an appearance resembling *cotton wool* patches
  - Enlargement and distortion of the shape of the skull including basilar invagination
- Evidence in the jaws of:
  - Haphazard deposition of sclerotic bone also resembling *cotton wool* patches
  - Enlargement and distortion of the shape of the affected jaw, particularly the alveolus
  - Encroachment of bone on the sinuses
  - Separation and displacement of the teeth, often with extensive hypercementosis
  - Loss of the lamina dura and periodontal ligament shadows.

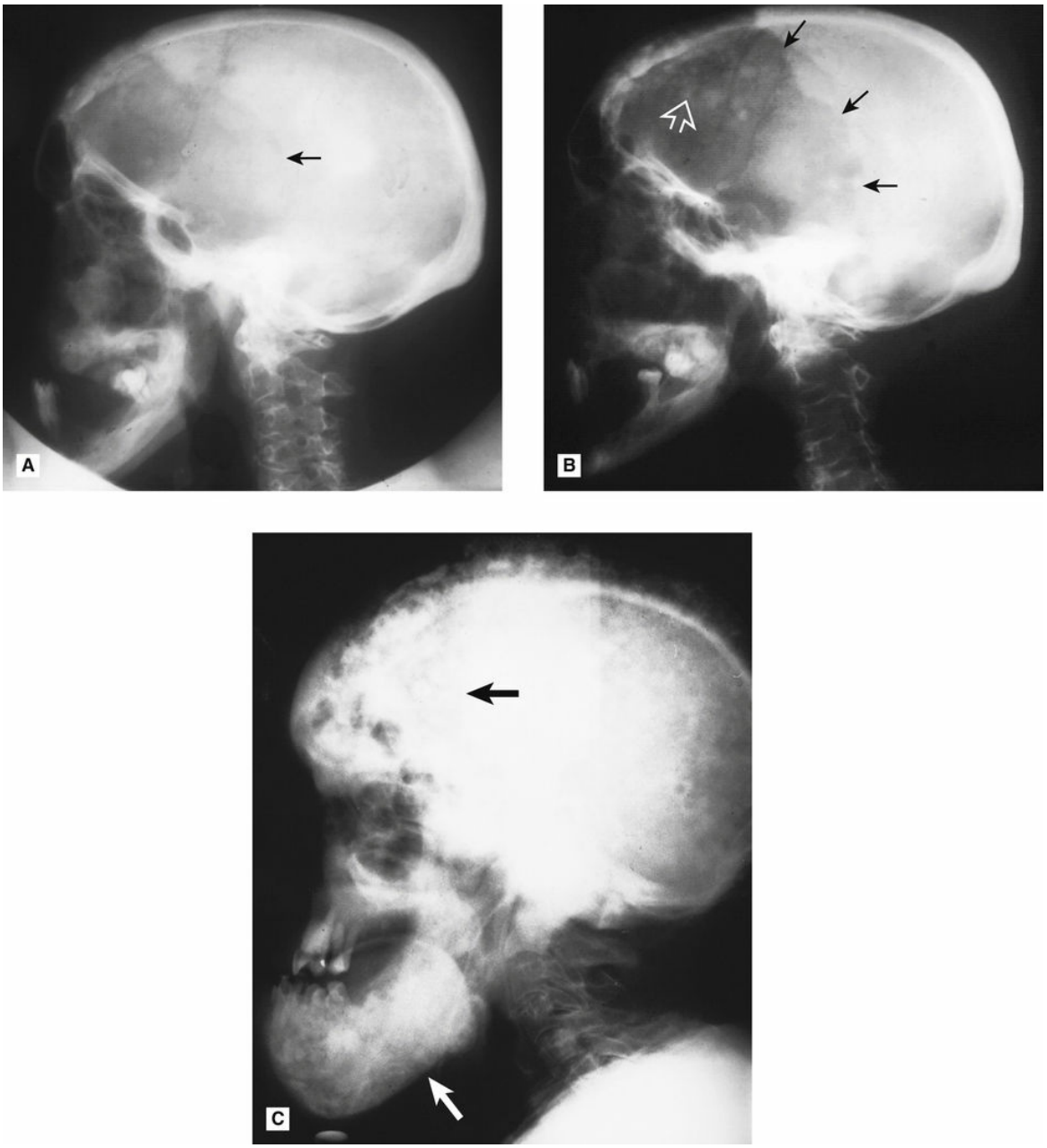


FIG. 28.14 Paget's disease of bone. **(A)** True lateral skull showing early cranial vault involvement – the frontal region appears radiolucent and the scalloped line of *osteoporosis circumscripta* is arrowed. **(B)** Same patient 12 months later – the scalloped line of *osteoporosis circumscripta* has progressed posteriorly (black arrows) and there is early haphazard deposition of bone in the frontal region (open white arrow). **(C)** True lateral skull of a different patient showing the typical late stage appearance of *cotton wool* patches affecting the frontal region of the skull vault (black arrow) and the mandible (white arrow). The occipital region is still in the early

stages.

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

29

Trauma to the Teeth and Facial Skeleton

Introduction

Injuries to the teeth and facial skeleton are, unfortunately, common. The type and severity of injuries can vary considerably, from minor damage to the teeth to grossly comminuted fractures of the skull.

Whatever the suspected injury, radiography is an essential requirement both in the initial assessment and in the follow-up appraisal. However, the radiographic examination may be restricted and limited by the general state of the patient and the type and severity of other injuries. For example, severe facial injuries are often associated with intracranial damage and/or cervical spine injuries, the importance of which far outweighs any damage to the teeth and their supporting structures. The radiographic investigation must therefore be tailored to each patient's needs.

This chapter outlines the approach to radiographic investigation of trauma by separating injuries into four distinct categories:

- Injuries to the teeth and their supporting structures
- Fractures of the mandible
- Fractures of the middle third of the facial skeleton
- Other injuries involving:
    - The skull vault
    - The cranial base
    - The cervical spine
    - Intracranial tissues.

Injuries to the Teeth and Their Supporting Structures

Types of Injury

Based broadly on the classification suggested by Andreasen and Andreasen (2001), the different types of dental injuries can be divided into:

- Fractures of the teeth
- Luxation injuries to the teeth
- Fractures of the alveolar bone
- Other injuries.

Fractures of the Teeth

These include:

- Coronal fractures:
  - Involving only enamel
  - Involving enamel and dentine
  - Involving enamel, dentine and the pulp
  - Involving enamel, dentine and cementum
  - Involving enamel, dentine, cementum and the pulp
- Root fractures:
  - Without a coronal fracture
  - With a coronal fracture.

Luxation Injuries

These include:

- Concussion
- Subluxation
- Intrusive luxation
- Extrusive luxation

- Lateral luxation
- Avulsion.

Fractures of the Alveolar Bone

These include:

- Fractures of the socket
- Fractures of the alveolar process
- Fracture of the associated jaw.

Other Injuries

These include:

- Displacement of an underlying developing tooth, which may become dilacerated as a result
- Soft tissue injuries, such as:
  - Laceration
  - Embedding of a foreign body in the lip
- Iatrogenic injuries, such as:
  - Injuries sustained during extractions, including damage to adjacent teeth and fracture of the associated alveolar bone
  - Perforation of the tooth apex or side of the root during conservative or endodontic treatment
- Swallowing or inhaling an avulsed tooth.

Radiographic Investigations

Although the type of injury may be evident clinically, radiographic investigation of all traumatized teeth is needed initially, to assess fully the degree of underlying damage. Radiographs are also required later to assess healing and/or the development of post-trauma complications. The ideal radiographic requirements include:

- Two views of the injured tooth from different angles, ideally at right angles to one another, but more usually with the X-ray tubehead in two different positions in the *vertical* plane
- Small volume cone beam computed tomography (CBCT) (if available) providing coronal, sagittal and axial images
- Reproducible views to provide a base-line assessment and to allow subsequent follow-up evaluation
- Views of the chest and/or abdomen if a tooth or foreign body is thought to have been inhaled or swallowed, including:
    - Soft tissue lateral and anteroposterior (AP) of the larynx and pharynx
    - Posteroanterior (PA) of the chest
    - Right lateral of the chest
    - Anteroposterior (AP) of the abdomen.

Diagnostic Information Provided

The diagnostic information provided by these radiographs may include:

- The type of injury to the teeth
- The site(s) of fractures
- The degree of displacement of the tooth fragments
- The stage of root development
- The condition of the apical tissues
- The presence, site and displacement of alveolar bone fractures
- The condition of adjacent or underlying teeth
- Evidence of healing
- Post-trauma complications, including:
    - Resorption
    - Infection
    - Cessation of tooth development
- The location of the tooth if swallowed or inhaled.

Radiographic Interpretation

The expected radiographic features indicating a fractured root are shown in Fig. 29.1 and include:

- A radiolucent line between the fragments
- An alteration in the outline shape of the root and discontinuity of the periodontal ligament shadow.

Examples of injured teeth and some of the more common post-injury complications evident radiographically are shown in Figs. 29.2 and 29.3 .

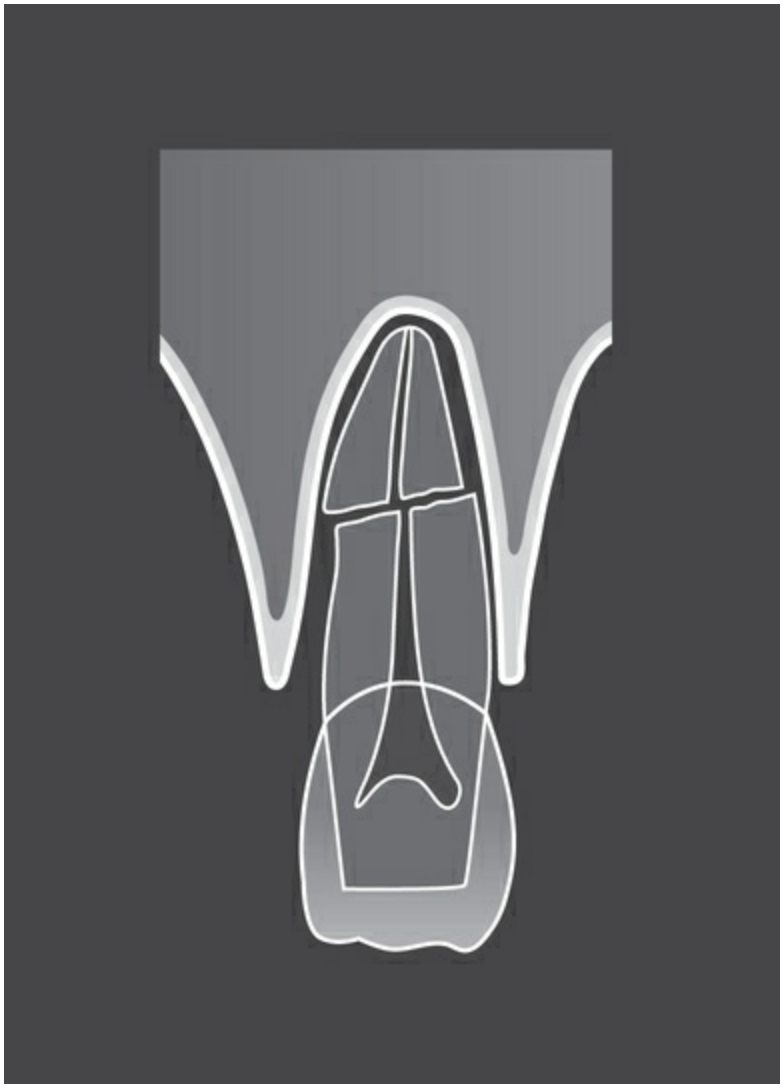


FIG. 29.1 Diagram illustrating the possible radiographic

appearances of a root fracture showing a radiolucent line between the fragments, alteration in the outline shape of the root and discontinuity of the periodontal ligament shadow.

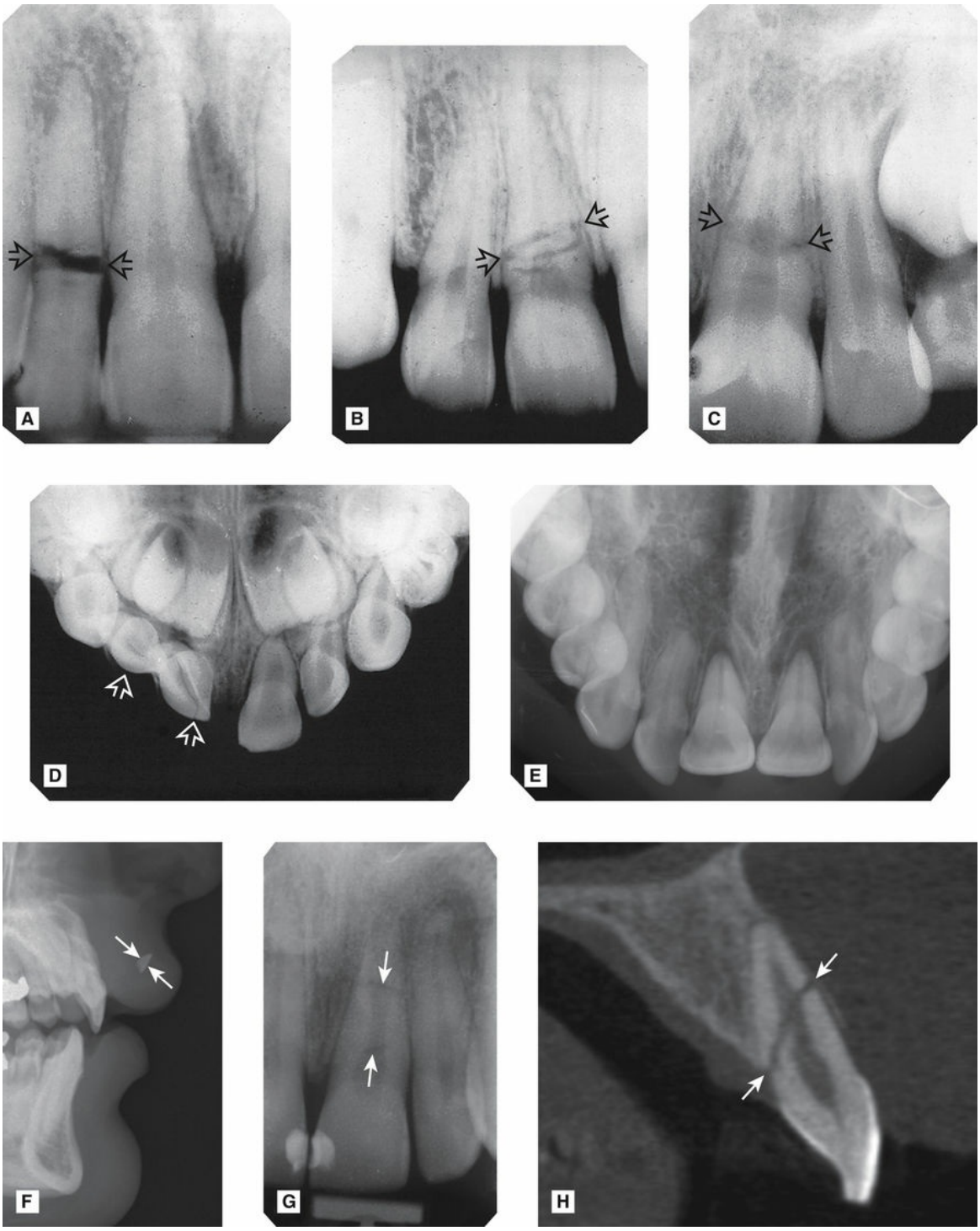


FIG. 29.2 Examples of traumatized teeth and their surrounding structures. **(A)** Root fracture of 2| (arrowed) with wide separation of the fragments. **(B)** Root fracture of |1 (arrowed) with minimal separation of fragments. **(C)** Root fracture of |1 (arrowed) with marked discontinuity in root outline. **(D)** Intrusion and fracture of BA| (arrowed). **(E)** Palatal

luxation of $\underline{1|1}$ – crowns displaced palatally, roots displaced buccally – hence they appear foreshortened. Note also the widening of the periodontal ligament space. **(F)** Tooth fragment in the upper lip (arrowed). **(G)** Periapical and **(H)** sagittal CBCT scan of a fractured $\underline{\lfloor 1}$ (arrowed).

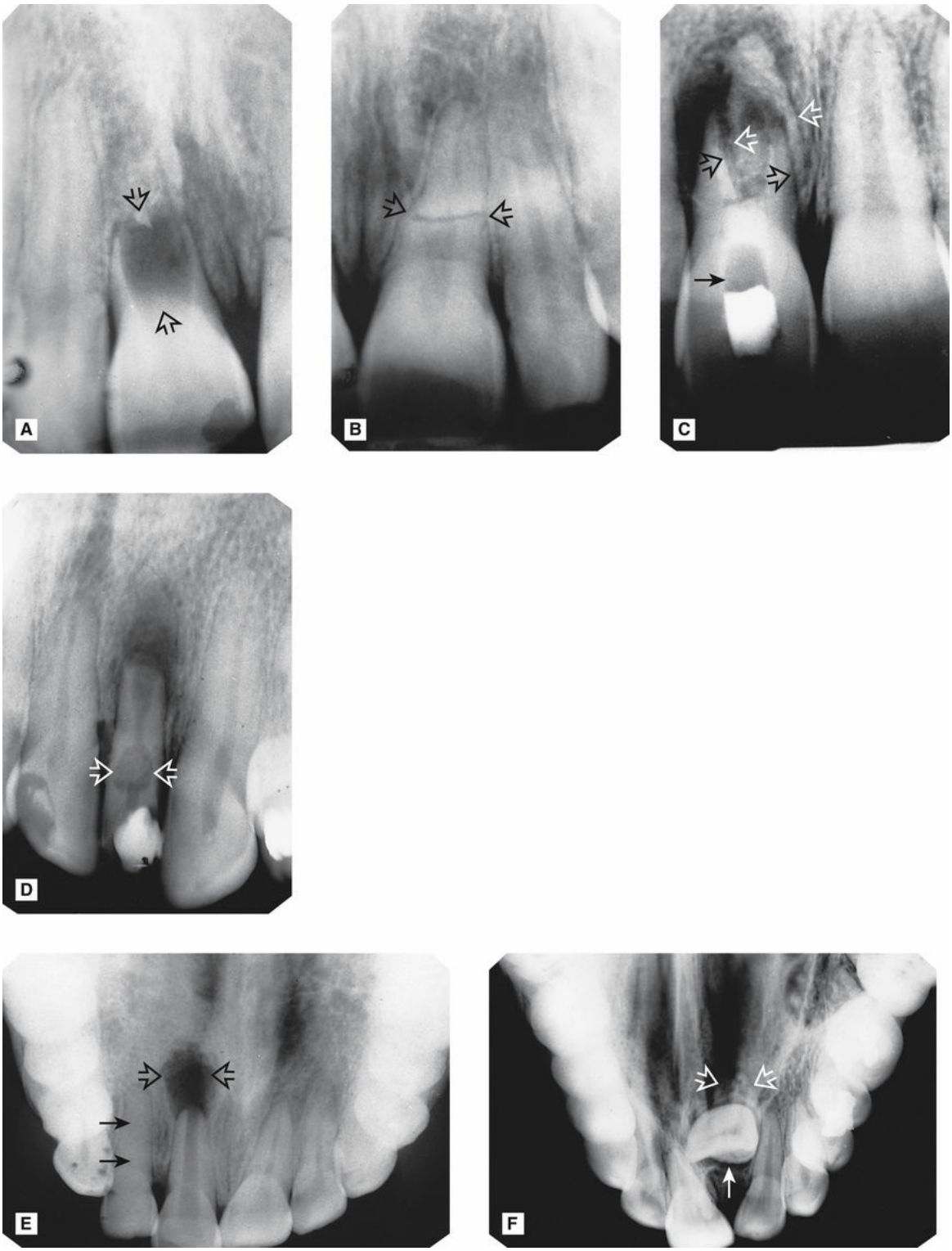


FIG. 29.3 Examples of common post-injury complications. **(A)** Immature root form following complete cessation of root development after death of 1 at the time of injury (arrowed). **(B)** 1 of the same patient showing a complete, but

abnormally shaped, root with (root) fracture (arrowed). The periodontal ligament shadow is continuous. **(C)** Apical infection and resorption of 1| resulting in separation and displacement of the root fragments (open arrows). A radiopaque calcium hydroxide dressing is evident in the root canal with a radiopaque temporary restoration in the crown. The radiolucent area in between contains cotton wool (solid arrow). **(D)** Apical infection, external resorption of the apex and extensive internal root resorption (arrowed) of |2 , following a coronal fracture involving the pulp. A radiopaque temporary dressing is evident in the crown. **(E)** Large area of apical infection associated with 1| (open arrows). Root formation of 1| has ceased and the apex is immature. In addition, the 2| (damaged but not killed by the original trauma) shows complete sclerosis of the pulp chamber (solid arrows). **(F)** Severe dilaceration and non-eruption of |1 (arrowed), following trauma to the deciduous incisors several years previously.

Limitations of Radiographic Interpretation of Fractured Roots

Unfortunately, as a result of the inherent limitations of a two-dimensional image, radiographic interpretation of traumatized teeth is not always straightforward.

As shown in Fig. 29.4 , the radiographic appearances can be influenced by:

- The position and severity of the fracture
- The degree of displacement or separation of the fragments
- The position of the image receptor and X-ray tubehead in relation to the fracture line(s).

It is for these reasons that a minimum of two views, from two different angles, is essential if small volume cone beam computed tomography is not available.

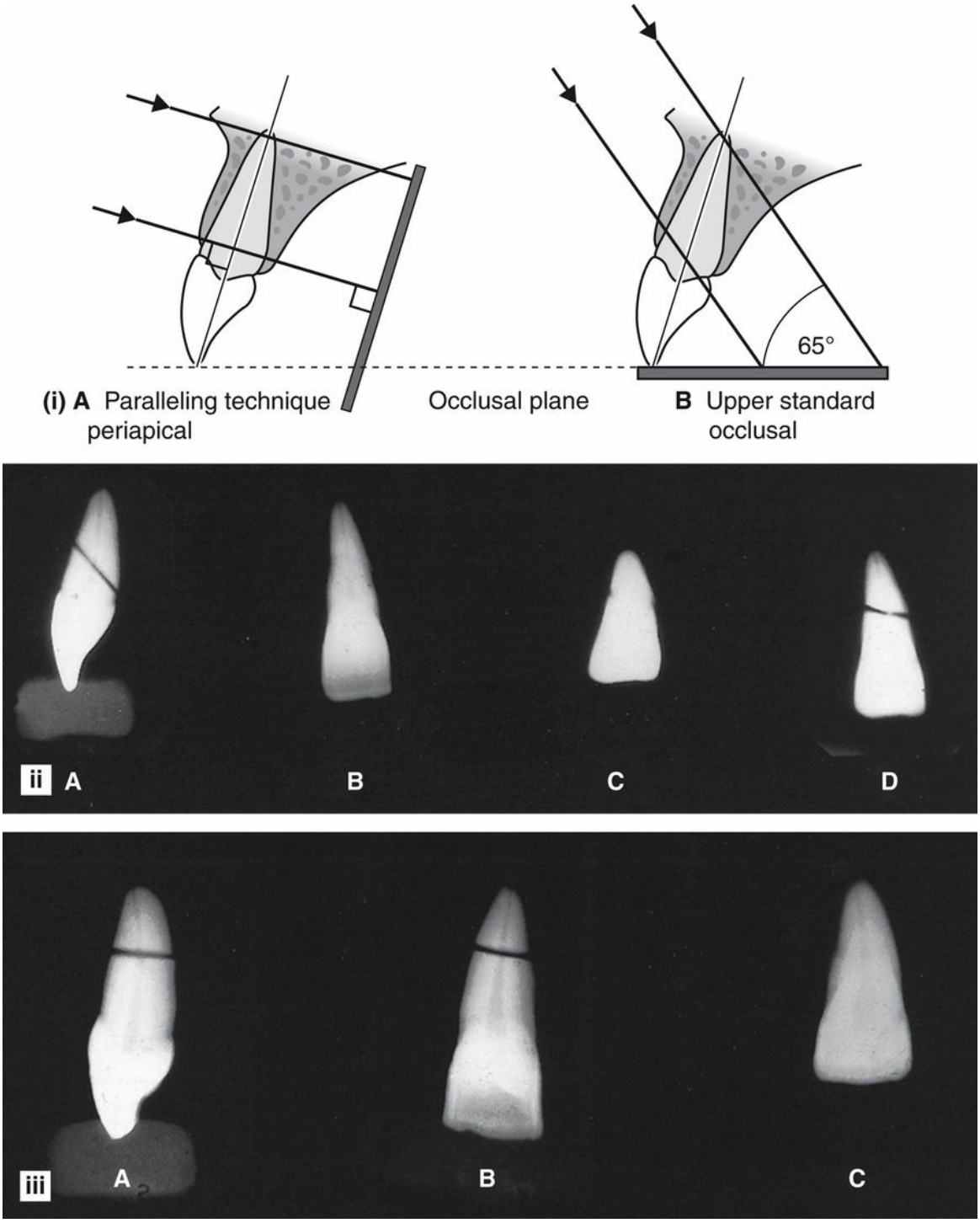


FIG. 29.4 **(i)** Diagram showing the difference in vertical angulation of the X-ray tubehead: **(A)** for a paralleling technique periapical; **(B)** an upper standard occlusal of the maxillary incisors. **(ii)** The different radiographic appearances of a tangential root fracture using different projections: **(A)** from the side showing the direction of the fracture and separation of the fragments; **(B)** using a horizontal X-ray

beam; **(C)** using a steeply angled (75°) X-ray beam; **(D)** using an angled (65°) X-ray beam. **(iii)** The different radiographic appearances of a horizontal root fracture: **(A)** from the side; **(B)** using a horizontal X-ray beam; **(C)** using an angled (65°) X-ray beam.

Skeletal Fractures

As mentioned, radiographs are an essential part of the initial assessment and follow-up appraisal of all patients with suspected facial fractures. They are crucial in evaluating:

- The presence of fractures
- The site and direction of the fracture line(s)
- The degree of displacement and separation of the bone ends
- The relationship of teeth to the fracture line
- The location of associated foreign bodies in hard and soft tissues
- The presence of coincidental or contributory disease
- The alignment of the bone fragments after treatment
- Healing and the identification of post-trauma complications including infection, non-union or malunion.

Fractures of the Mandible

Clinicians need to know:

- **Where** the mandible tends to fracture
- **Which** radiographic views are required to show each of the fracture sites
- **What** radiological features indicate the presence of fracture(s)
- **How** to assess the radiographs for possible fractures.

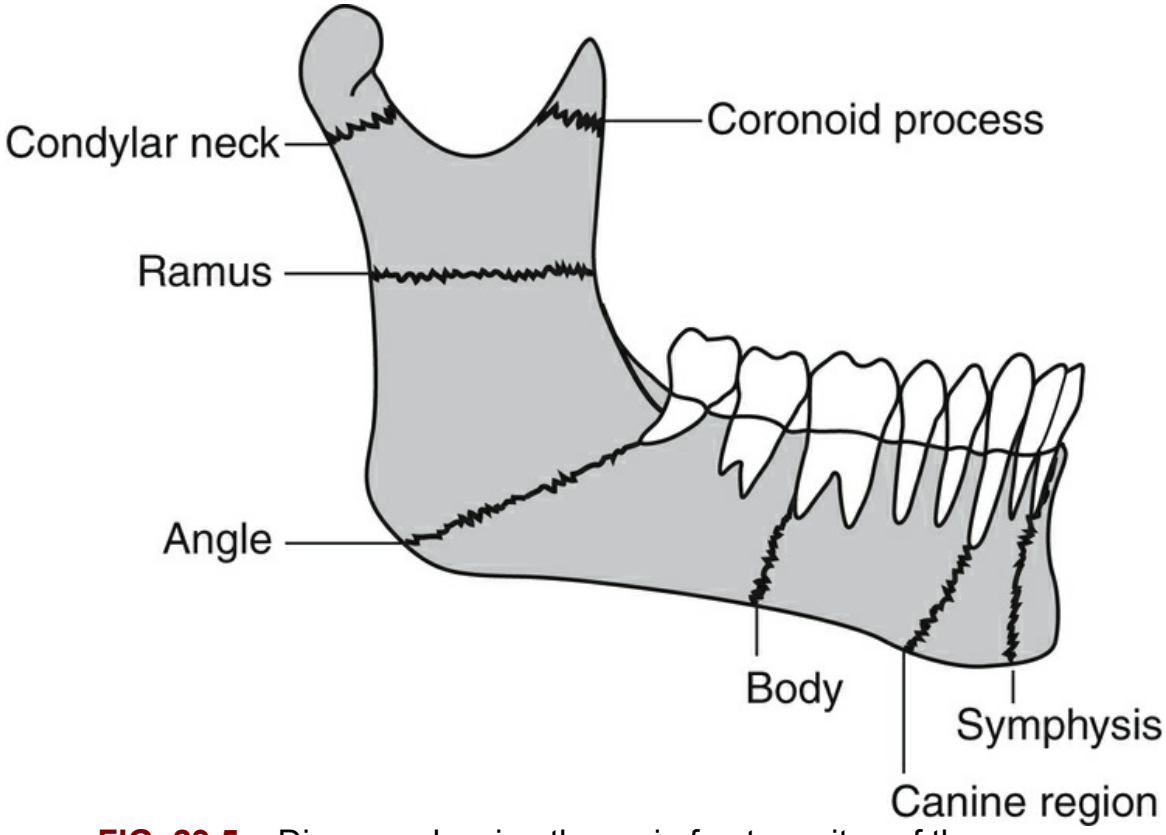


FIG. 29.5 Diagram showing the main fracture sites of the mandible. Although only one side of the jaw is illustrated, mandibular fractures are often bilateral.

Main Fracture Sites

The main sites where the mandible tends to fracture are shown in Fig. 29.5 .

Radiographic Projections Required

Several different views are used to show the various fracture sites. Once again, the ideal minimum requirement in all cases is two views at right angles to one another. When that is not possible, two views at two different angles should be used. In addition, intraoral views (either periapicals or occlusals) are required when fractures are in the tooth-bearing portion of the mandible and teeth are involved in the fracture line. The typical projections that can be used for the different

sites are summarized in Table 29.1 .

Table 29.1

Summary of the main mandibular fracture sites and the common radiographic projections used for each site

Fracture site	Commonly used radiographs
Angle	Panoramic radiograph or oblique lateral Posteroanterior (PA jaws)
Condylar neck	Panoramic radiograph or oblique lateral Posteroanterior (PA jaws) (for low neck fractures) Reverse Towne's (for high neck fractures)
Body	Panoramic radiograph or oblique lateral Posteroanterior (PA jaws) Periapicals of involved teeth Lower 90° occlusal
Canine region	Panoramic radiograph or oblique lateral Periapicals of involved teeth True lateral skull
Symphysis	Lower 45° occlusal Lower 90° occlusal
Ramus	Panoramic radiograph or oblique lateral Posteroanterior (PA jaws)
Coronoid process	Panoramic radiograph or oblique lateral 0° occipitomental

Radiological Features of Mandibular Fractures

The typical radiographic appearances (see Fig. 29.6) include:

- Radiolucent line(s) between the bone fragments if they are separated. Note that fractures through the buccal and lingual cortical plates may produce *two* radiolucent lines
- A radiopaque line if the fragments overlie one another
- An alteration in the outline of the bone if the fragments are displaced, producing a step deformity of the lower border or the occlusal plane.

Important Points to Note

- The extent and severity of any displacement depends on:
  - The direction and strength of the fracturing force
  - The direction of the resultant fracture line
  - The relevant muscles attached to each fragment and their direction of pull
  - If the fracture line runs in such a manner that the associated muscles tend to hold the fragments together, the fracture is described as *favourable*
  - If the associated muscles tend to pull the fragments apart, the fracture is described as *unfavourable*
  - If the fracture involves a tooth socket there may be widening of the periodontal ligament space
  - If the fracture involves an unerupted tooth the follicle may be enlarged.

Radiographic Limitations

As mentioned, the limitations of the radiographic image mean that these appearances can be influenced by:

- The position and severity of the fracture
- The degree of displacement or separation of the fragments
- The position of the image receptor and X-ray tubehead in relation to the fracture line(s) as shown in Fig. 29.7 .

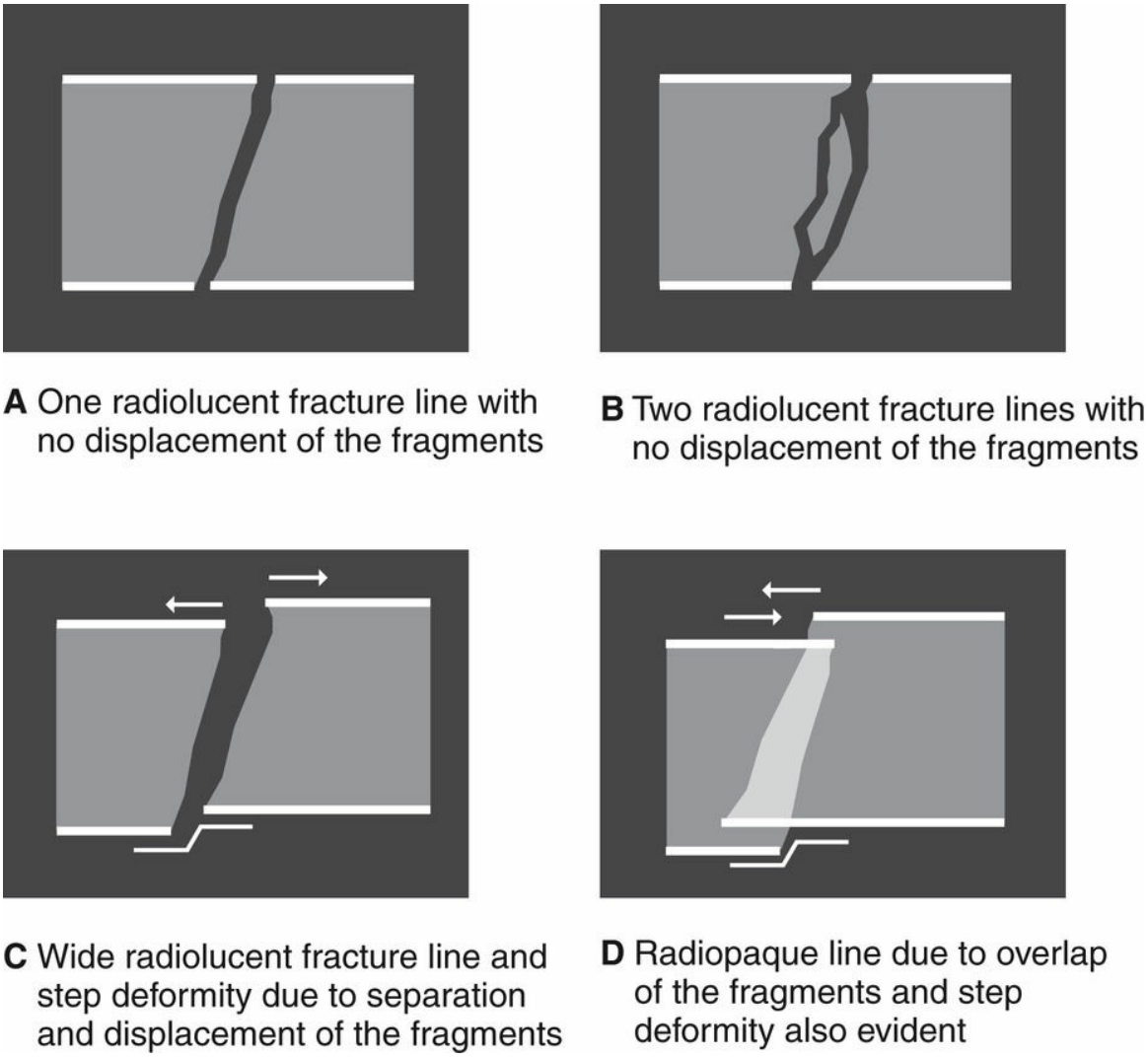


FIG. 29.6 Diagrams illustrating the radiographic appearances of fractures depending on the bony displacement, separation, or overlap that could be present.

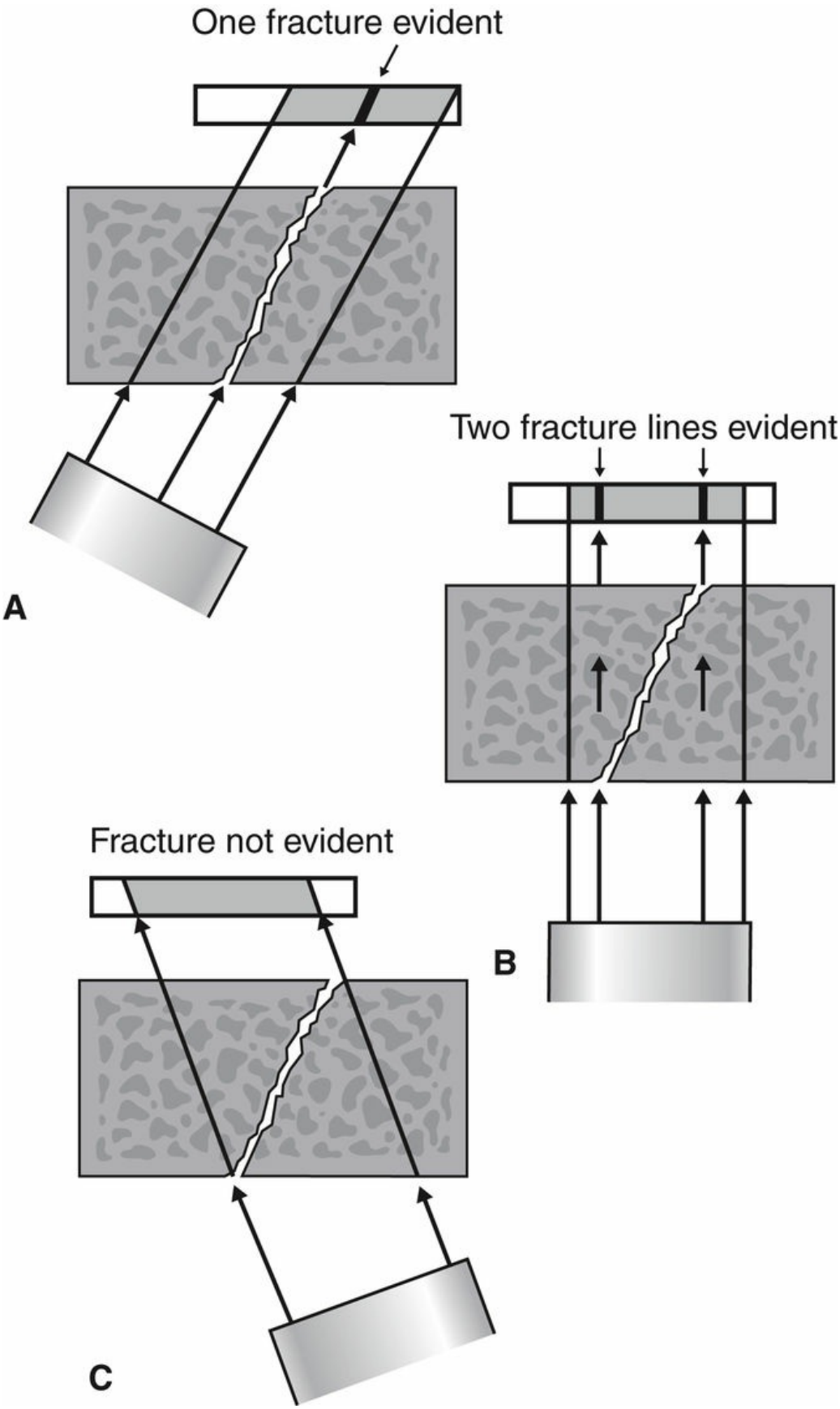

One fracture evident
A
Two fracture lines evident
B
Fracture not evident
C

FIG. 29.7 Diagrams illustrating how the position of the film and X-ray tubehead in relation to a fracture can affect the final image.

Important Points to Note

- It is because of these limitations that at least two views, at different angles, are required.
- If displacement and separation are minimal, there may be **no radiographic evidence** of a fracture at all.
- If available, cone beam computed tomography using medium or large sized *fields of view* may be useful in fracture diagnosis if patient management will be affected.

Interpretation of Fractures

To emphasize, yet again, the importance of the principles outlined in Chapter 18 , before any attempt is made to diagnose a fracture the *quality* of the radiographs should be assessed.

While doing the *overall* critical assessment, it is worth remembering that many patients who have recently been injured may be very difficult to radiograph because of pain, medication, overlying soft tissue wound dressings or other injuries that they may have sustained at the same time. In addition, blood in the antra, nose and pharynx may adversely affect image contrast.

Clinicians should not be too critical of the radiographer; the radiographs obtained are probably the best possible under the circumstances. However, due allowance should be made for these likely technique difficulties when interpreting the final radiographs.

Systematic Approach

A suggested sequence for examining radiographs when attempting to diagnose mandibular fractures is shown in Fig. 29.8 .

Postoperative and Follow-up Appraisal

When using radiographs postoperatively or in the follow-up appraisal, a similar systematic approach is adopted, but particular attention should be paid to:

- The alignment and approximation of the bone fragments
- The position of intra-osseous wires, bone plates or other fixation
- Healing and bone union
- The condition of any teeth involved in the fracture line
- Evidence of infection or other complications.

Examine the lateral view of the mandible
(usually a panoramic radiograph)

1 Trace the outline of the mandible from one condyle to the other along the lower border

2 Note particularly:
- Any alteration in the outline shape
- Step deformities

3 Examine the ramus and body of the mandible, paying particular attention to the sites where fractures are most common -
- Angle
- Condylar necks
- Body
- Canine region
- Ramus
- Coronoid process

4 Note particularly:
- The presence of radiolucent fracture line(s)
- The direction of the fracture lines
- The degree of separation of the bone fragments
- Any radiopaque line(s) indicating overlying bone ends

Examine the second view of the mandible
(usually a PA jaws)

5 Repeat steps(1) – (4) for the relevant areas of the mandible shown on the second view

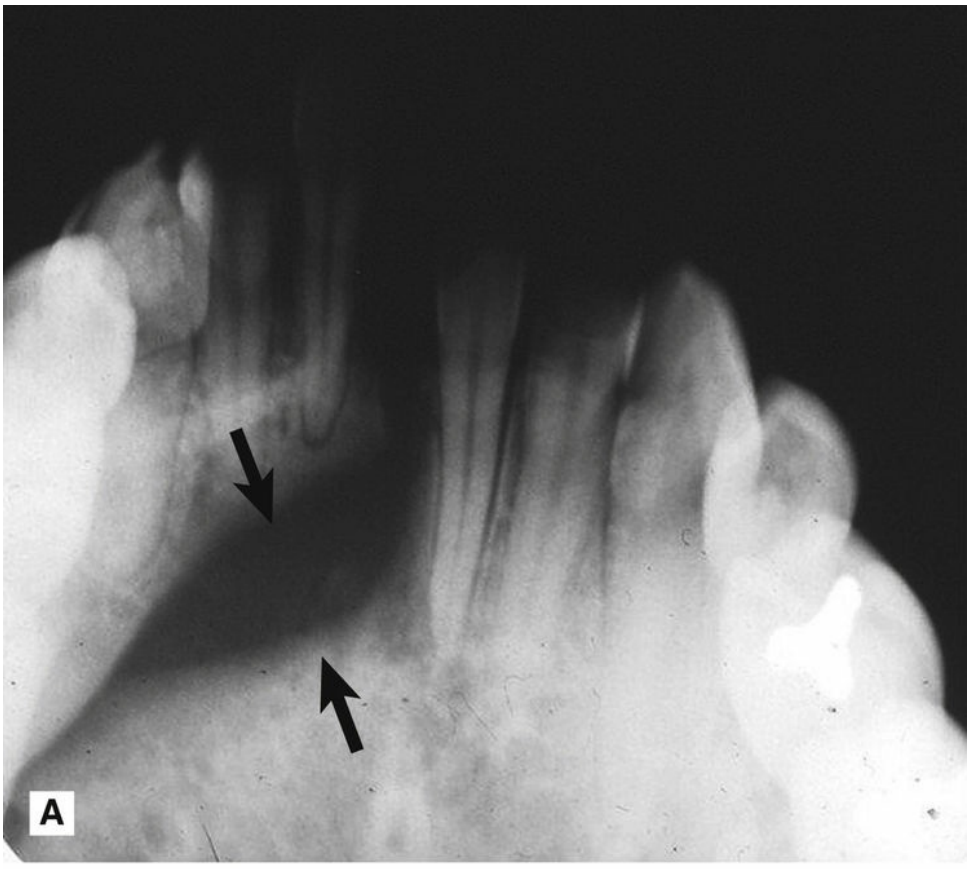
Examine the intraoral views of the teeth

6 Note particularly:
- The relationship of the erupted and unerupted teeth to the fracture line
- The state of the teeth and surrounding tissues, including:
  - fractured crowns or roots
  - caries
  - size of restorations
  - periodontal condition
  - width of the periodontal ligament space
  - apical condition
  - size of any unerupted follicles

FIG. 29.8 Suggested sequence to follow when examining radiographs for mandibular fractures.

Examples of Mandibular Fractures

Examples of various fractures of different sites of the mandible, preoperatively and postoperatively, are shown in Figs. 29.9 –29.17 .


A

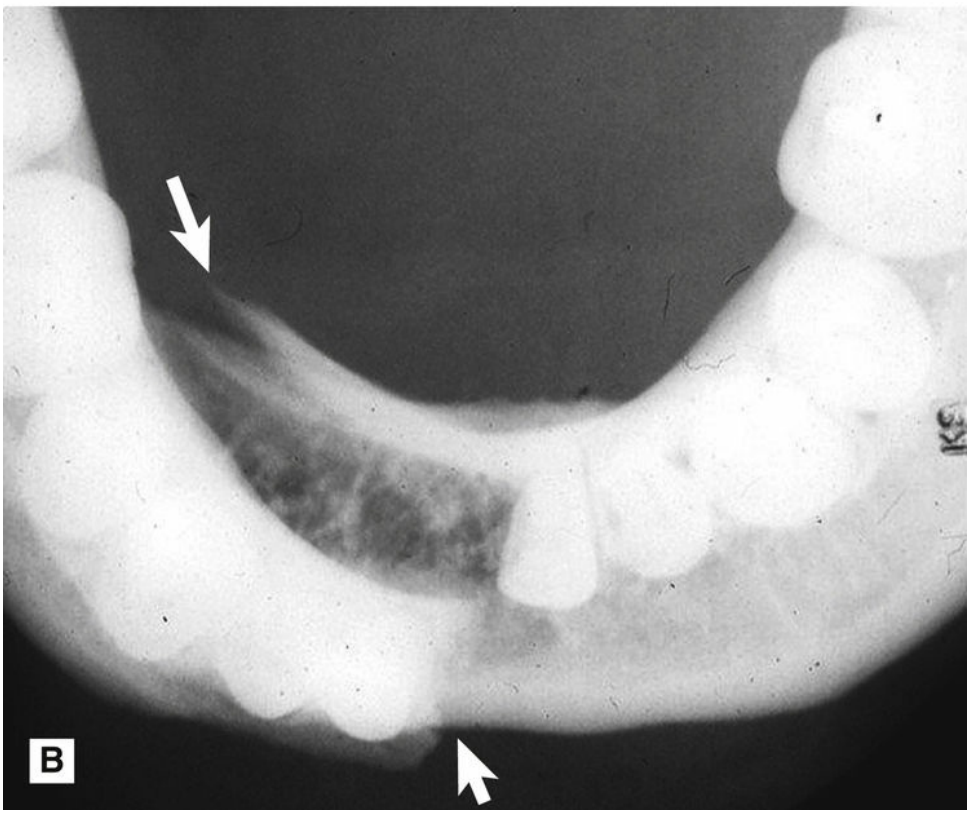

B

FIG. 29.9 (A) Lower 45° occlusal and **(B)** lower 90° occlusal showing a fracture in the symphyseal region (arrowed). Note the lower 45° occlusal shows the displacement in the vertical plane, while the lower 90° occlusal shows the displacement in the horizontal plane.

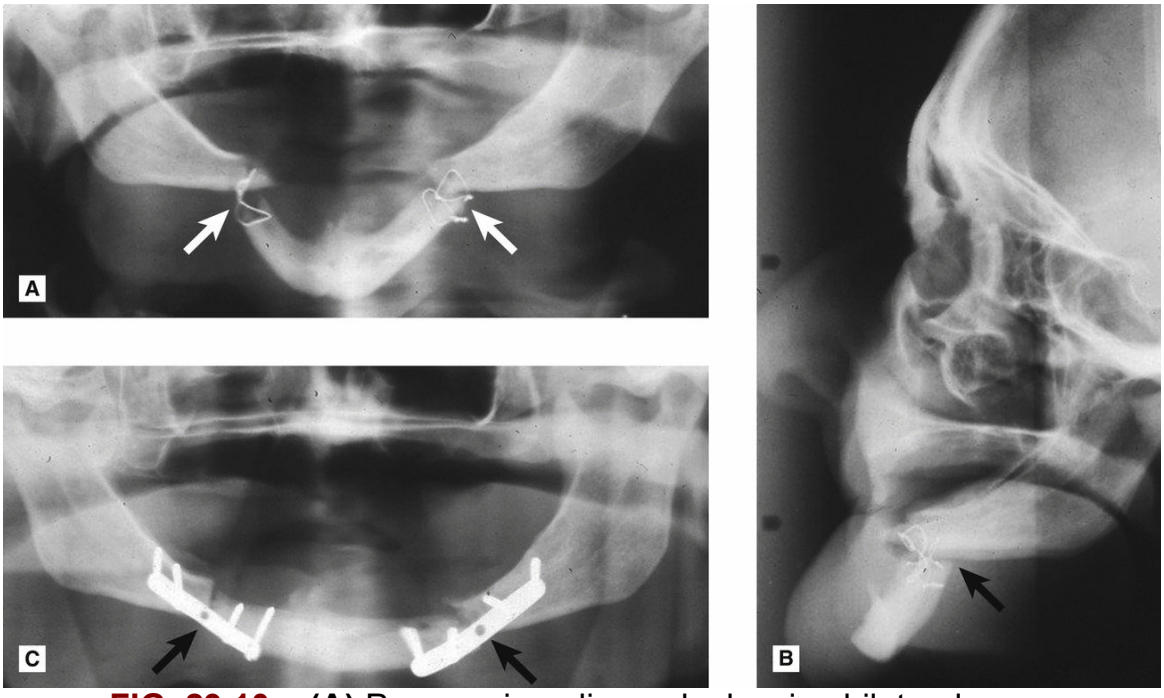


FIG. 29.10 **(A)** Panoramic radiograph showing bilateral fractures of the canine region, so-called *bucket handle* fractures (arrowed), after the first attempted fixation with intra-osseous wires. **(B)** True lateral skull. Note the extensive displacement of the anterior segment of the mandible owing to the unopposed pull of the muscles attached to this fragment. This is described as an unfavourable fracture. The inadequate intra-osseous wires are again evident. **(C)** Panoramic radiograph after fixation with bone plates (arrowed).

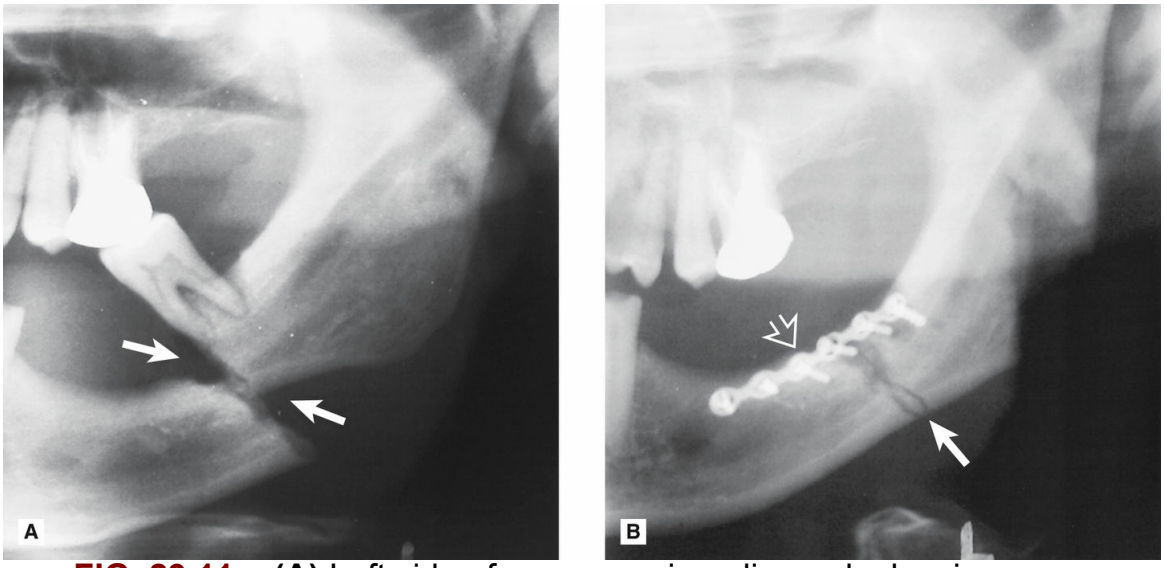


FIG. 29.11 **(A)** Left side of a panoramic radiograph showing an unfavourable markedly displaced fracture of the body of the mandible (arrowed). **(B)** Left side of a panoramic radiograph taken postoperatively showing accurate reduction of the fragments (solid arrow) and fixation with a bone plate (open arrow). The lower molar has been extracted.

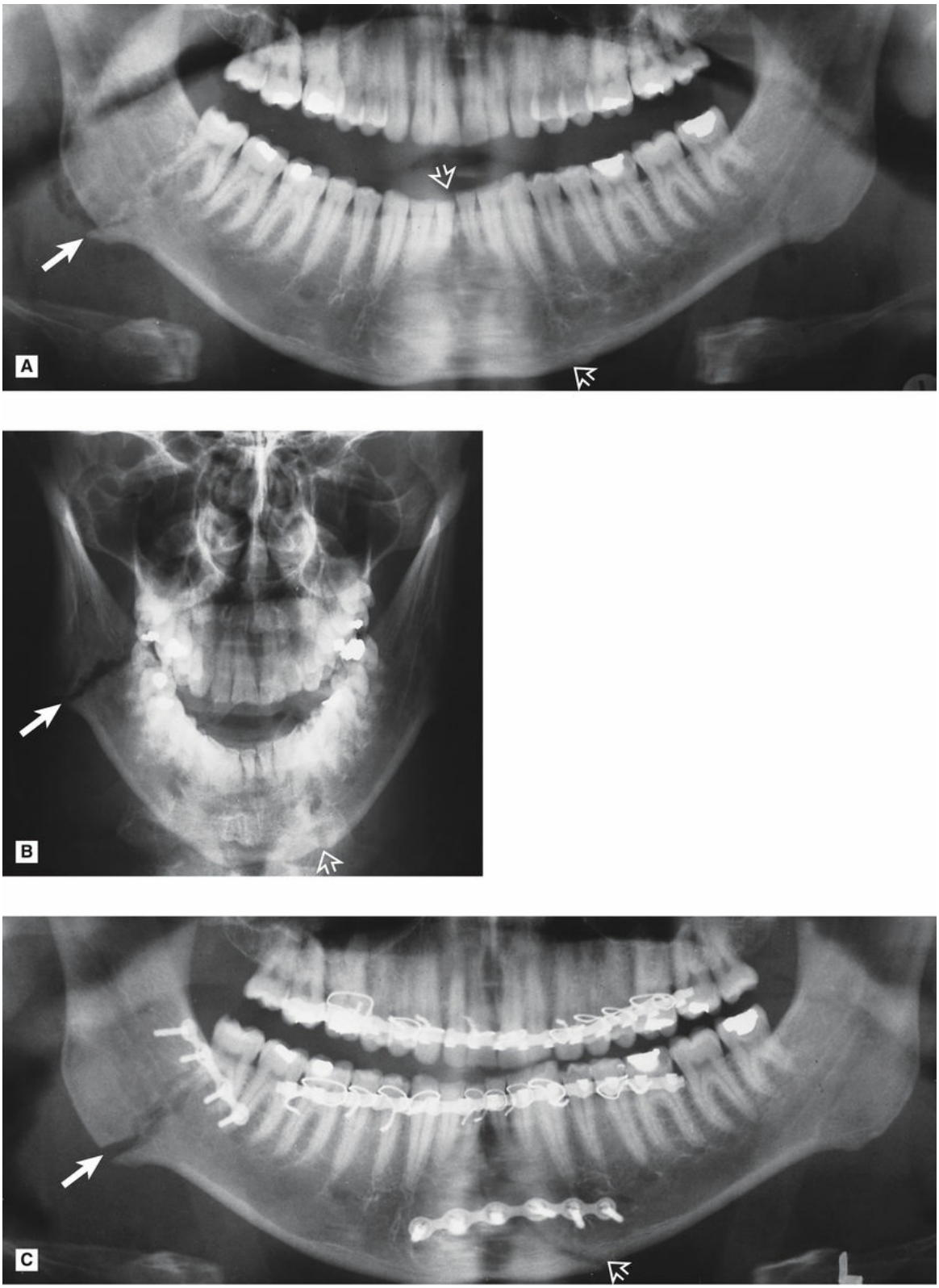


FIG. 29.12 **(A)** Panoramic radiograph showing bilateral fractures of the mandible – through the right angle and symphyseal/left canine region. Note that the fracture through

the angle appears radiopaque as the bony fragments are overlying one another (solid arrow) and that the symphyseal/canine region fracture (open arrow) is almost totally obscured by the overlying ghost shadow of the cervical spine. **(B)** PA jaws showing the fracture through the angle clearly as a radiolucent line (solid arrow) while the symphyseal/canine region fracture is still difficult to see (open arrow) as a result of superimposition of the cervical spine. **(C)** Postoperative panoramic radiograph showing reduction and fixation of the bone fragments (arrowed) using bone plates. Arch bars and islet wiring around the teeth are also evident.

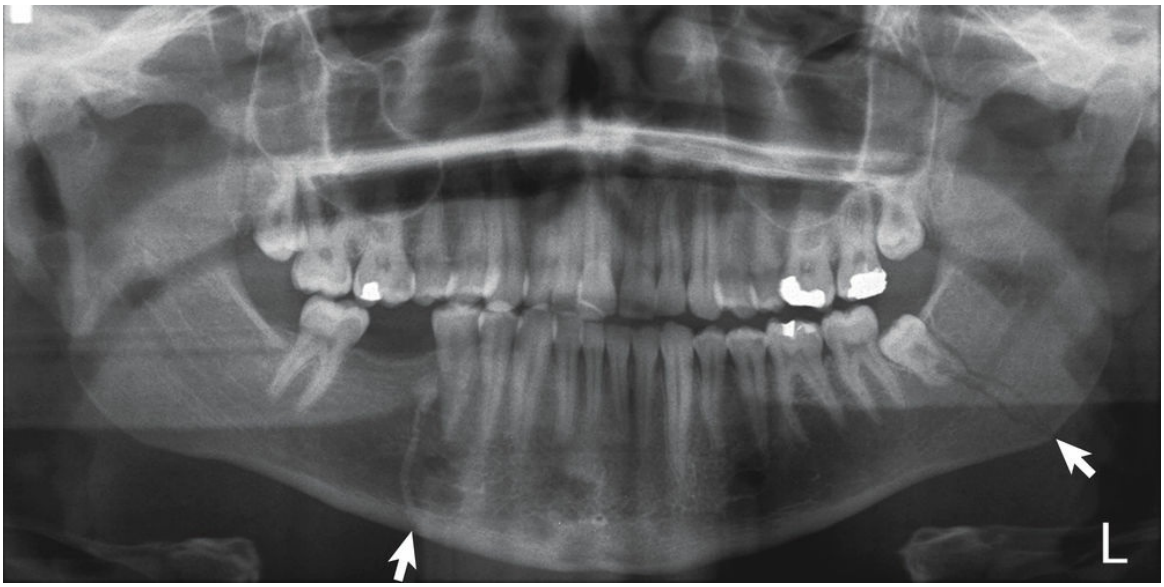


FIG. 29.13 Panoramic radiograph showing a bilateral fracture of the mandible through the left angle and right body (arrowed). The fracture of the left angle shows as two radiolucent lines with widening of the distal periodontal ligament space and follicle 8 . The fracture of the right body shows as a radiopaque line owing to overlap of the fragments.

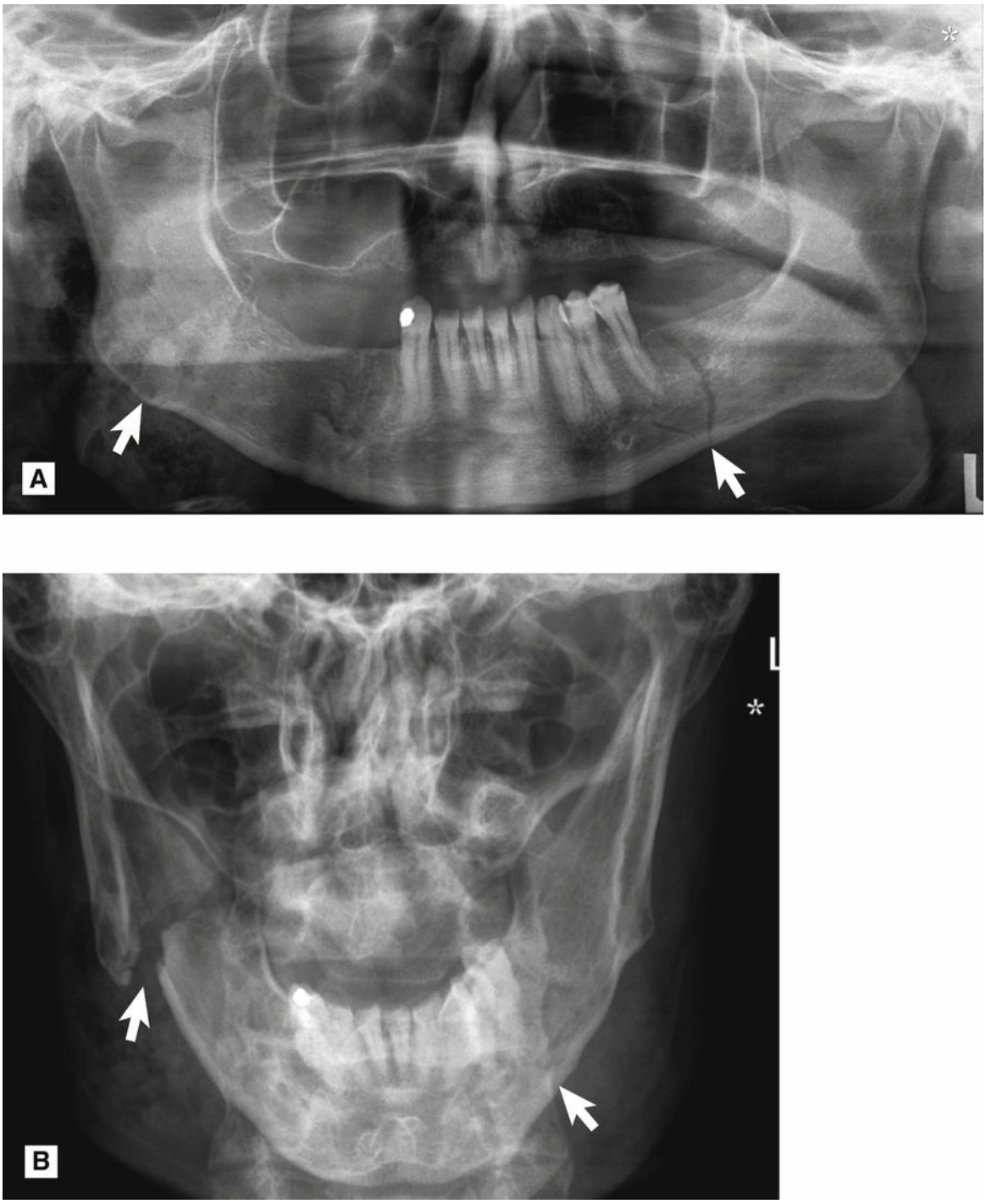


FIG. 29.14 **(A)** A panoramic radiograph showing bilateral fractures of the mandible through the left body (radiolucent) and right angle (radiopaque) (arrowed). **(B)** PA jaws showing both fractures (arrowed). There is also evidence of traumatic emphysema on the right side.

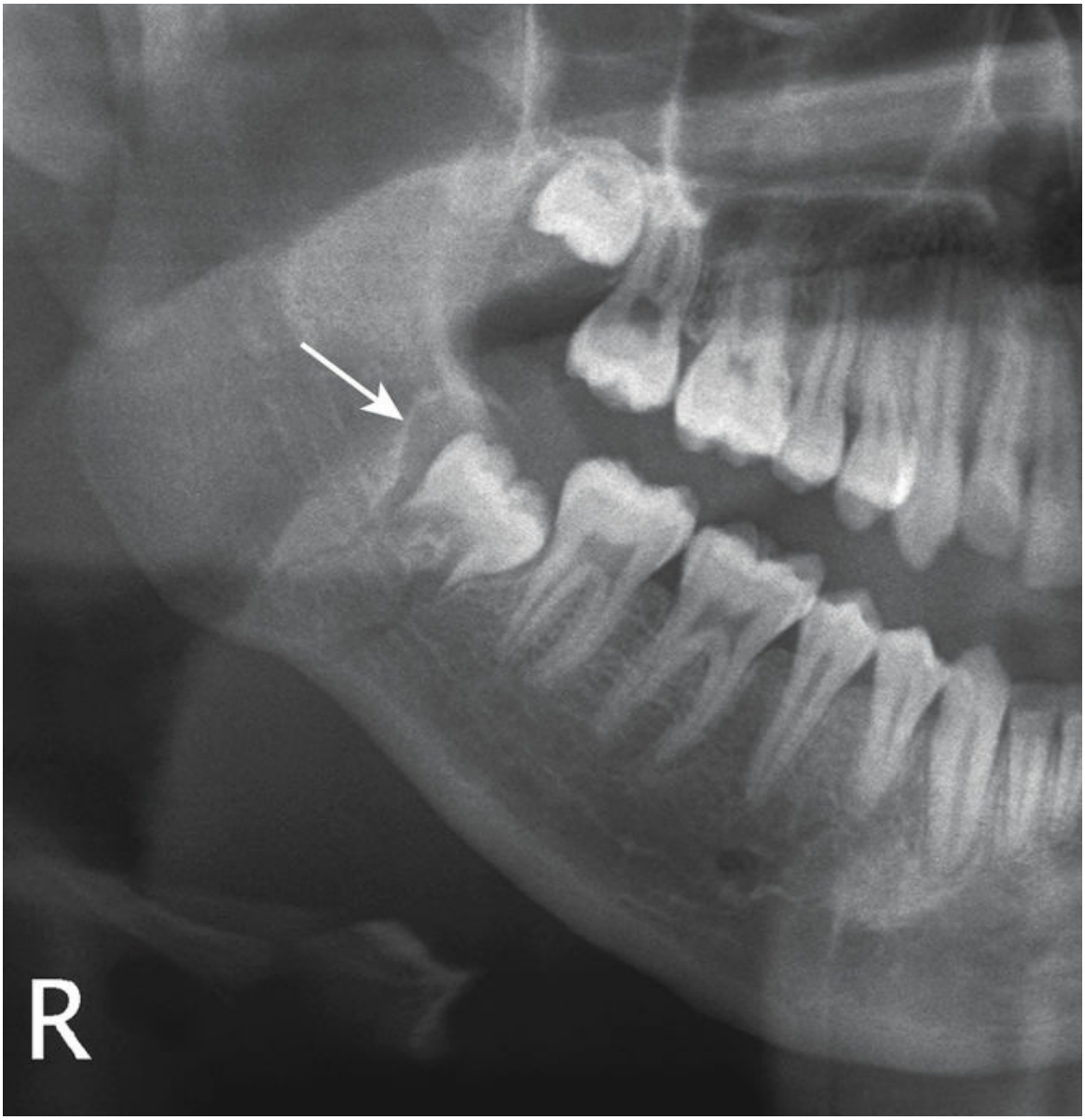


FIG. 29.15 Right sectional panoramic radiograph showing a fracture of the right angle with widening of the distal follicle of $\overline{8|}$ (arrowed).



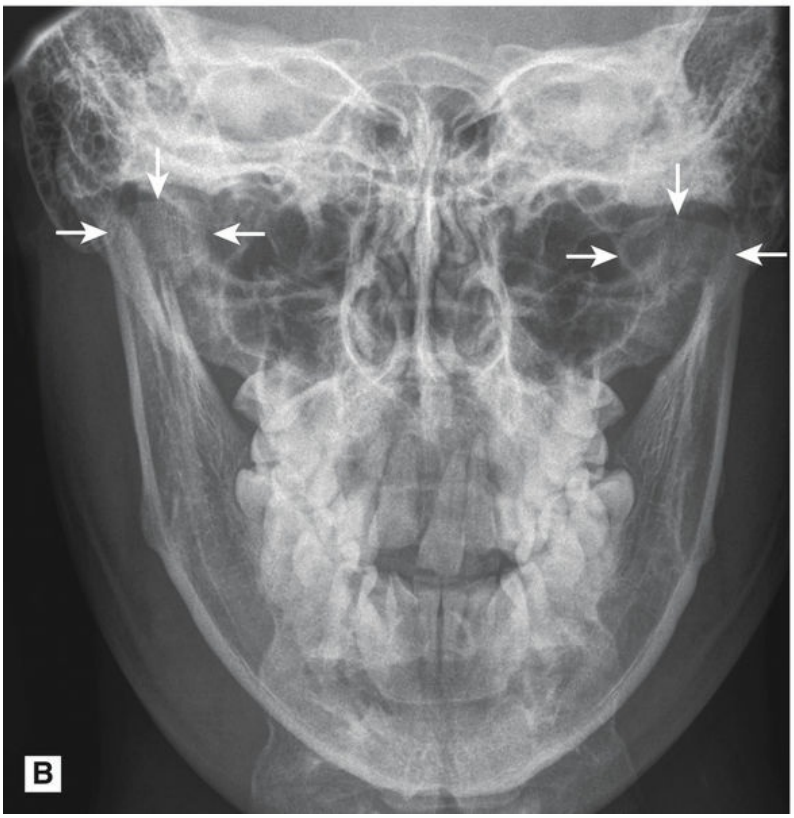


FIG. 29.16 **(A)** Panoramic radiograph showing bilateral fractures of the condyles (arrowed). Note the condylar heads have been displaced anteriorly. **(B)** PA jaws showing the

medial displacement of the condyles (arrowed).

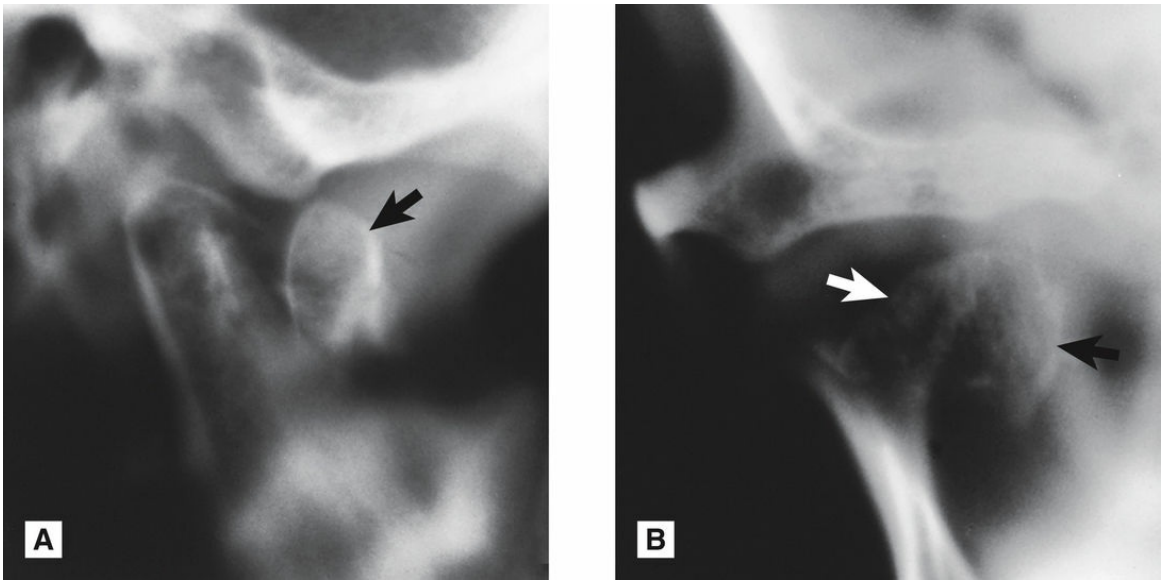


FIG. 29.17 **(A)** Sagittal and **(B)** coronal spiral tomographs showing an intracapsular fracture of the head of the right condyle. The anteromedially displaced fractured fragment of the head is arrowed.

Fractures of the Middle Third of the Facial Skeleton

This is probably one of the most difficult and confusing topics in dental radiology. The problem now concerns *multiple-bone* fractures instead of the relatively simple *one-bone* fractures encountered with the mandible. Owing to the complexity of the facial skeleton, there is a fundamental requirement for a sound knowledge of anatomy.

In addition, the knowledge required by the clinician can again be summarized as follows:

- **Where** the middle third of the face tends to fracture
- **Which** radiographic views are required to show each of the

fracture sites
- **What** radiological features indicate the presence of fracture(s)
- **How** to assess the radiographs for fractures.

Classification and the Main Fracture Sites

Most injuries to the middle third of the face are from the front, forcing part or parts of the facial skeleton downwards and backwards along the cranial base. The resulting lines of fracture follow the lines of weakness of the facial skeleton, as shown in Fig. 29.18 . This allows a broad classification based on site, as follows:

- Dento-alveolar fractures
- Central middle third fractures, including:

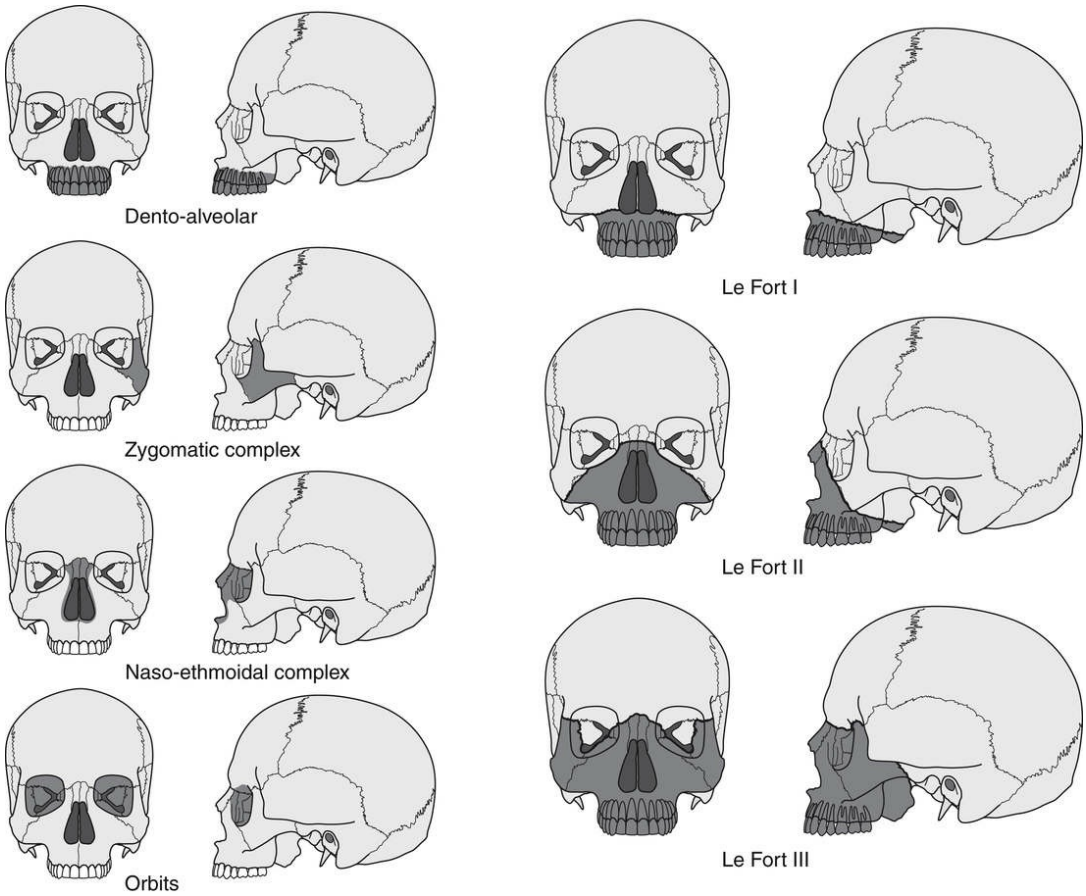


FIG. 29.18 Diagrams of the skull from the front and side illustrating the main sites of middle third facial fractures.

  - Le Fort type I, bilateral detachment of the alveolar process and palate, or the low-level subzygomatic fracture of Guérin
  - Le Fort type II, pyramidal, subzygomatic fracture of the maxilla
  - Le Fort type III, high-level suprazygomatic fracture of the central and lateral parts of the face
- Fractures of the *zygomatic complex* , including:
  - Zygoma depressed with fractures at several sites
  - Fracture of the zygomatic arch
- Fractures of the naso-ethmoidal complex
- Fractures of the orbit, including:
  - Fractures of the orbital rim (usually as part of a

complex fracture)
– Orbital blow-out fracture.

Radiographic Investigation

As mentioned, radiographic investigation of facial fractures depends on available facilities, the general state of the patient, associated injuries, particularly intracranial and spinal (odontoid peg), and the severity of the facial trauma.

Nevertheless, in **all cases** radiographic investigation should include a *true lateral skull* projection to exclude fractures of the cranial base, a characteristic feature of which is the presence of a fluid level in the sphenoidal air sinus.

Important Points to Note

- In a casualty department, the patient is usually X-rayed lying down. The true lateral projection should be taken with the patient supine (brow up), and with the X-ray beam horizontal, to show the possible fluid level. This projection is therefore sometimes referred to as a *brow-up lateral* or *shoot-through lateral* .
- The projections that can be used for the different fracture sites are summarized in Table 29.2 . Again the principle of requiring a minimum of two views at right angles applies but, as indicated, several views may be necessary.

Table 29.2

Summary of the common radiographic projections used to show the various middle third fracture sites

Fracture type/site	Commonly used investigations
Dento-alveolar	Periapicals Upper standard occlusal Upper oblique occlusal
Le Fort I	0° occipitomental (0° OM)

	30° occipitomental (30° OM) True lateral skull (*brow-up*)
Le Fort II	0° occipitomental (0° OM) 30° occipitomental (30° OM) True lateral skull (*brow-up*)
Le Fort III	0° occipitomental (0° OM) 30° occipitomental (30° OM) True lateral skull (*brow-up*) CT or CBCT
Zygomatic complex	0° occipitomental (0° OM) 30° occipitomental (30° OM) CT or CBCT Submentovertex (SMV)
Naso-ethmoidal complex	True lateral skull (*brow-up*) 0° occipitomental (0° OM) 30° occipitomental (30° OM) Soft tissue lateral view of the nose Posteroanterior (25° PA) CT or CBCT
Orbit	0° occipitomental (0° OM) True lateral skull (*brow-up*) Posteroanterior (25° PA) CT or CBCT

Postoperative and Follow-Up Appraisal

Again, systematic viewing sequences are adopted when using radiographs postoperatively or in the follow-up appraisal of fractures, but special attention should be paid to:

- The alignment and approximation of the bone fragments
- The position of bone plates and other fixation
- Healing and bone union
- The condition of the antra
- Evidence of infection or other complications.

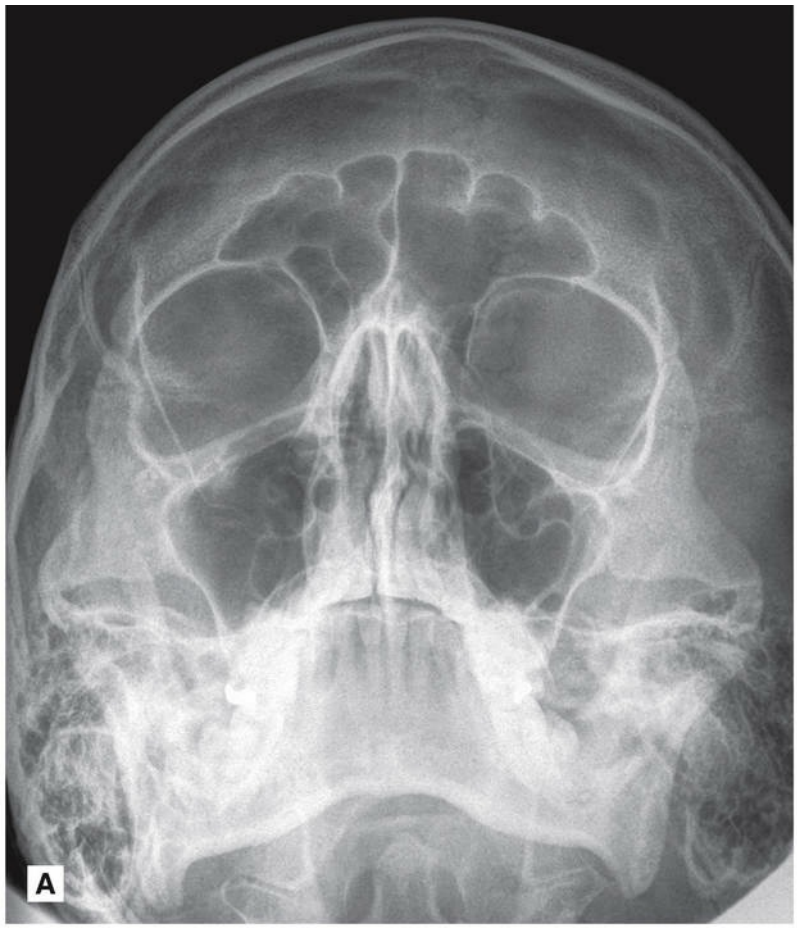
Interpretation of Middle Third Fractures

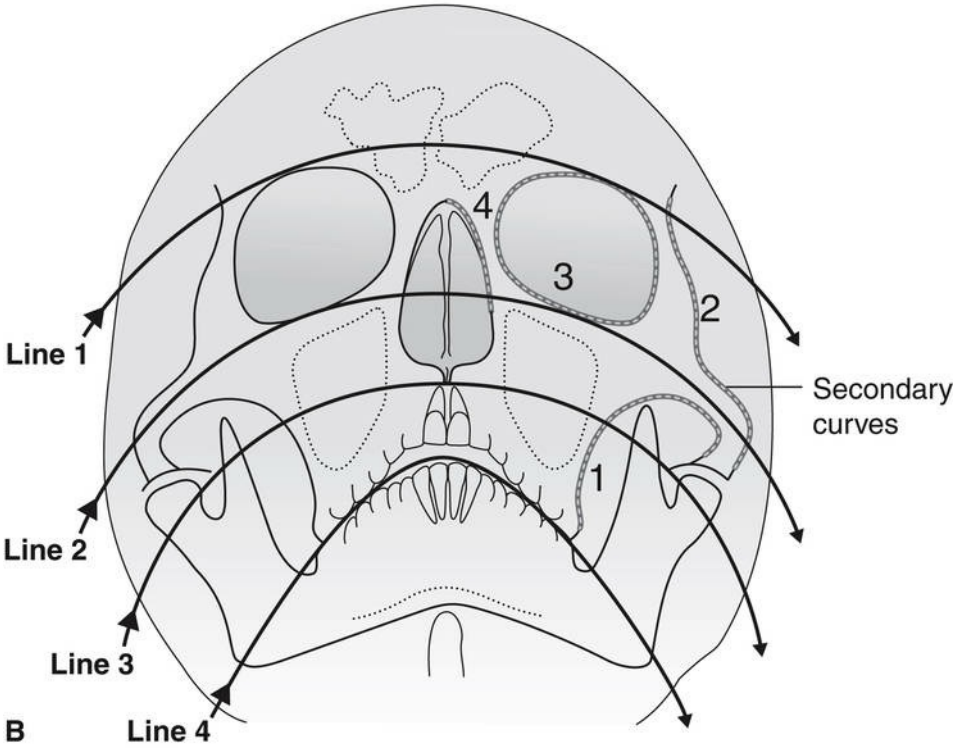
Systematic Approach

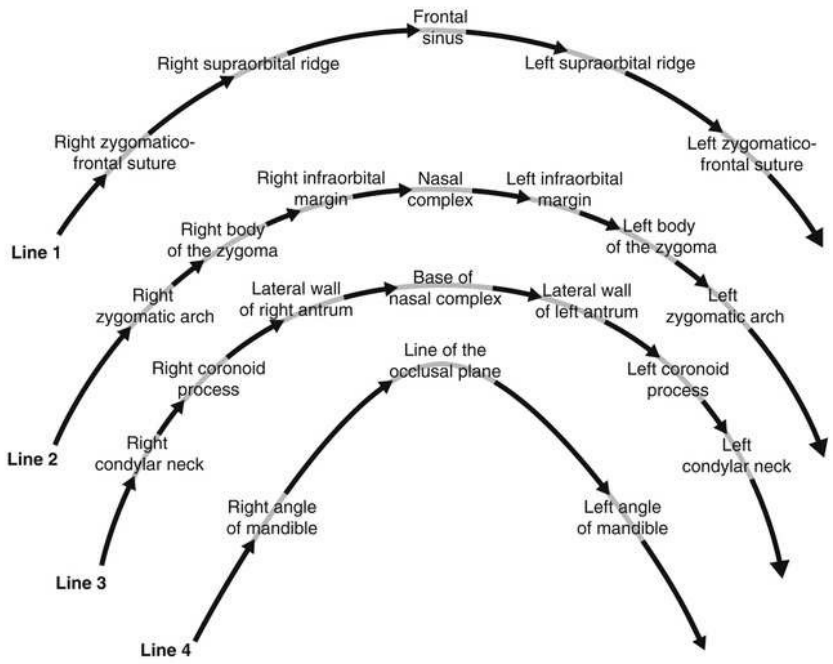
In view of the numerous possible fracture sites, an ordered sequence to viewing is essential. One suggested approach can be summarized

as follows:

- Examine the 0° occipitomental using an approach based broadly on that suggested originally by McGrigor and Campbell (1950), often referred to as *Campbell's lines* (see Fig. 29.19).
- Examine the 30° occipitomental as shown in Fig. 29.20 .
- Examine the true lateral skull as shown in Fig. 29.21 .
- Examine any other images.


A


4
3
2
1
Line 1
Line 2
Line 3
Line 4
Secondary curves
B



Step I : Compare both sides by traversing across the radiograph following Campbell's lines
Step II : Compare both sides of the radiograph tracing the *secondary curves*, indicated on the right side of the diagram:

Curve 1 – Lateral wall of the antrum and the inferior surface of the body of the zygoma and zygomatic arch
Curve 2 – Superior margin of the zygomatic arch and the lateral aspect of the body of the zygoma and orbital margin
Curve 3 – Inner aspect of the orbital rim
Curve 4 – Outer curvature of the nasal complex

In both steps (I) and (II) the features to note include:

- Any alteration or asymmetry in bony outline or shape
- Step deformities
- Widening of suture lines
- The presence of radiolucent fracture line(s)
- The direction of the fracture lines
- The degree of separation of the bone fragments
- Any radiopaque lines or shadows indicating overlying bone ends

Particular attention should be paid to the radiographic sites on a 0° OM where middle third facial fractures are usually identified including:

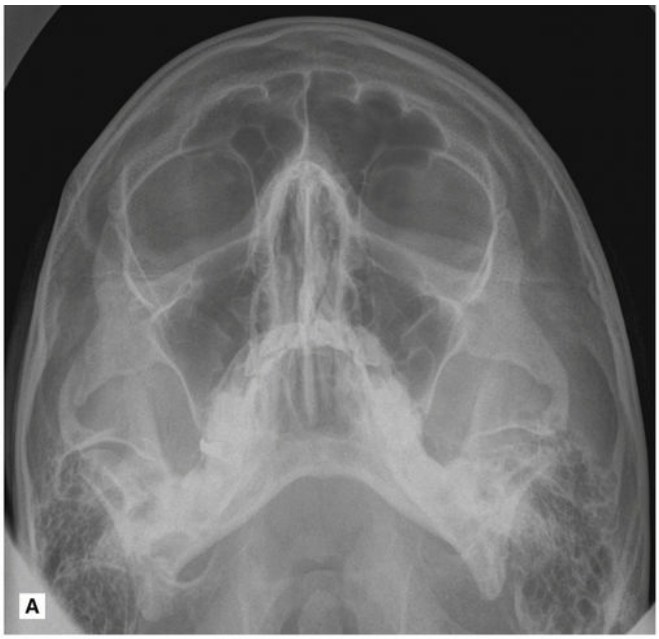
- Zygomatico-frontal sutures
- Frontonasal sutures
- Zygomatico-temporal sutures (zygomatic arch)
- The inferior margins of the orbits
- The lateral margins of the antra
- The nasal septum and complex

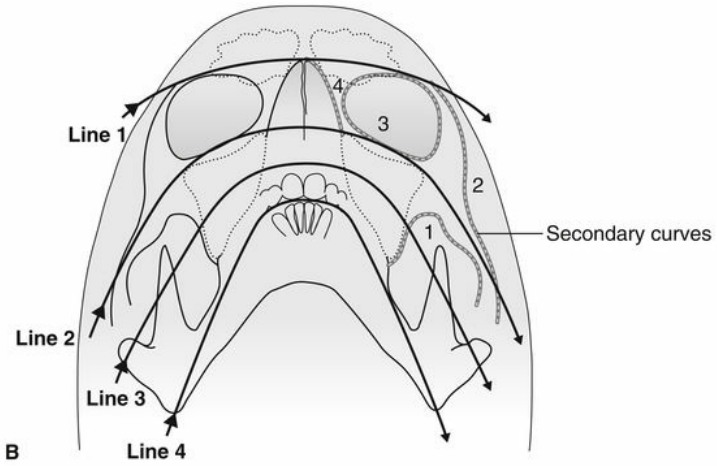
Note: All of these sites are automatically checked if the suggested systematic sequences for viewing the occipitomental radiograph are followed.

Step III : Examine the antra — compare both sides and check for opacity and/or fluid levels suggesting haemorrhage into the antra

C

FIG. 29.19 Suggested systematic approach to interpretation of the 0° occipitomental (OM). **(A)** An example of a 0° OM. **(B)** Diagram of a 0° OM showing Campbell's curvilinear lines and the secondary curves. **(C)** An explanation of Campbell's lines and the secondary curves.





Use a similar approach as suggested for 0° OM

Step I : Compare both sides following the same *curvilinear lines,* traversing the radiograph from one side to the other, as indicated.

↓

Step II : Compare both sides following the same *secondary curves,* as illustrated again on the right side of the diagram.

Note: Although not at right angles to the 0° OM, the 30° OM provides another view of the facial bones at a different angle. All the usual sites for middle third fractures should be checked as for the 0° OM. However, because of the angulation of the X-ray beam the zygomatico-frontal sutures may be difficult to see.

C

FIG. 29.20 Suggested systematic approach to interpretation of the 30° occipitomental (OM). **(A)** An example of a 30° OM. **(B)** Diagram of a 30° OM showing Campbell's curvilinear lines and the secondary curves. **(C)** An explanation of the systematic approach.

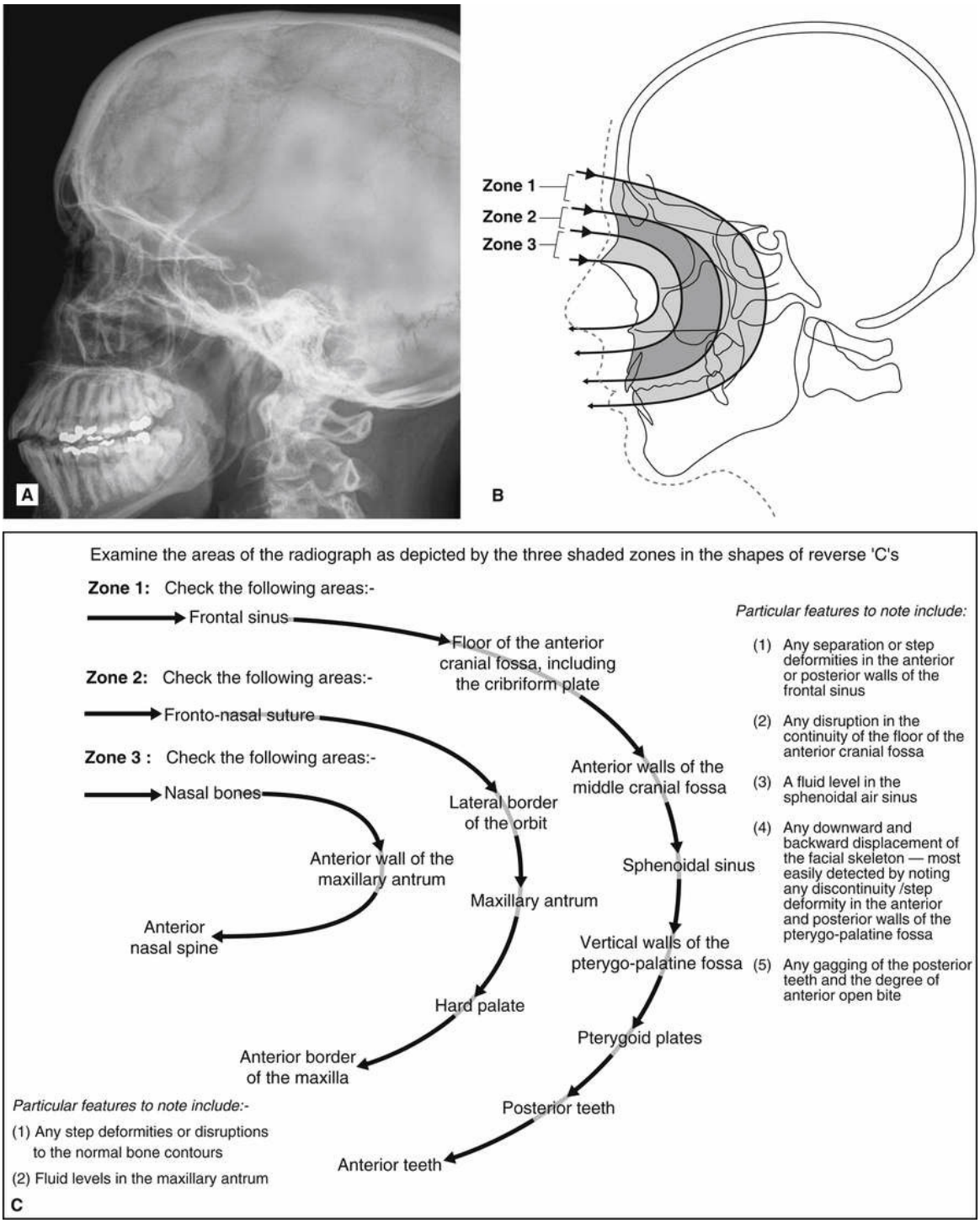


FIG. 29.21 Suggested systematic approach to interpretation of the true lateral skull. **(A)** An example of a true lateral skull. **(B)** Diagram of a lateral skull showing the three curved zones. **(C)** An explanation of the systematic approach to the zones.

Examples of Middle Third Facial Fractures

Examples of injuries to different parts of the facial skeleton are shown in Figs. 29.22 –29.29 .

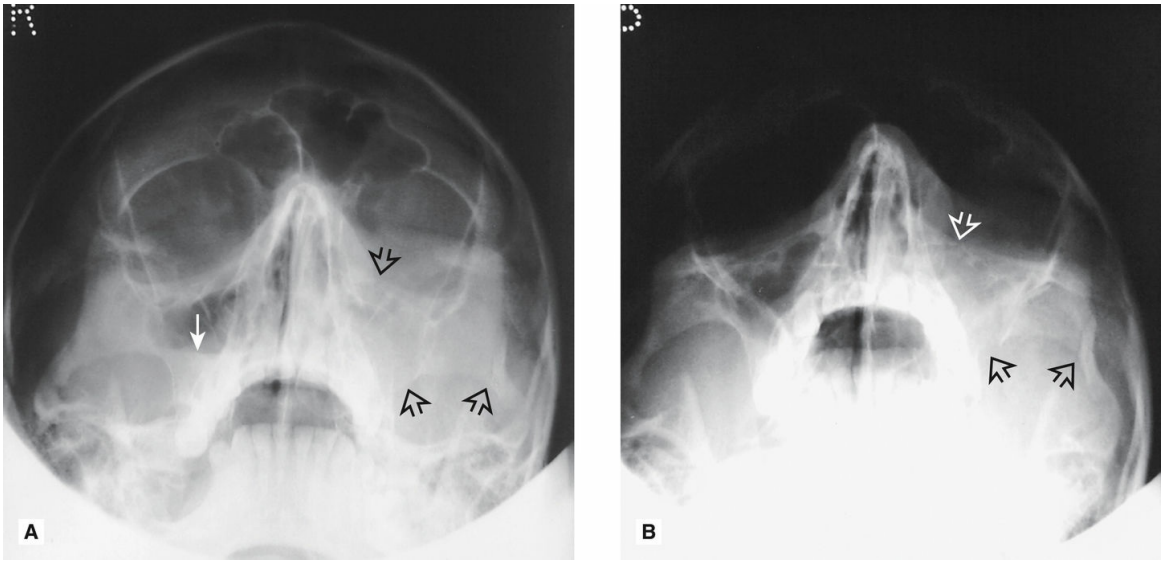


FIG. 29.22 **(A)** 0° occipitomental (OM) and **(B)** 30° OM showing a fracture of the left zygomatic complex. Three of the usual fracture sites are arrowed: the lower border of the orbit, the zygomatico-temporal suture (zygomatic arch) and the lateral wall of the antrum. There is a fluid level evident in the right antrum (white arrow).

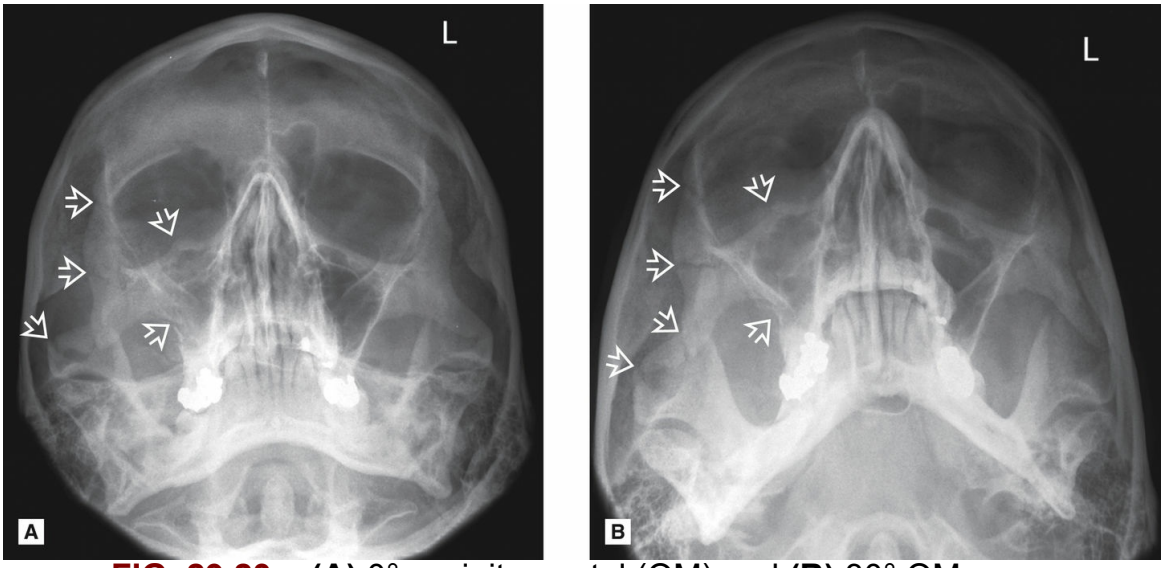


FIG. 29.23 **(A)** 0° occipitomental (OM) and **(B)** 30° OM showing a fracture of the right zygomatic complex. The main fracture sites are arrowed.

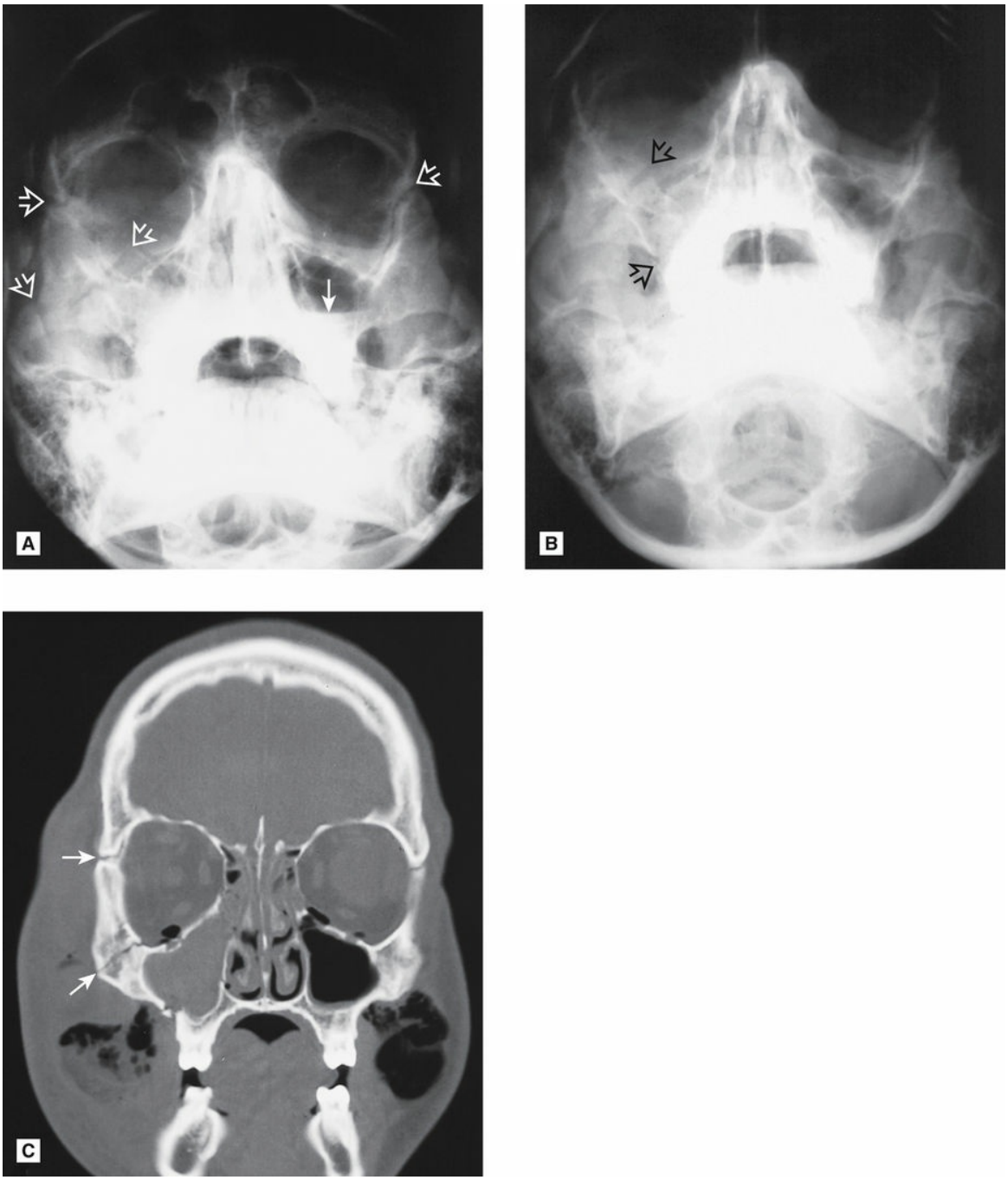


FIG. 29.24 **(A)** 0° occipitomental (OM), **(B)** 30° OM and **(C)** coronal section CT scan of different patients showing multiple middle third fracture sites, the more obvious of which are arrowed. In addition, the CT shows the right antrum to be totally opaque, the extensive soft tissue swelling and air in the orbits and soft tissues.

Courtesy of Dr J. Luker.

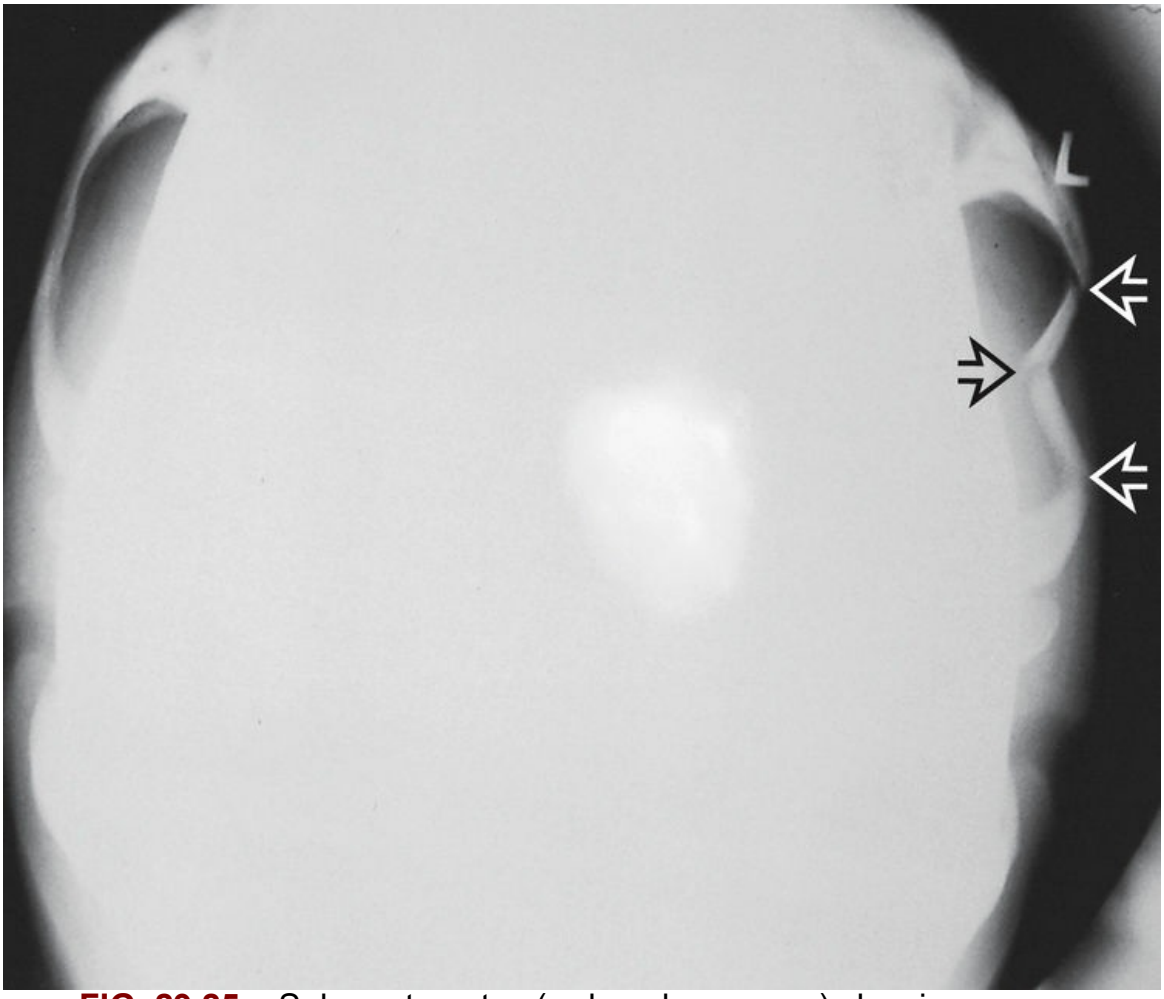


FIG. 29.25 Submentovertex (reduced exposure) showing a depressed fracture of the left zygomatic arch. Typically this type of injury results in three fracture sites, which are arrowed.

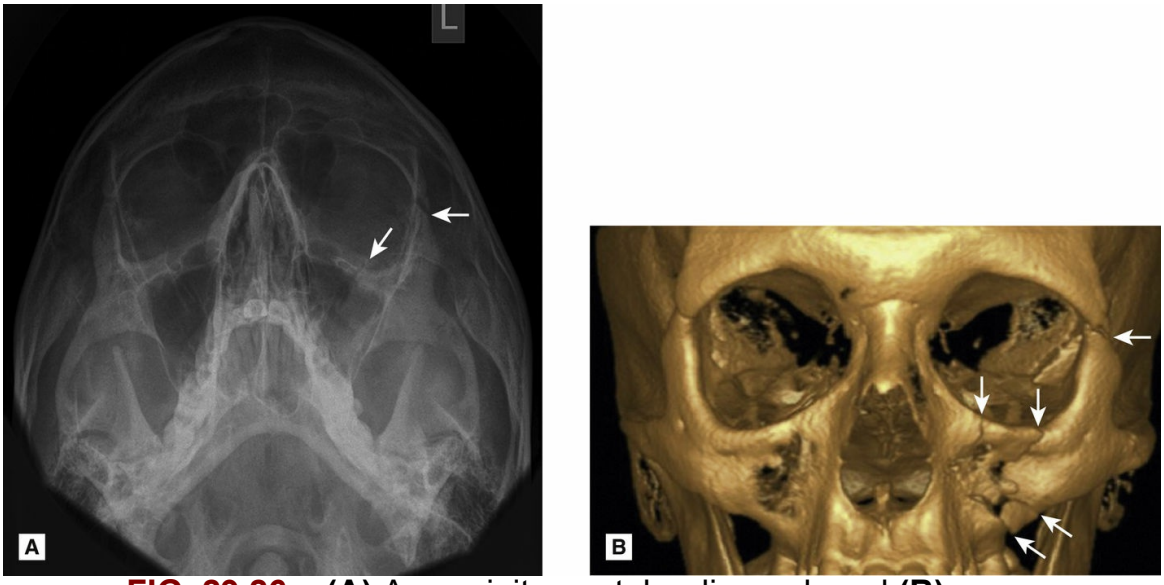


FIG. 29.26 **(A)** An occipitomental radiograph and **(B)** volume-rendered 3-D CBCT image showing a fracture of the left zygomatic complex. The more obvious fracture sites are arrowed.

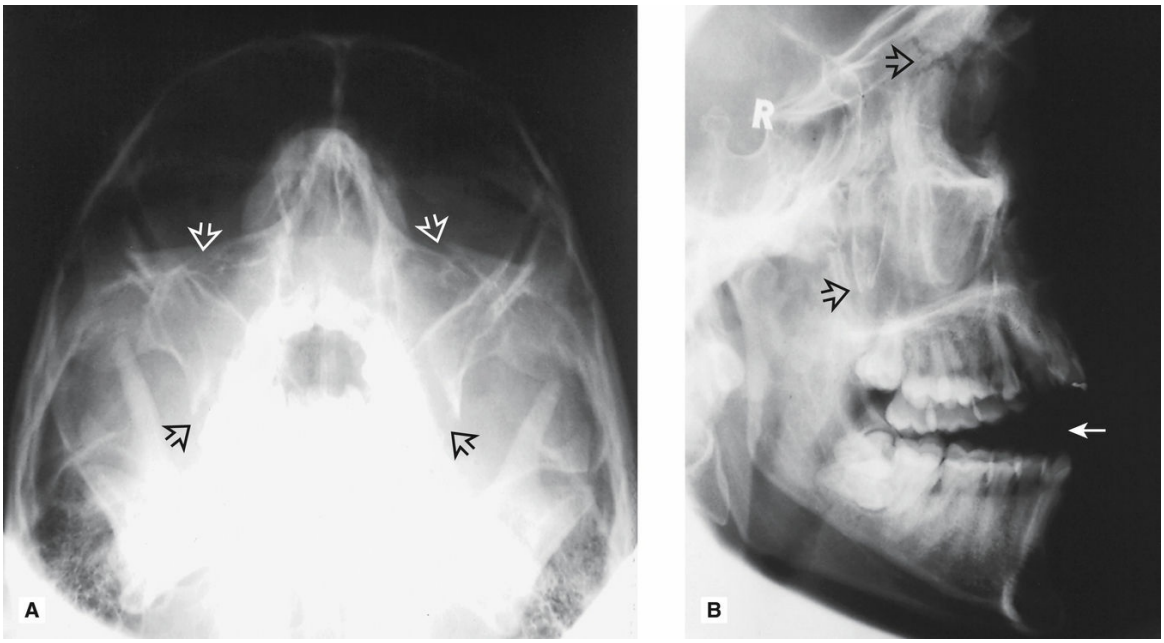


FIG. 29.27 **(A)** A 30° occipitomental and **(B)** true lateral skull showing Le Fort II fracture. The more obvious fractures are arrowed including the pterygopalatine fossa walls. As a result of the backward displacement of the facial skeleton the

posterior teeth are in occlusion and there is an anterior open bite (solid arrow).

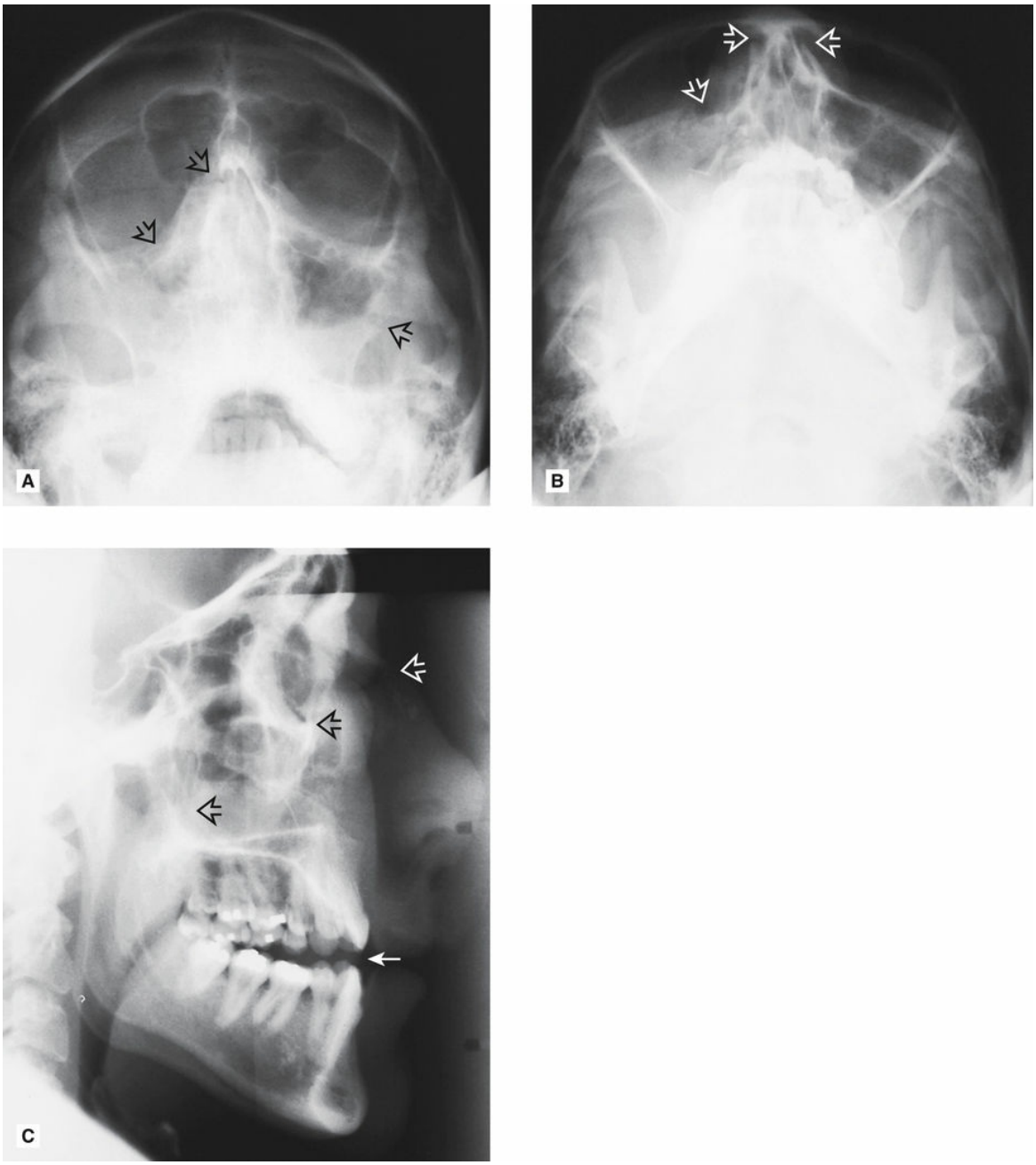


FIG. 29.28 **(A)** 0° occipitomental (OM) and **(B)** 30° OM and **(C)** true lateral skull showing multiple middle facial fractures including the nasal complex (arrowed). The facial skeleton has again been displaced backwards, producing an anterior open bite.

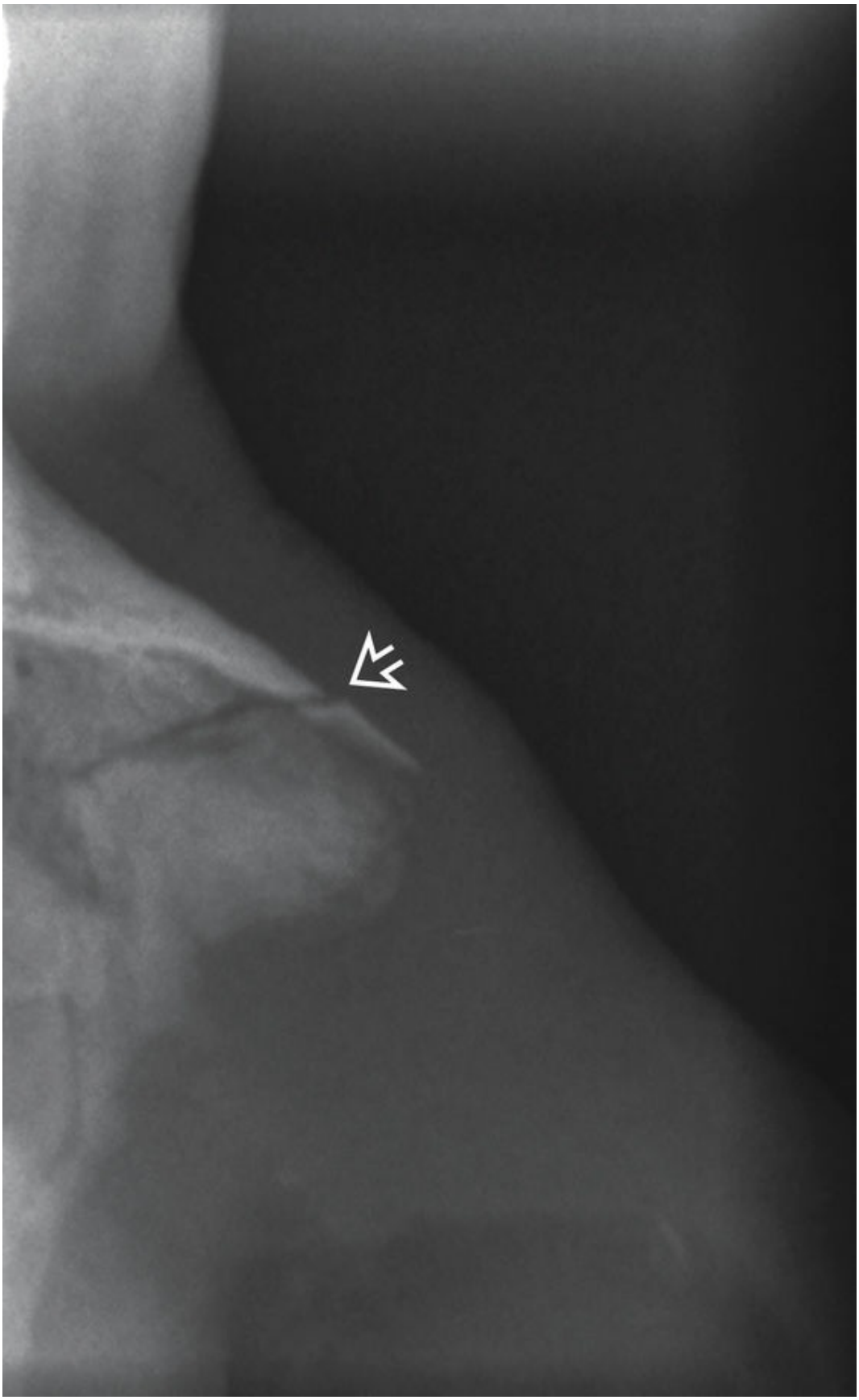


FIG. 29.29 Soft tissue lateral view of the nose showing fracture of the nasal bones (arrowed).

Orbital Blow-out Fracture

After a direct blow to the globe of the eye, the orbital rim remains intact but the force of the blow is transmitted either downwards or medially. The very thin bones of the orbital floor can break and allow the contents of the globe to herniate downwards into the antrum. Superimposition on conventional radiographs makes this type of fracture difficult to detect, hence the need for computed tomography (if available) or cone beam computed tomography to determine the site and severity of the injury (see Fig. 29.30).

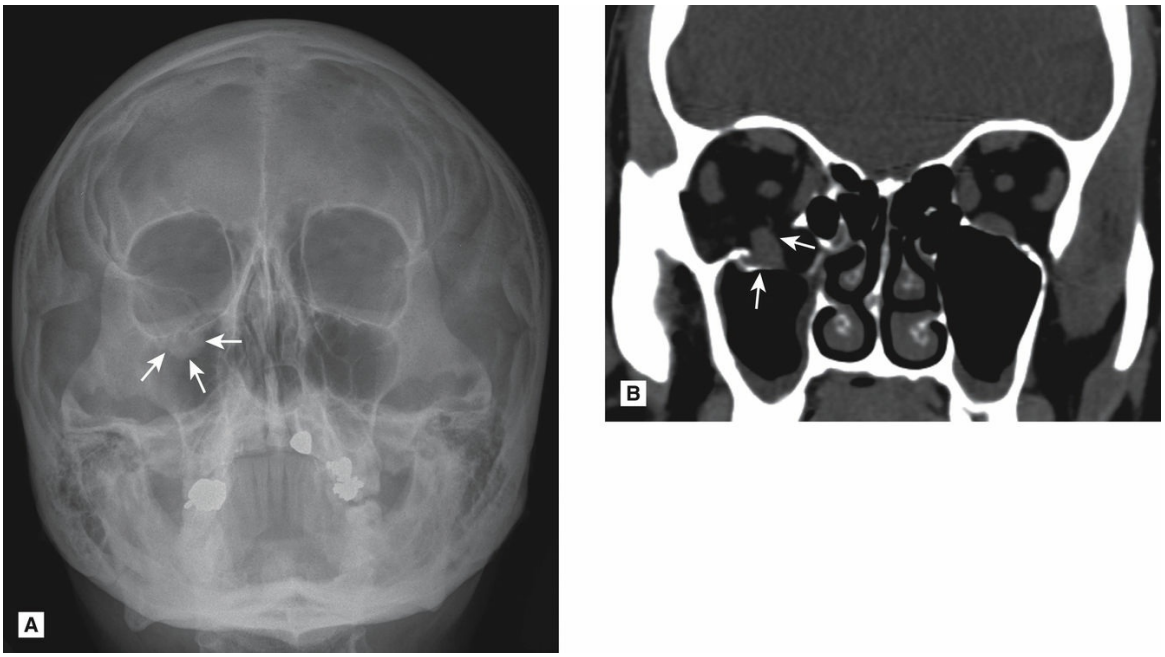


FIG. 29.30 Fracture of the orbital floor producing the *hanging drop* appearance on **(A)** an occipitomental radiograph (arrowed) and **(B)** a coronal section CT scan (arrowed).

Other Fractures and Injuries

Facial fractures are often associated with some other injury involving the head and neck. These can be divided broadly into:

- Fractures of the skull vault
- Fractures of the cranial base
- Fractures of the cervical spine
- Intracranial injuries.

It is beyond the scope of this book to discuss these injuries in detail, but the more commonly used radiographic investigations of the cranium and cervical spine are summarized in Table 29.3 .

Table 29.3

Summary of the various investigations that have traditionally been used for fractures of the cranium and cervical spine (many of these have now been replaced by CT scanning)

Fracture type/site	Commonly used investigations
Skull vault	Posteroanterior (PA skull) (for the frontal bones) True lateral skull (for the sides of the skull, including the parietal bones, frontal bones, squamous temporal bones, sphenoid bone – greater wings) Anteroposterior (AP skull) or Towne's view (for the occipital bone) Tangential views of trauma site to show depressed fractures
Cranial base	True lateral skull (*brow-up*) Submentovertex (SMV)
Cervical spine	True lateral of the neck Anteroposterior (AP) of the neck Anteroposterior (AP) with the mouth open (for the odontoid peg)

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

30

The Temporomandibular Joint

Introduction

The temporomandibular joint (TMJ) is one of the most difficult areas to investigate radiographically. This fact is underlined by the many types of investigations that have been developed over the years. Several plain radiographic projections and various modern imaging modalities are used for showing different parts of the complex joint anatomy. The clinical problems are complicated by the broad spectrum of conditions that can affect the joints, which can present with very similar signs and symptoms, and by prolonged searches for objective signs to explain TMJ pain dysfunction.

From the investigative point of view the knowledge required by clinicians includes:

- The normal anatomy of the TMJ
- What investigations are available, and in particular for each investigation:
  - The clinical indications
  - How the investigation is performed
  - The clinical information provided
  - The limitations and disadvantages
- The radiographic features of the more common pathological conditions that can affect the joints.

Normal Anatomy

The basic components of the TMJ include:

- The mandibular component, i.e. the head of the condyle
- The disc
- The temporal component, i.e. the glenoid fossa and articular eminence
- The capsule surrounding the joint (see Figs. 30.1 and 30.2).

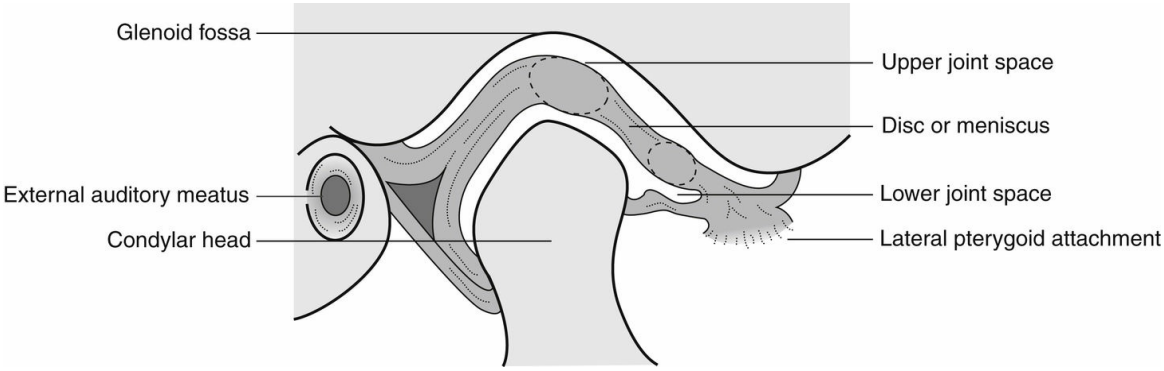


FIG. 30.1 Diagram of a sagittal section through the right temporomandibular joint showing the various components.

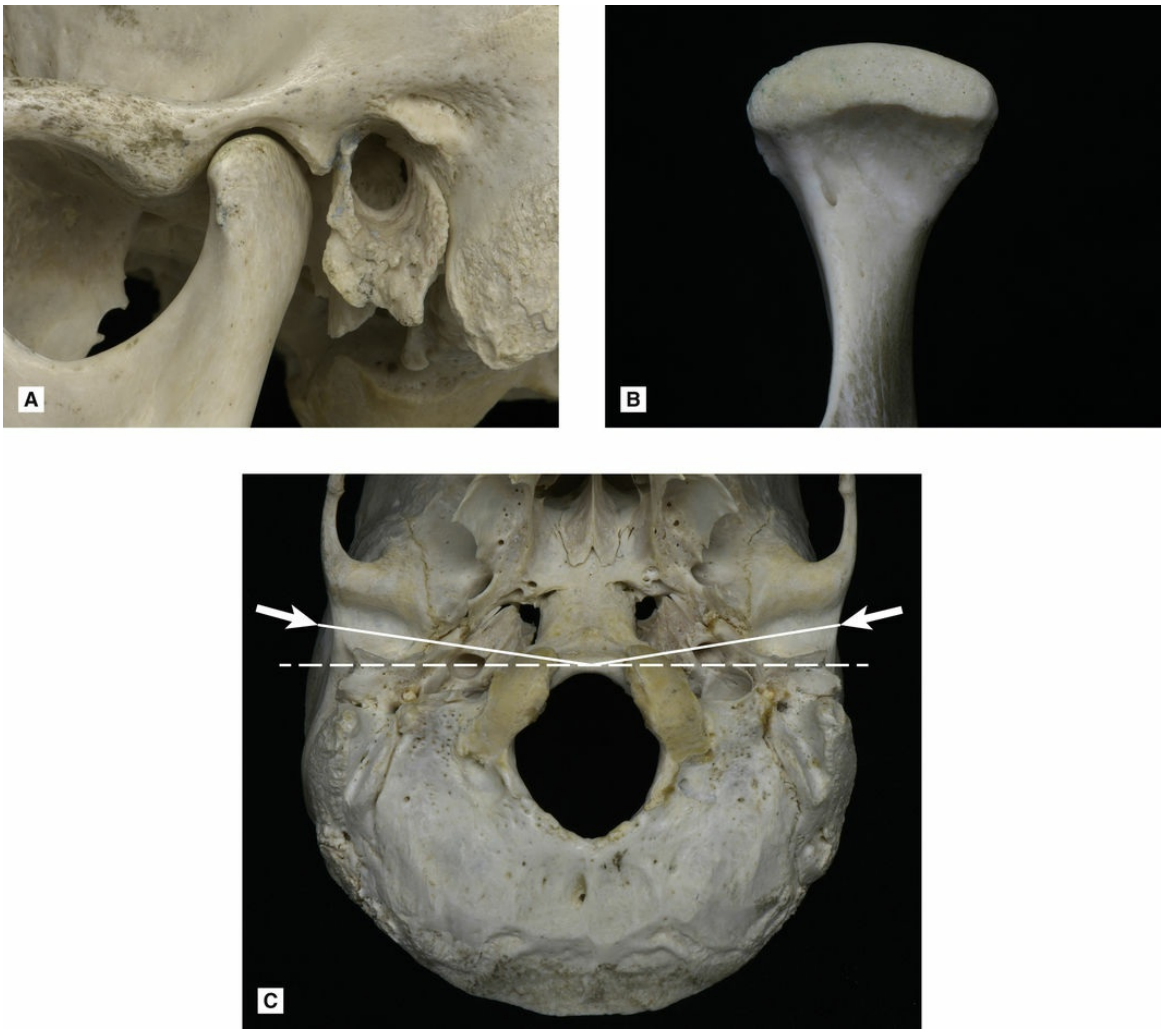


FIG. 30.2 **(A)** The bony components of the joint from the side. **(B)** The head of the condyle from the anterior aspect. **(C)** The base of the skull from below. The glenoid fossae (arrowed) and their angulation to the coronal plane have been drawn in.

In addition to this knowledge of the *static* anatomy, clinicians need to be aware of the types and range of joint movements which result in the condyles moving *downwards* and *forwards* when patients open their mouths. These include:

- Hinge or rotation of the condyle within the fossa
- Translation or excursive movement of the condyle down the articular eminence. The disc being attached to the condyle also moves forwards as shown in Fig. 30.3 .

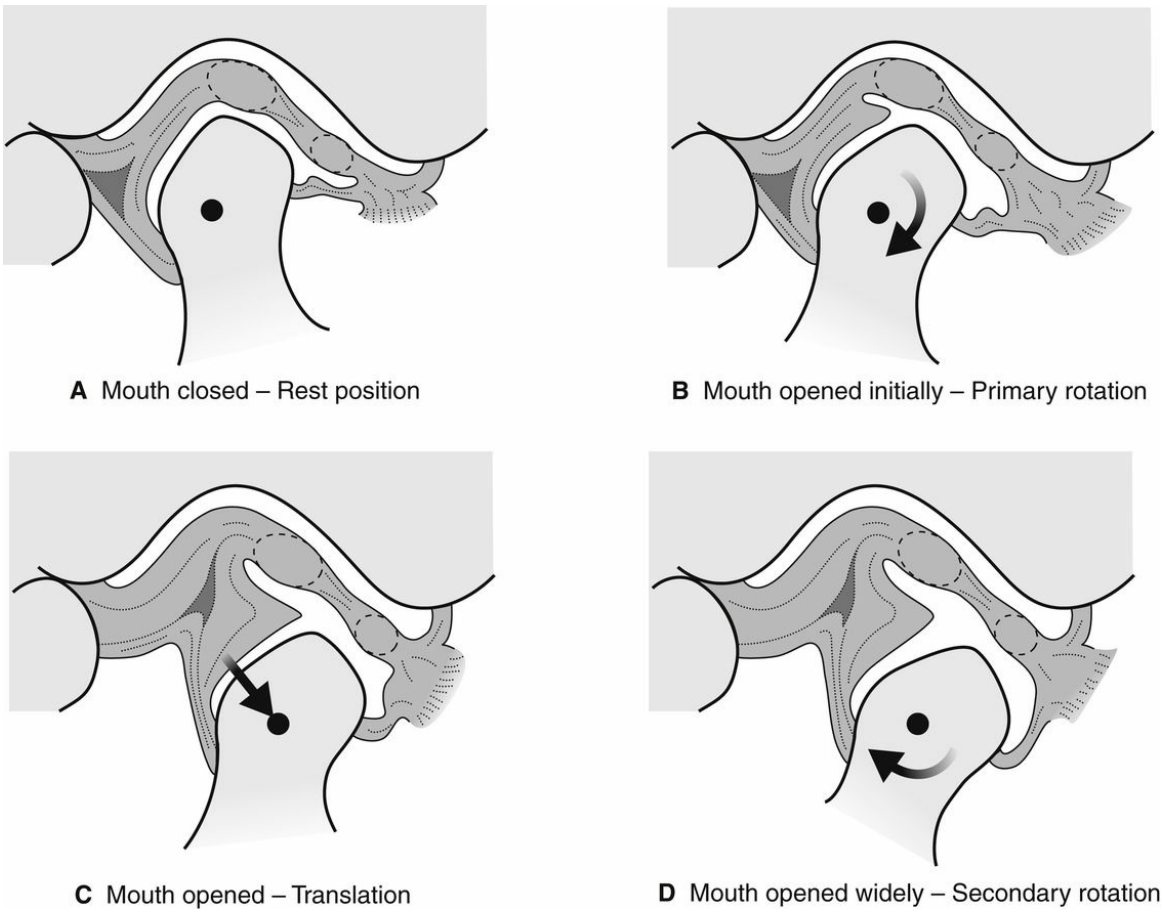


FIG. 30.3 Diagrams showing the rotary and translatory movements of the condyle during normal mouth opening.

Investigations

Modern imaging of the TMJ depends on the facilities available, but could include:

- Conventional panoramic radiography
- Specific field limitation TMJ panoramic programmes
- Transpharyngeal radiography
- Cone beam computed tomography (CBCT)
- Magnetic resonance imaging
- Computed tomography (CT)
- Nuclear medicine, e.g. single photon emission computed tomography (SPECT)

- Arthrography
- Arthroscopy.

Previously described *transorbital* and *transcranial* views are now seldom used and are only of historical interest.

Panoramic Radiography

Main Indications

The main clinical indications include:

- TMJ pain dysfunction syndrome if bone anomalies are suspected clinically
- To investigate disease within the joint
- To investigate pathological conditions affecting the condylar heads
- Fractures of the condylar heads or necks
- Condylar hypo/hyperplasia.

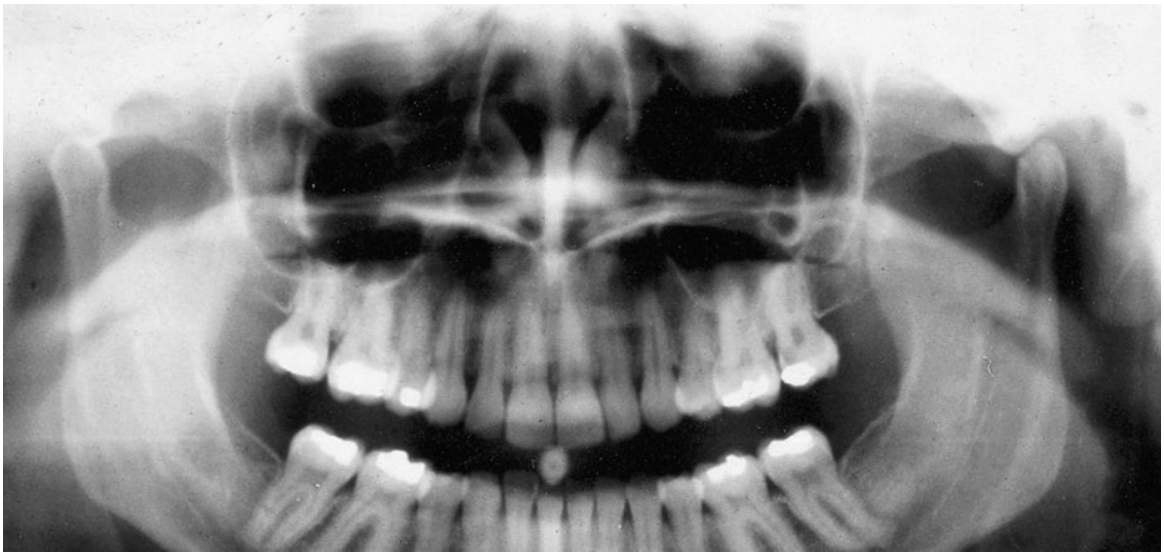


FIG. 30.4 A *high* panoramic radiograph showing normal condylar heads.

Technique Summary

Conventional panoramic radiographs usually image both condylar heads, although to guarantee this the technique can be modified by raising the X-ray tubehead and cassette carriage assembly to a slightly higher level in relation to the patient, the so-called *high* panoramic, as shown in Fig. 30.4 .

Diagnostic Information

The information provided includes:

- The shape of the condylar heads and the condition of the articular surfaces from the lateral aspect
- A direct comparison of both condylar heads.

Panoramic TMJ Programmes

Main Indications

The main clinical indications are the same as for a conventional panoramic radiograph. If the equipment includes specific TMJ programmes these should be regarded as the views of choice because additional information can be provided when the mouth is opened.

Technique Summary

The technique can be summarized as follows:

- The patient is positioned with their Frankfort plane angled 5° downwards within a panoramic unit with their mouth closed but using a special nose/chin support, as shown in Fig. 30.5A instead of the bite-peg
- The head is accurately positioned using the light beam markers and immobilized using the temple supports
- The distance from the external auditory meatus to the canine light is measured and the anteroposterior position of the chin

support adjusted manually to ensure that the condyles appear in the middle of the image
- During the exposure, first the left and then the right condyle is imaged in the closed position
- The equipment automatically returns to the start position
- The patient is instructed to open the mouth as shown in Fig. 30.5B
- The left and right condyles are then exposed in the open position and the resultant image is shown in Fig. 30.6 .

Diagnostic Information

The information provided includes:

- The shape of the condylar heads and the condition of the articular surfaces from the lateral aspect
- The range of movement of the condyles when the mouth is open
- A direct comparison of both condylar heads.



FIG. 30.5 **(A)** Patient positioned with the mouth closed within the Planmeca ProOne panoramic unit using the special nose/chin support and **(B)** positioned with the mouth open.

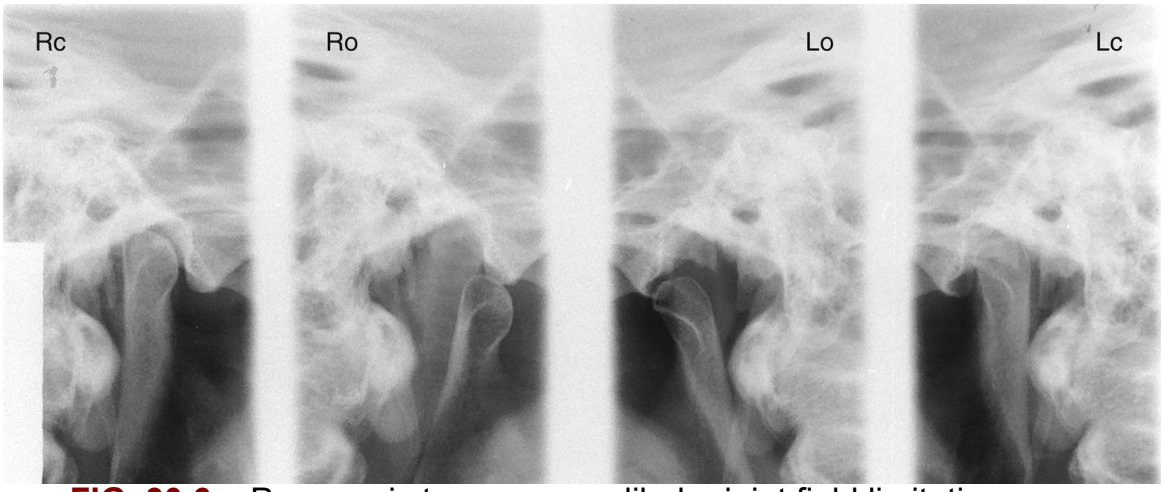


FIG. 30.6 Panoramic temporomandibular joint field limitation programme images of normal right and left condylar heads in the mouth closed (c) and open (o) positions.

Transpharyngeal Radiography

Main Indications

The main clinical indications include:

- TMJ pain dysfunction syndrome
- To investigate the presence of joint disease, particularly osteoarthritis and rheumatoid arthritis
- To investigate pathological conditions affecting the condylar head, including cysts or tumours
- Fractures of the neck and head of the condyle.

Technique and Positioning

This projection can be taken with a dental X-ray set and an extraoral cassette. The technique can be summarized as follows:

1. The patient holds the cassette against the side of the face over the TMJ of interest. The image receptor and the mid-sagittal plane of the head are parallel. The patient's mouth is open and a bite-block is inserted for stability.

2. The X-ray tubehead is positioned in front of the opposite condyle and beneath the zygomatic arch. It is aimed through the sigmoid notch, slightly posteriorly, across the pharynx at the condyle under investigation as shown in Fig. 30.7 . Usually this view is taken of both condyles to allow comparison.

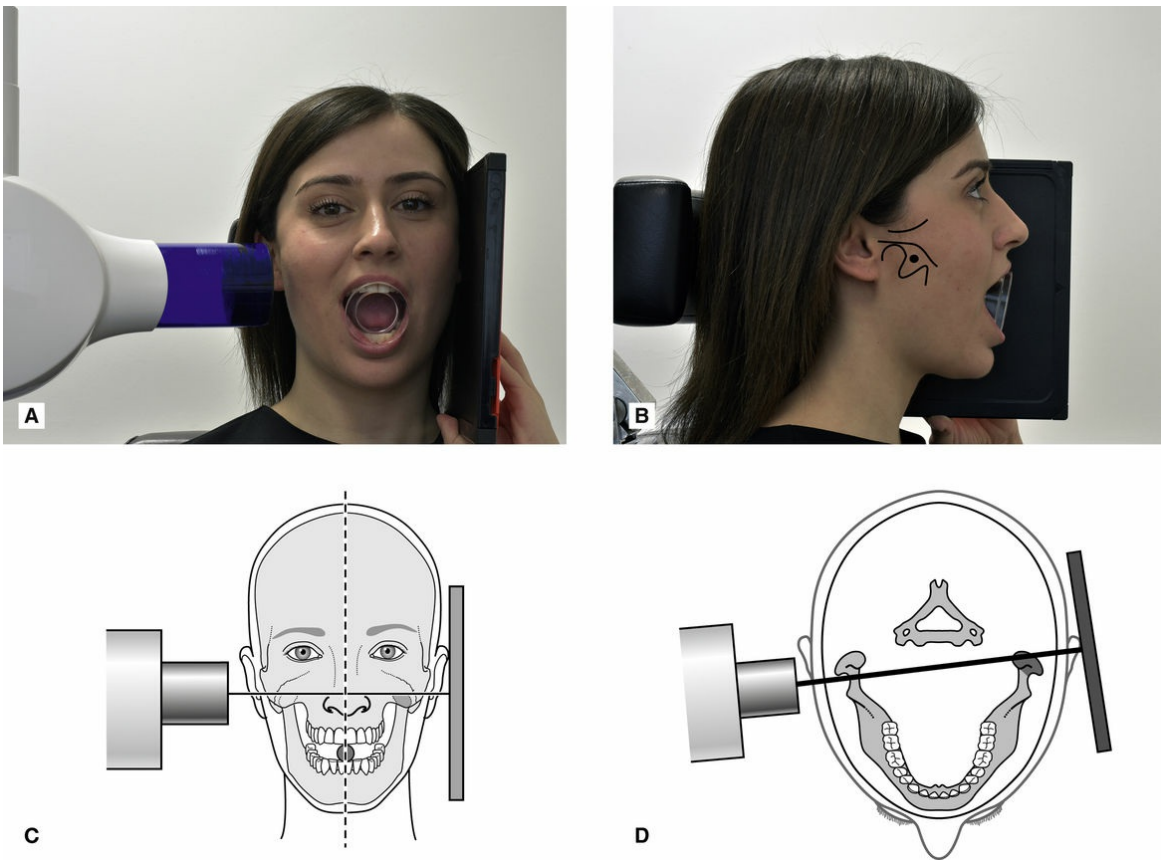


FIG. 30.7 **(A)** Positioning for the left transpharyngeal – the patient is holding the cassette against the left temporomandibular joint, the mouth is open and the X-ray beam is aimed across the pharynx. **(B)** The side of the face with various anatomical structures – the zygomatic arch, condyle, sigmoid notch and coronoid process – drawn in to clarify the centring point of the X-ray beam which is marked. **(C)** Diagram of the positioning from the front showing the film parallel to the mid-sagittal plane and the X-ray beam aimed across the pharynx. **(D)** Diagram of the positioning from above, showing the X-ray beam aimed slightly posteriorly across the pharynx.

Diagnostic Information

The information provided includes:

- The shape of the head of the condyle and the condition of the articular surface from the lateral aspect as shown in Fig. 30.8

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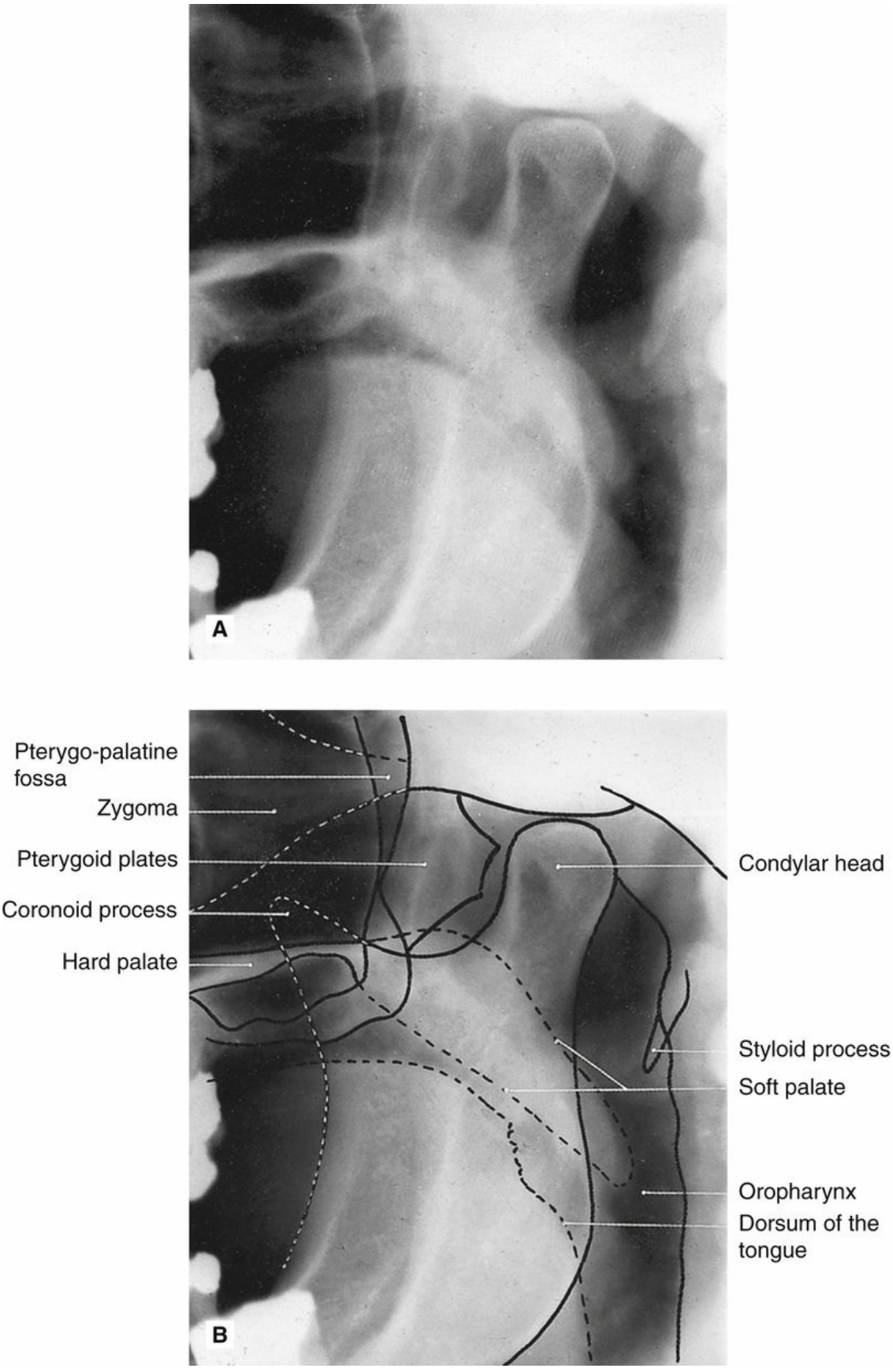

A
Pterygo-palatine fossa
Zygoma
Pterygoid plates
Coronoid process
Hard palate
Condylar head
Styloid process
Soft palate
Oropharynx
Dorsum of the tongue
B

FIG. 30.8 **(A)** An example of a transpharyngeal radiograph of a normal left condyle. **(B)** The same radiograph with the major anatomical features drawn in.

Cone Beam Computed Tomography (CBCT)

CBCT, which is described in Chapter 16 , is increasingly being used as an alternative to CT to image the bony elements of the TMJ (see Figs. 30.9 and 30.10). Sectional or slice images of all aspects of the joints are produced, but in addition, using appropriate software, three-dimensional images can be created as shown in Fig. 30.11 .

Main Indications

The main clinical indications include:

- Full assessment of the whole of the joint to determine the presence and site of any bone disease or abnormality
- To investigate the condyle and articular fossa when the patient is unable to open the mouth
- Assessment of fractures of the condylar head and articular fossa and intracapsular fractures.

Diagnostic Information

The information provided includes:

- The shape of the condyles and the condition of the articular surfaces
- The condition of the glenoid fossae and eminences
- The nature of any disease affecting the condylar heads.

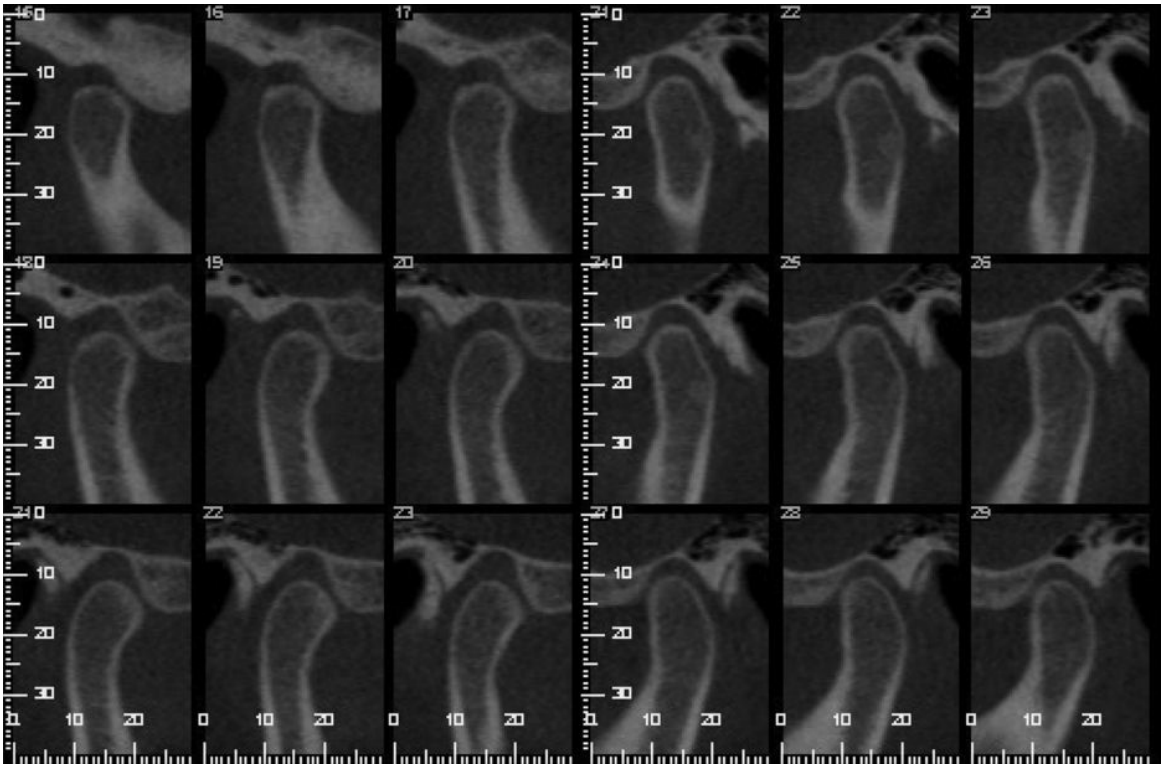


FIG. 30.9 A series of near-sagittal CBCT images of normal right and left condyles.

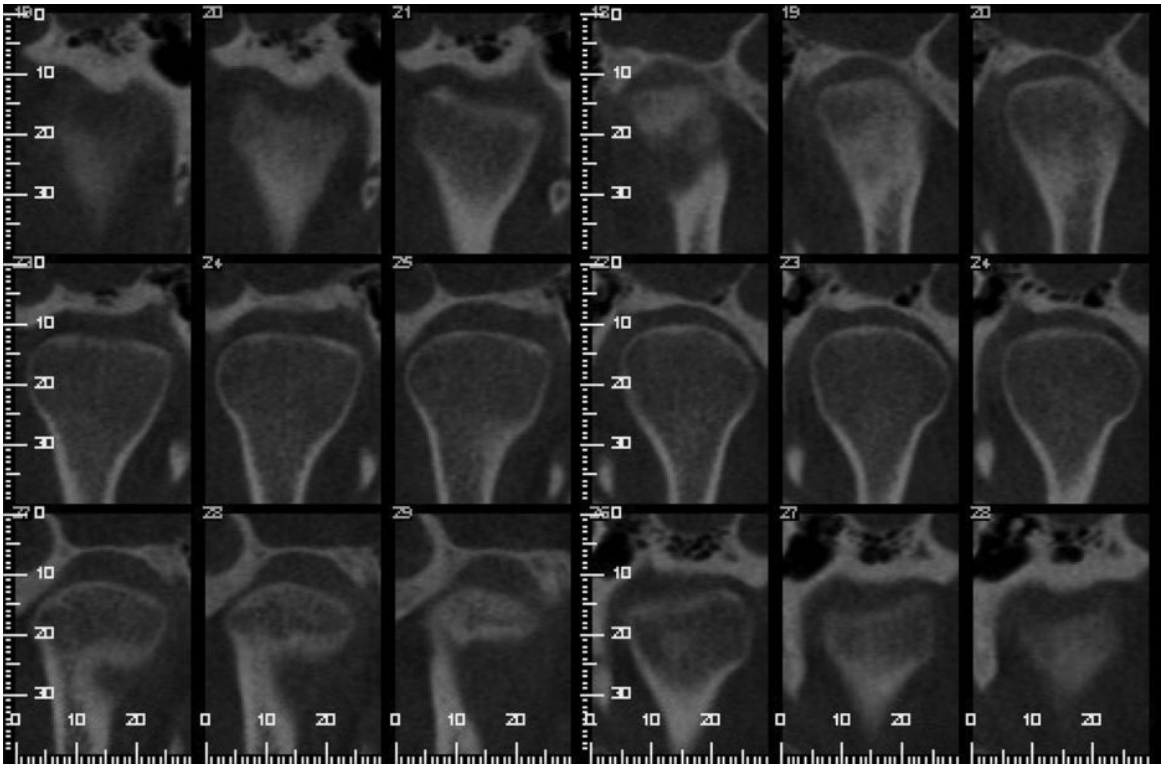


FIG. 30.10 A series of near-coronal CBCT images of normal right and left condyles.

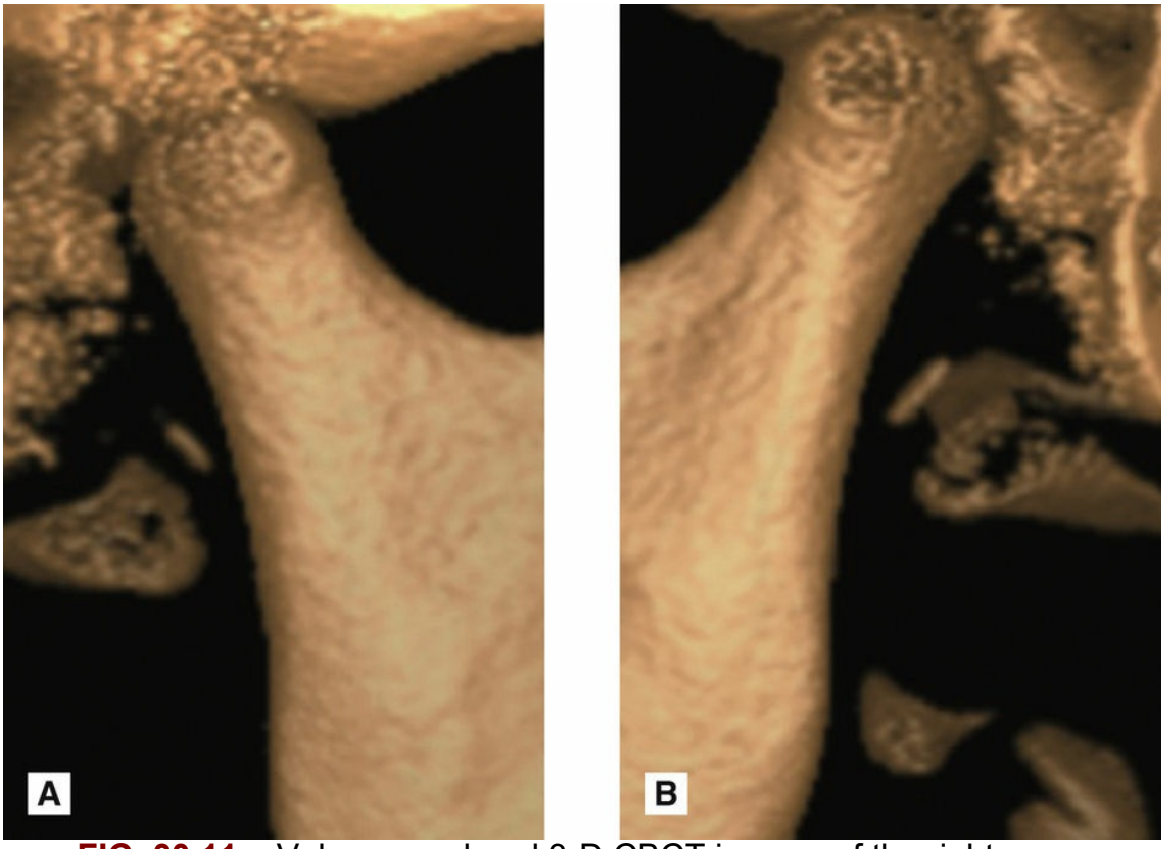


FIG. 30.11 Volume-rendered 3-D CBCT images of the right and left temporomandibular joints.

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging, described in Chapter 18 , is now established as one of the more useful investigations of the bony **and** soft tissue elements of the TMJ. It is particularly useful for determining the position and form of the disc when the mouth is both open and closed (see Fig. 30.12). As mentioned in Chapter 18 , cineloop or pseudodynamic echo sequences are generally used for TMJ imaging:

- When diagnosis of internal derangements is in doubt
- As a preoperative assessment before disc surgery.

Computed Tomography (CT)

CT, which is described in Chapter 18 , like CBCT, provides sectional or slice images of the joint. The advantages of CT are that it can produce images of the hard and soft tissues in the joint, including the disc, in different planes.

Diagnostic Information

This includes:

- The shape of the condyle and the condition of the articular surface
- The condition of the glenoid fossa and eminence
- The position and shape of the disc
- The integrity of the disc and its soft tissue attachments
- The nature of any condylar head disease.

Arthrography

Main Indications

These include:

- Longstanding TMJ pain dysfunction unresponsive to simple treatments
- Persistent history of locking
- Limited opening of unknown aetiology.

Main Contraindications

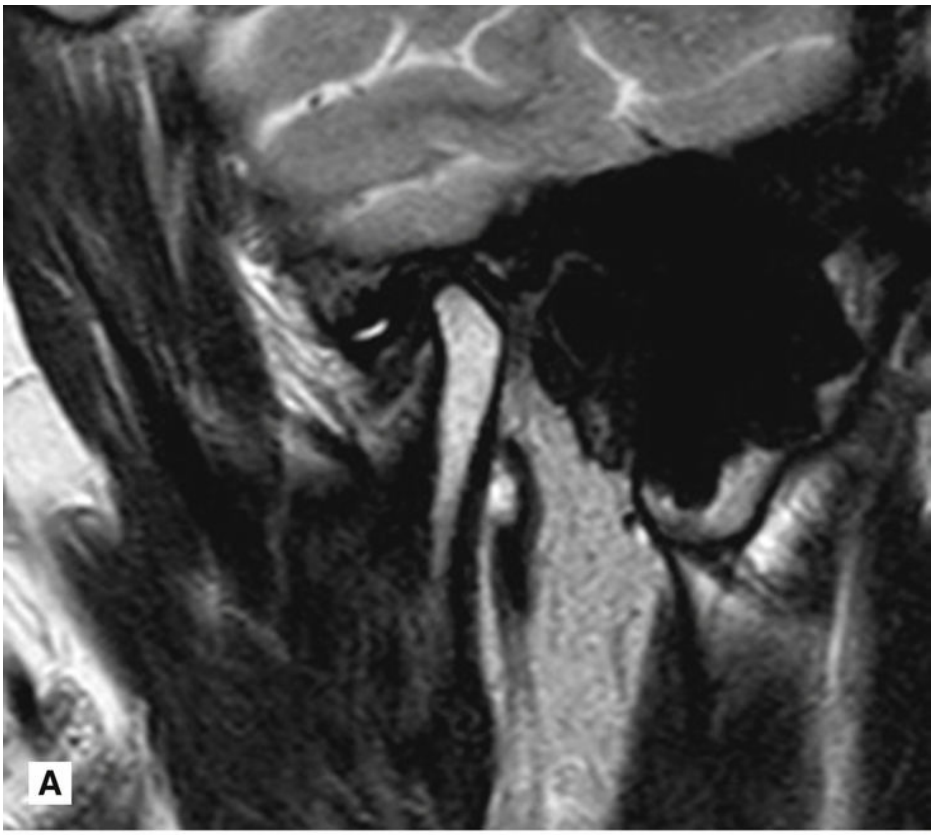
These include:

- Acute joint infection
- Allergy to iodine or the contrast medium.

Technique

The technique used for arthrography can be summarized as follows:

1. Non-ionic aqueous contrast medium (e.g. iopamidol-Niopam® 370) is injected carefully into the lower joint space, using fluoroscopy to aid the accurate positioning of the needle.


A

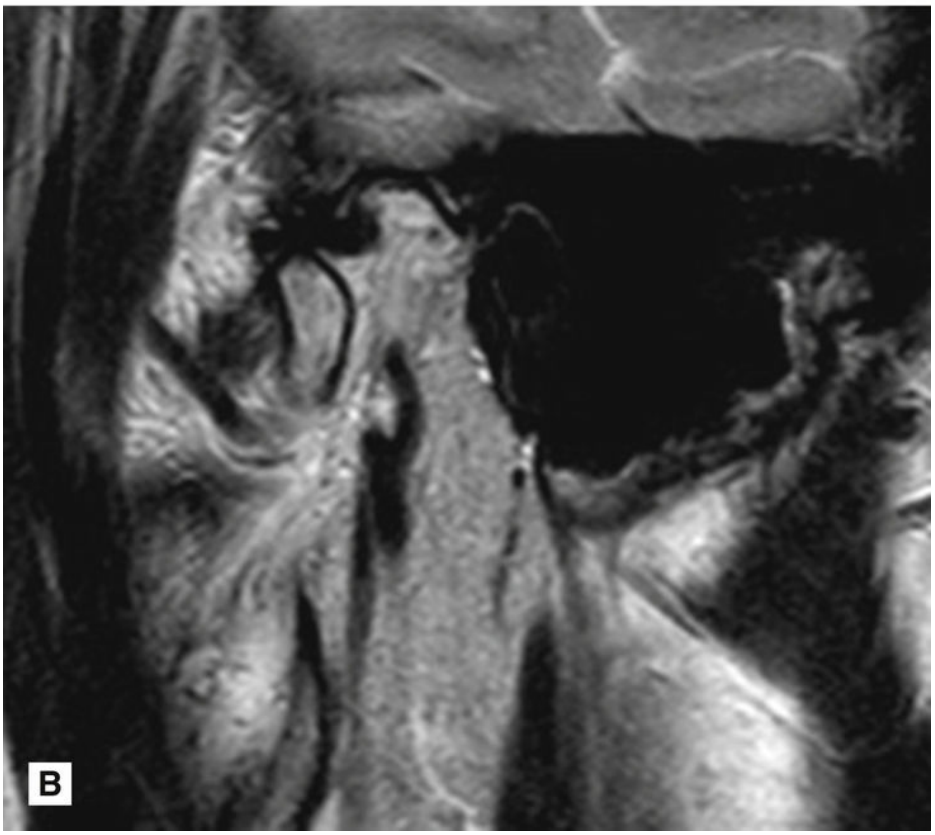

B

FIG. 30.12 Parasagittal T2-weighted images showing a normal temporomandibular joint with **(A)** the mouth closed and **(B)** the mouth open.
Courtesy of Mr S. Harvey.

2. The primary record is obtained ideally using video-recorded fluorography or cinefluorography, which allows imaging of the joint components as they move. Only the lateral aspects of the joints are seen.
3. Thin section tomography of the joint can also be performed if required, to provide information on the medial and lateral aspects of the joint. Typically, five or six slices, 2–3 mm apart, are used with the patient's mouth open and closed.
4. If further information is required, the contrast medium can be introduced into the upper joint space and the investigation repeated.

Diagnostic Information (see Fig. 30.13)

The information provided includes:

- Dynamic information on the position of the joint components and disc as they move in relation to one another
- Static images of the joint components with the mouth closed and with the mouth open. Any anterior or anteromedial displacement of the disc can be observed
- The integrity of the disc, i.e. the presence of any perforations.

NOTE : Outlining the **lower** joint space usually provides the more useful information on the disc.

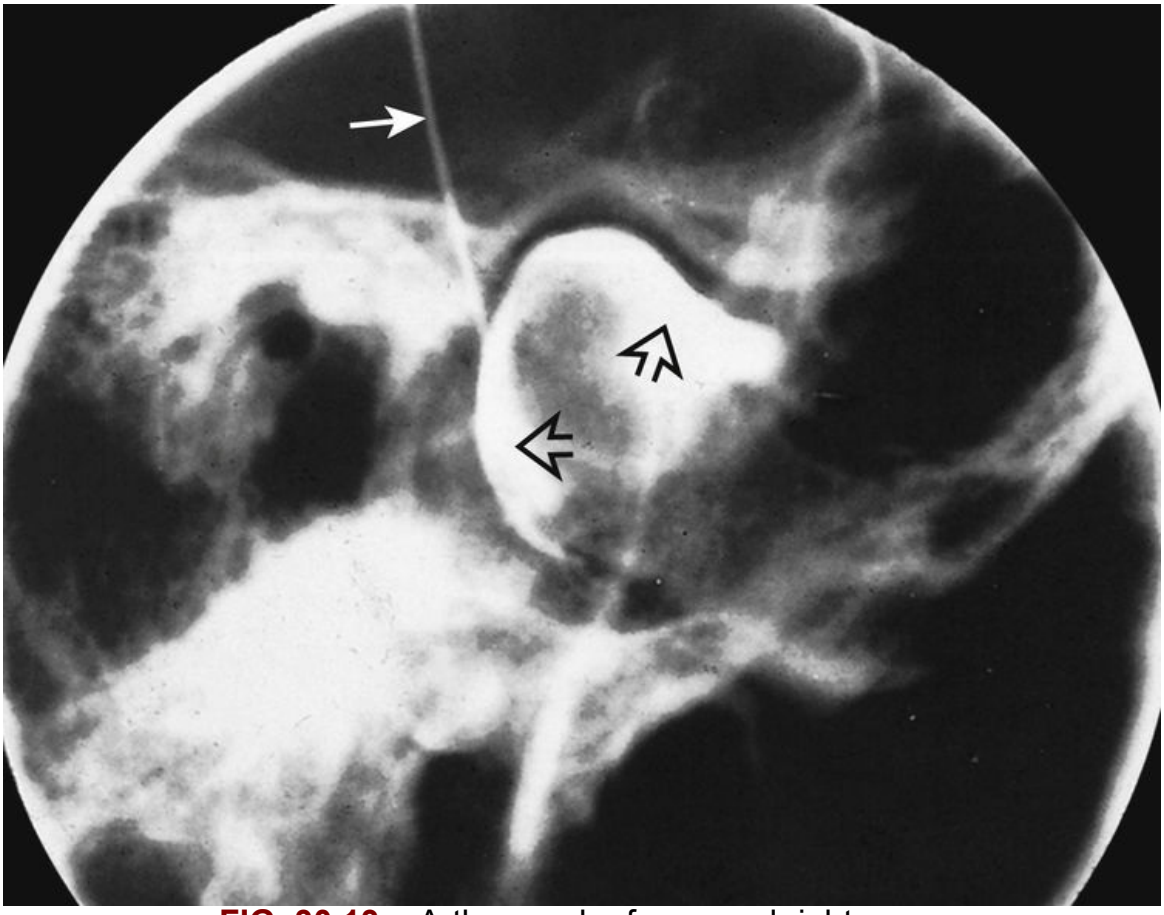


FIG. 30.13 Arthrograph of a normal right temporomandibular joint with the mouth closed. The needle (white arrow) and the contrast medium outlining the lower joint space (open black arrows) are indicated.

Arthroscopy

Arthroscopy gives direct visualization of the TMJ and allows certain interventional procedures to be performed; these include:

- Washing out the joint with saline
- Introduction of steroids directly into the joint
- Division of adhesions
- Removal of loose bodies from within the joint.

Arthroscopy is usually considered as the last line of investigation

before full surgical exploration of the joint is carried out.

Main Pathological Conditions Affecting the TMJ

The main pathological conditions that can affect the TMJ include:

- TMJ pain dysfunction syndrome (myofascial pain dysfunction syndrome)
- Internal derangements
- Osteoarthritis (osteoarthrosis)
- Rheumatoid arthritis
- Juvenile rheumatoid arthritis (Still's disease)
- Ankylosis
- Tumours
- Fractures and trauma
- Developmental anomalies.

TMJ (Myofascial) Pain Dysfunction Syndrome

TMJ pain dysfunction syndrome is the most common clinical diagnosis applied to patients with pain in the muscles of mastication, often worst in the early morning and evening, with occasional clicking and stiffness. The aetiology is said to include anxiety or depression, malocclusion, or muscle spasm.

Main Radiographic Features

These include:

- Normal condylar head shape and articular surface
- Normal glenoid fossa shape
- Possible increase or reduction in the overall size of the *joint space* – an increase in the size of the joint space is only indicative of inflammation

- Possible displacement of the condylar head anteriorly or posteriorly in the glenoid fossa when the mouth is closed and the teeth are in occlusion
- Reduction in the range of condylar movement.

NOTE: In their 2017 publication *iRefer: Making the Best Use of Clinical Radiology* (eighth edition), the Royal College of Radiologists in the UK state that in relation to TMJ dysfunction, radiographs 'do not add information as the majority of TMJ problems are due to soft tissue dysfunction rather than bony changes (which appear late and are often absent in the acute phase)'.

Internal Derangements

Symptoms include clicking which may be painful, pain from the joint and/or musculature, trismus and hesitation of movement and locking usually with failure of opening. Conventional radiography may have revealed an alteration in the position of the head of the condyle, implying an abnormality in disc position. MRI is the investigation of choice (see Fig. 30.14) to show:

- Disc position – it may dislocate anteriorly or anteromedially
- Disc movement relative to the condyle during opening and closing.

Osteoarthritis

This degenerative arthrosis increases in incidence with age and commonly causes pain in the stress-bearing joints, such as the hips and spine. It is now thought to be a systemic disease, or a complication of internal derangement of a joint, and stress merely causes the affected joint to be painful. Radiographic signs of osteoarthritis of the TMJ are often seen in the elderly, but are frequently of no clinical significance. Symptoms, if they occur, can include painful crepitus and trismus and are usually persistent.

Main Radiographic Features (see Figs. 30.15 –30.17)

These include:

- Osteophyte (bony spur) formation on the anterior aspect of the articular surface of the condylar head. The radiological appearance of small osteophyte formation is often referred to as *lipping* ; extensive osteophyte formation is referred to as *beaking*

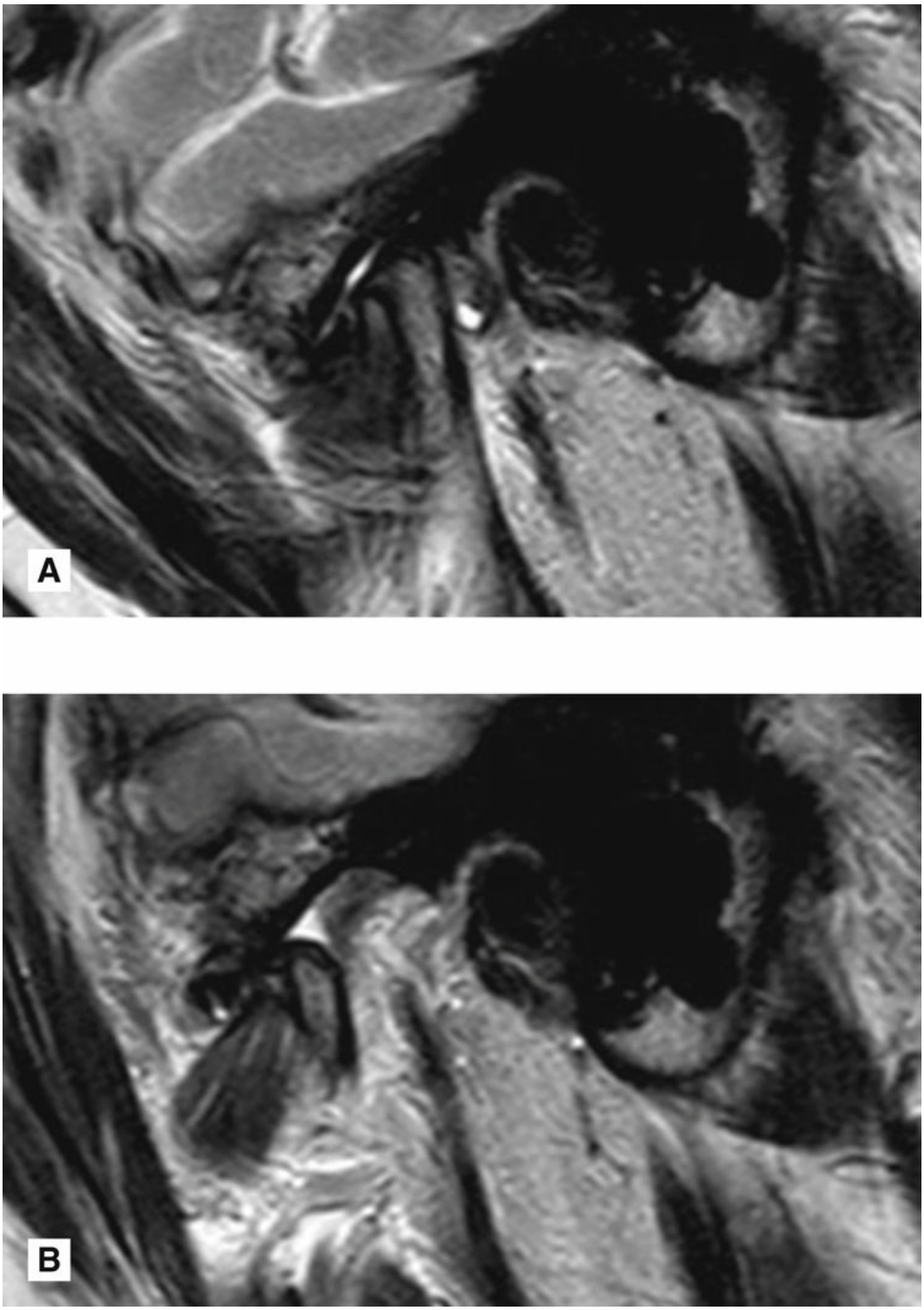


FIG. 30.14 Parasagittal T2-weighted magnetic resonance images showing internal derangement with the disc anteriorly positioned with **(A)** the mouth closed and **(B)** the mouth open.
Courtesy of Mr S. Harvey.

- Flattening of the head of the condyle on the anterosuperior margin
- Subchondral sclerosis of the condylar head, which becomes dense and more radiopaque – a process sometimes referred to as *eburnation*
- A normal outline to the glenoid fossa though it may also become sclerotic
- Very rarely, there may be evidence of:
  - Osteophyte formation posteriorly
  - Subchondral cysts
  - Erosion of the articular surface of the condylar head.



FIG. 30.15 Panoramic TMJ programme showing an example of osteoarthritic change in the left condyle (arrowed) – the shape of the head of the condyle is altered and there is evidence of early anterior osteophyte formation. The right condyle is normal.

Courtesy of Dr J. Luker.

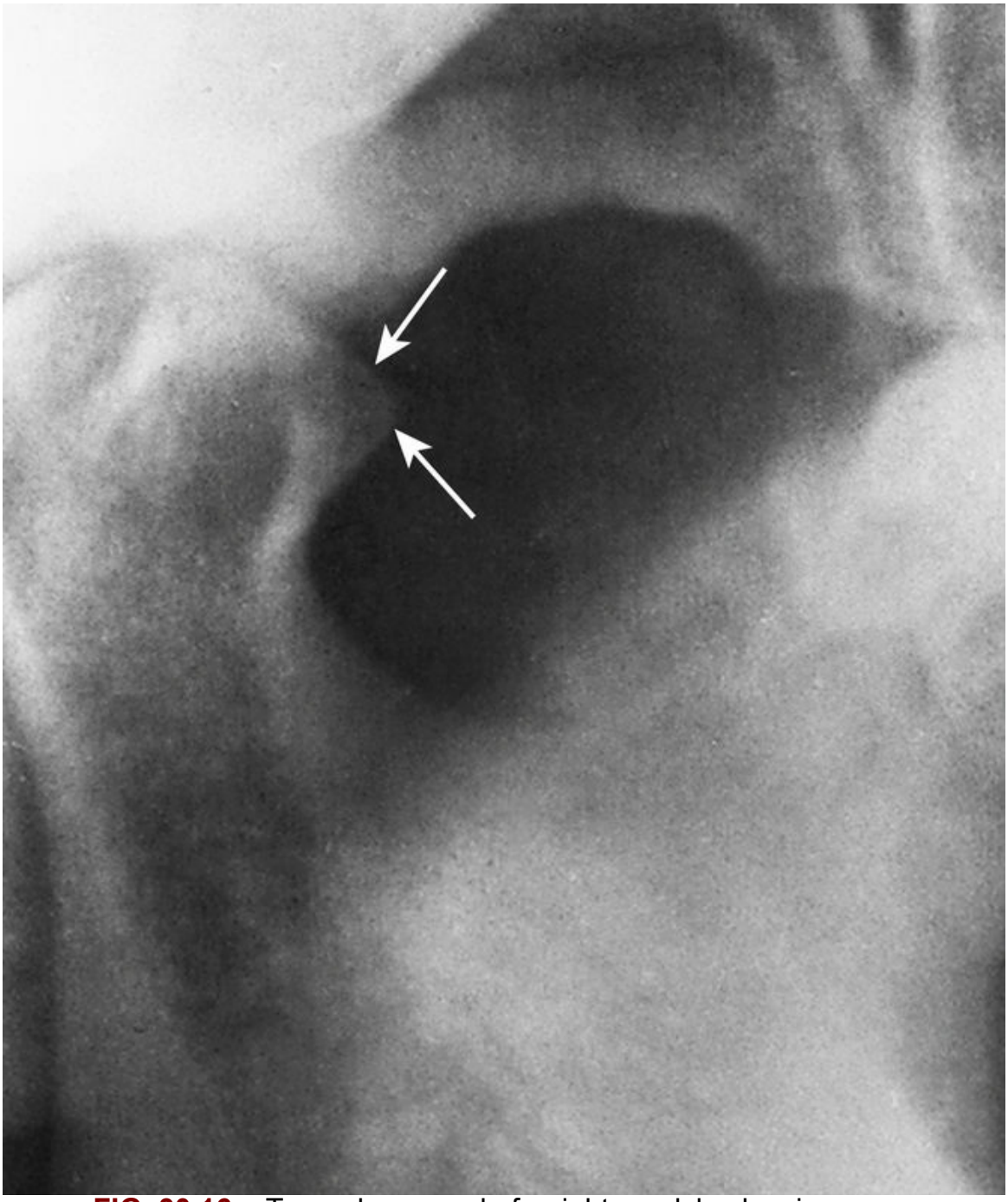


FIG. 30.16 Transpharyngeal of a right condyle showing advanced osteoarthritic change with pronounced anterior osteophyte formation (*beaking*) (arrowed).

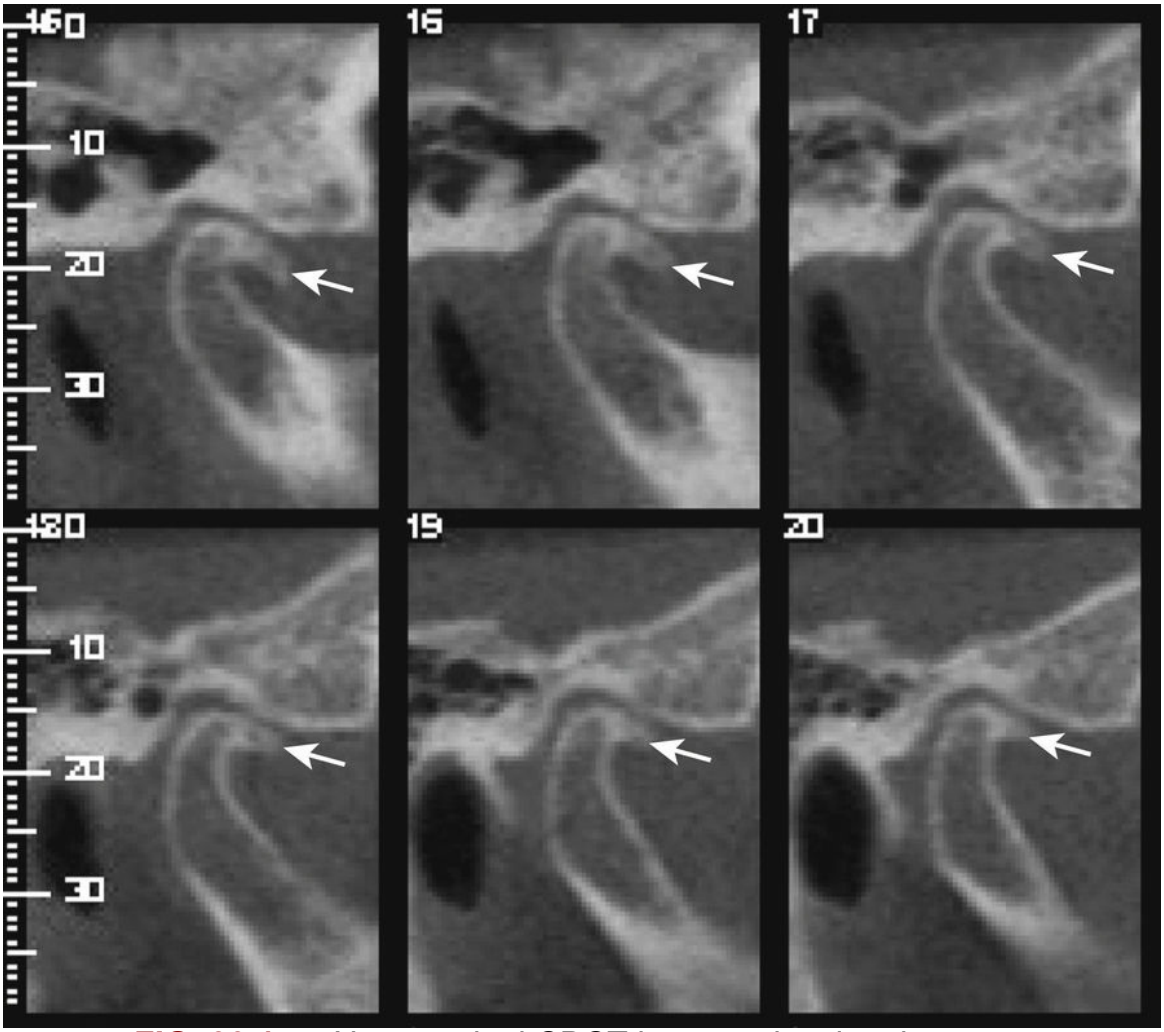


FIG. 30.17 Near-sagittal CBCT images showing the degenerative changes of flattening and anterior ostophyte formation of osteoarthritis affecting the right condyle (arrowed).

Rheumatoid Arthritis

Rheumatoid arthritis is a generalized, chronic inflammatory, connective tissue disease affecting many joints. TMJ involvement can be found, particularly in severe rheumatoid arthritis, but even then TMJ symptoms are usually minor.

Main Radiographic Features (see Figs. 30.18

–30.21)

These include:

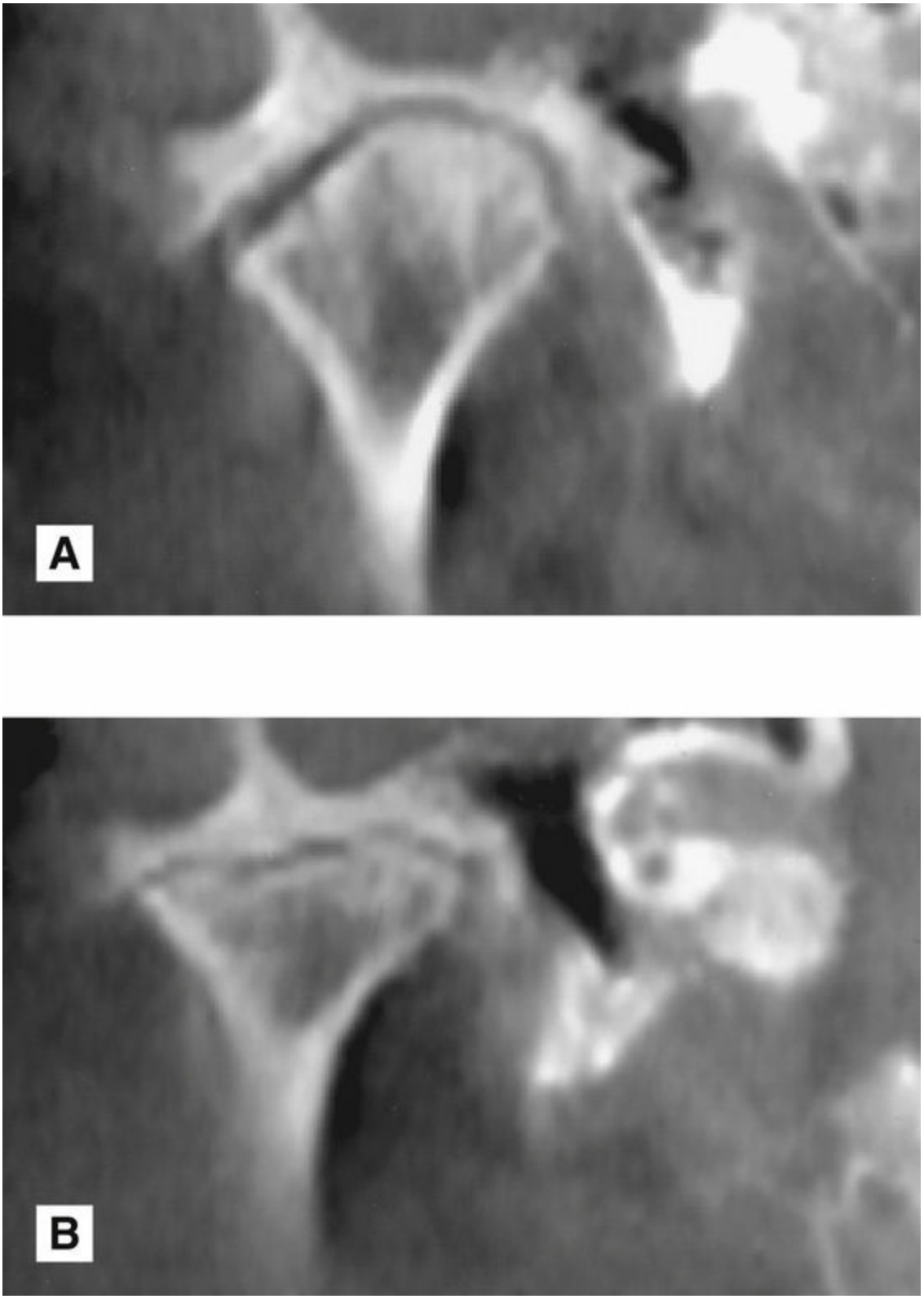


FIG. 30.18 **(A, B)** Coronal CBCT images showing flattening, erosion and destruction of the condylar head.
Courtesy of Prof K. Tsiklakis.

- Flattening of the head of the condyle
- Erosion and destruction of the articular surface of the head of the condyle which may be extensive causing the outline to become irregular
- Occasional osteophyte formation on the condylar head
- Hollowing of the glenoid fossa
- Reduction in the range of movement
- Features are usually bilateral and fairly symmetrical.

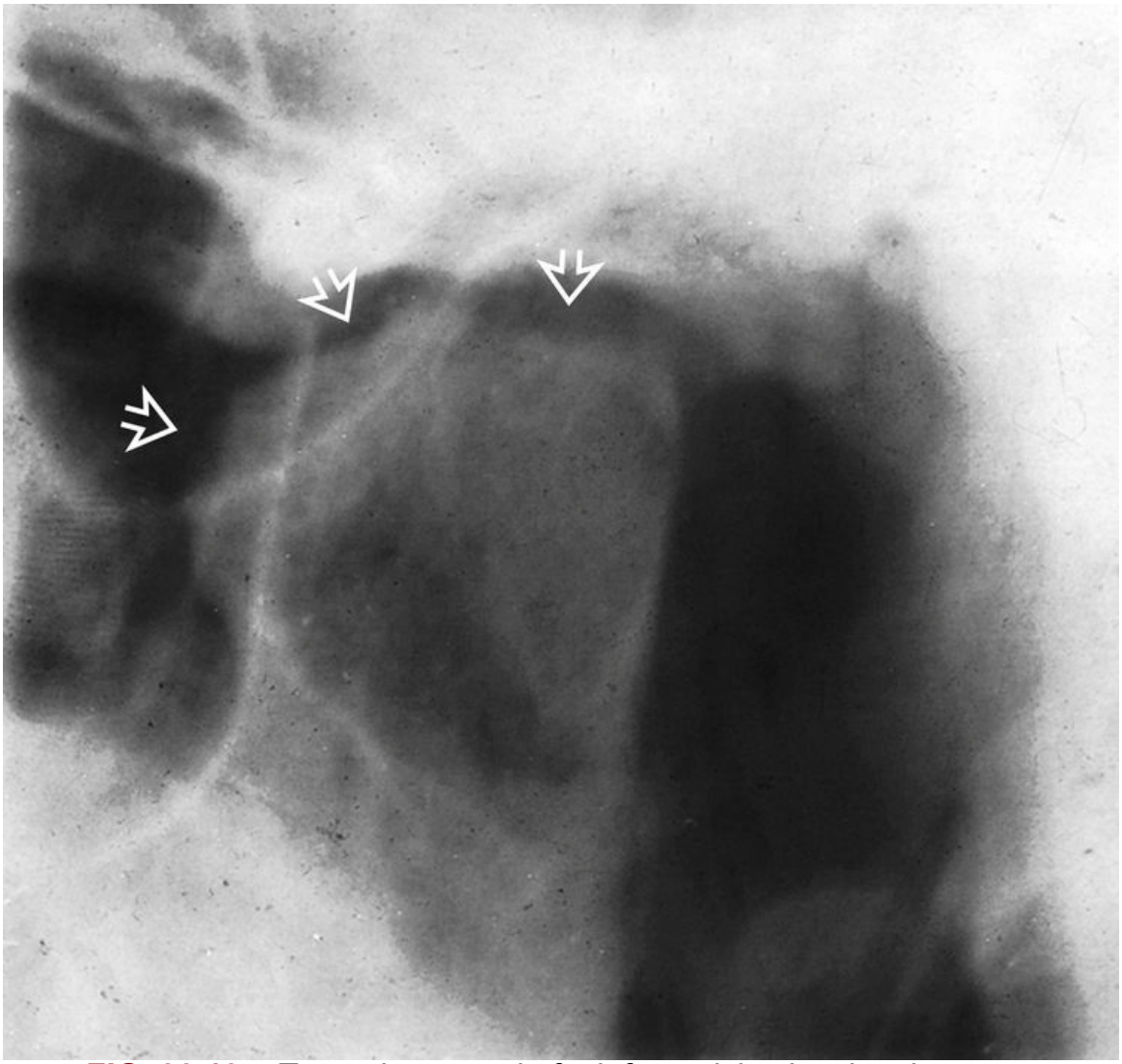


FIG. 30.19 Transpharyngeal of a left condyle showing the

typical erosion and destruction of the articular surface (arrowed) caused by severe rheumatoid arthritis.



FIG. 30.20 Panoramic radiograph showing advanced rheumatoid arthritic change in both right and left condyles in a 75-year-old woman with widespread joint involvement. The right (solid arrow) shows marked flattening while the left (open arrow) shows erosion of the articular surface. Despite these pronounced changes the patient was symptom free.

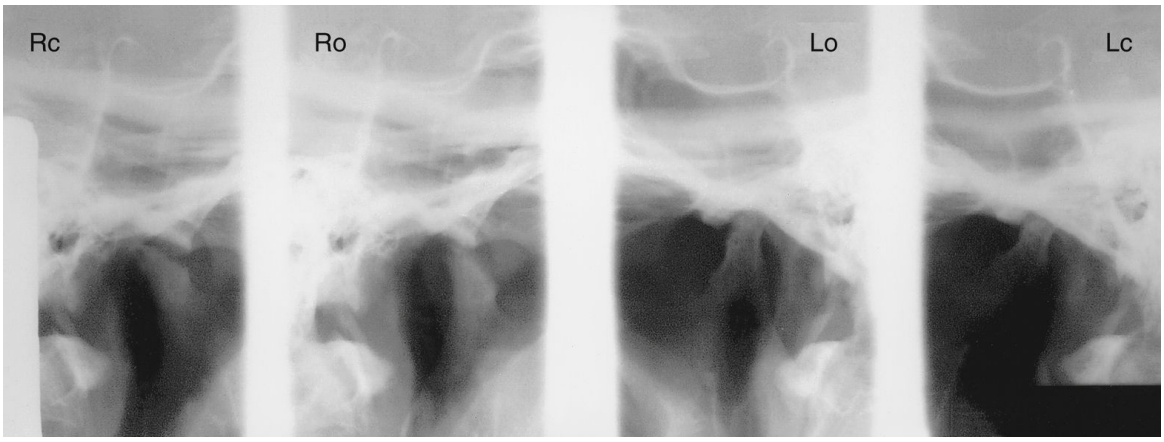


FIG. 30.21 Panoramic TMJ programme showing advanced rheumatoid arthritic change in both right and left condyles.

Juvenile Rheumatoid Arthritis (Still's Disease)

The radiographic features of juvenile rheumatoid arthritis are similar to the adult disease. In severe cases, the disease may cause interference with normal condylar growth producing micrognathia, or it may result in TMJ ankylosis.

Ankylosis

True ankylosis, i.e. fusion of the bony elements of the joint (see Fig. 30.22), is uncommon but is usually the result of:

- Trauma, particularly condylar head fractures and birth injury, and bleeding into the joint
- Infection
- Severe juvenile rheumatoid arthritis.

Tomography, CBCT or CT are the investigations of choice because of the obvious problems of opening the mouth.

Main Radiographic Features

These include:

- Little or no evidence of a joint space
- Bony fusion between the head of the condyle and the glenoid fossa with total loss of the normal anatomical outlines
- Associated evidence of condylar neck hypoplasia and mandibular underdevelopment on the affected side producing asymmetry, if the ankylosis precedes completion of mandibular growth. A prominent antegonial notch on the affected side is often evident.

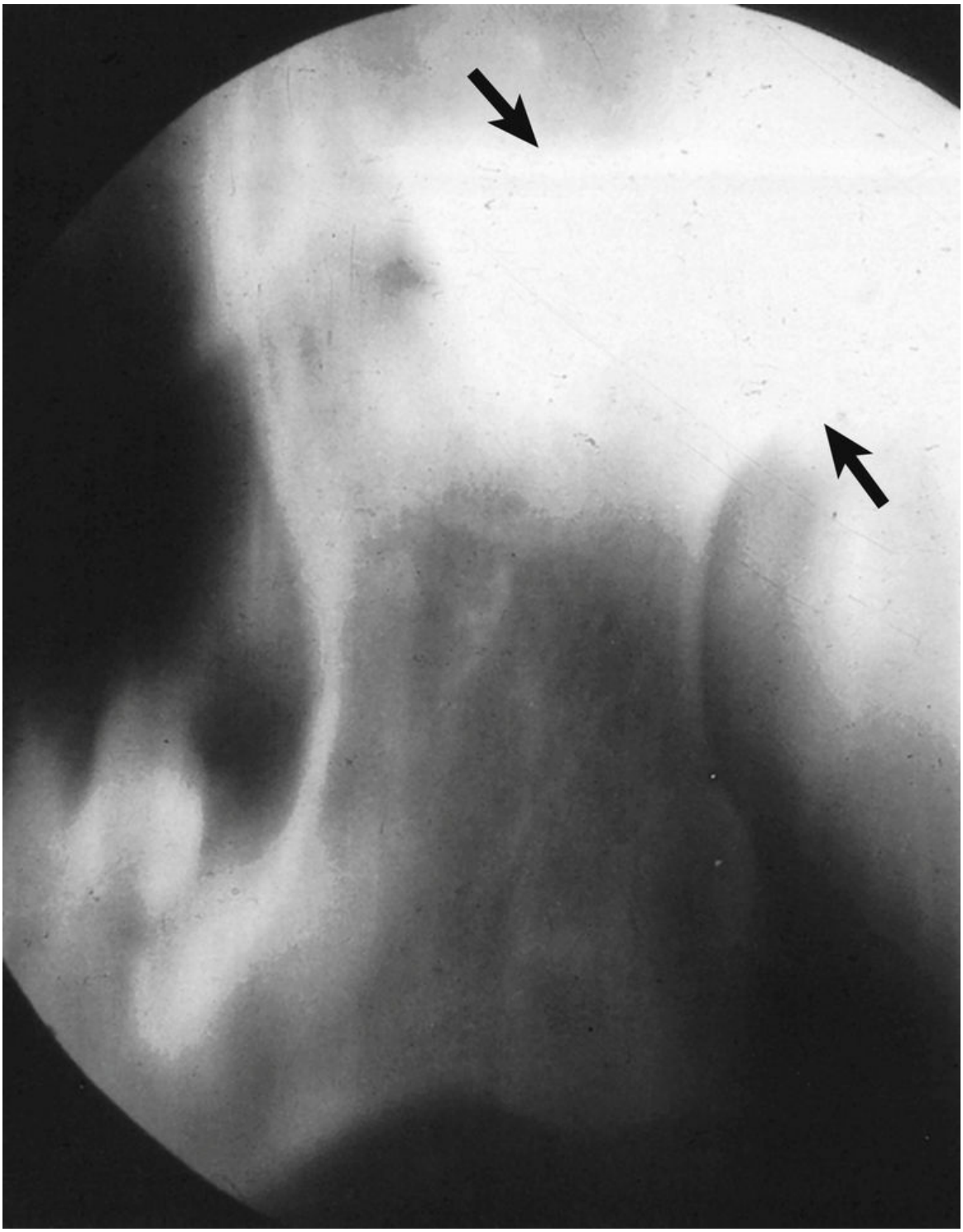


FIG. 30.22 Sagittal section tomograph of the left temporomandibular joint showing complete ankylosis and bony fusion of the condyle and glenoid fossa (arrowed).

Tumours

Benign or malignant tumours develop occasionally in the head of the condyle. The radiographic features depend on the type and nature of the tumour involved, but there is usually an alteration in the shape of the condylar head. Typical examples include osteoma, chondroma (see Fig. 30.23) and chondrosarcoma.

Fractures and Trauma

Fractures of the condylar necks are common after a blow to the chin (see Chapter 29). Very occasionally with this type of injury the condylar neck does not fracture but the head of the condyle either fractures, a so-called intra-capsular fracture (see Fig. 30.24), or is forced upwards, through the glenoid fossa into the middle cranial fossa (see Fig. 30.25). Tomography, CBCT or CT will demonstrate the extent of any injury. Trauma can also result in unilateral or bilateral dislocation (see Fig. 30.26).

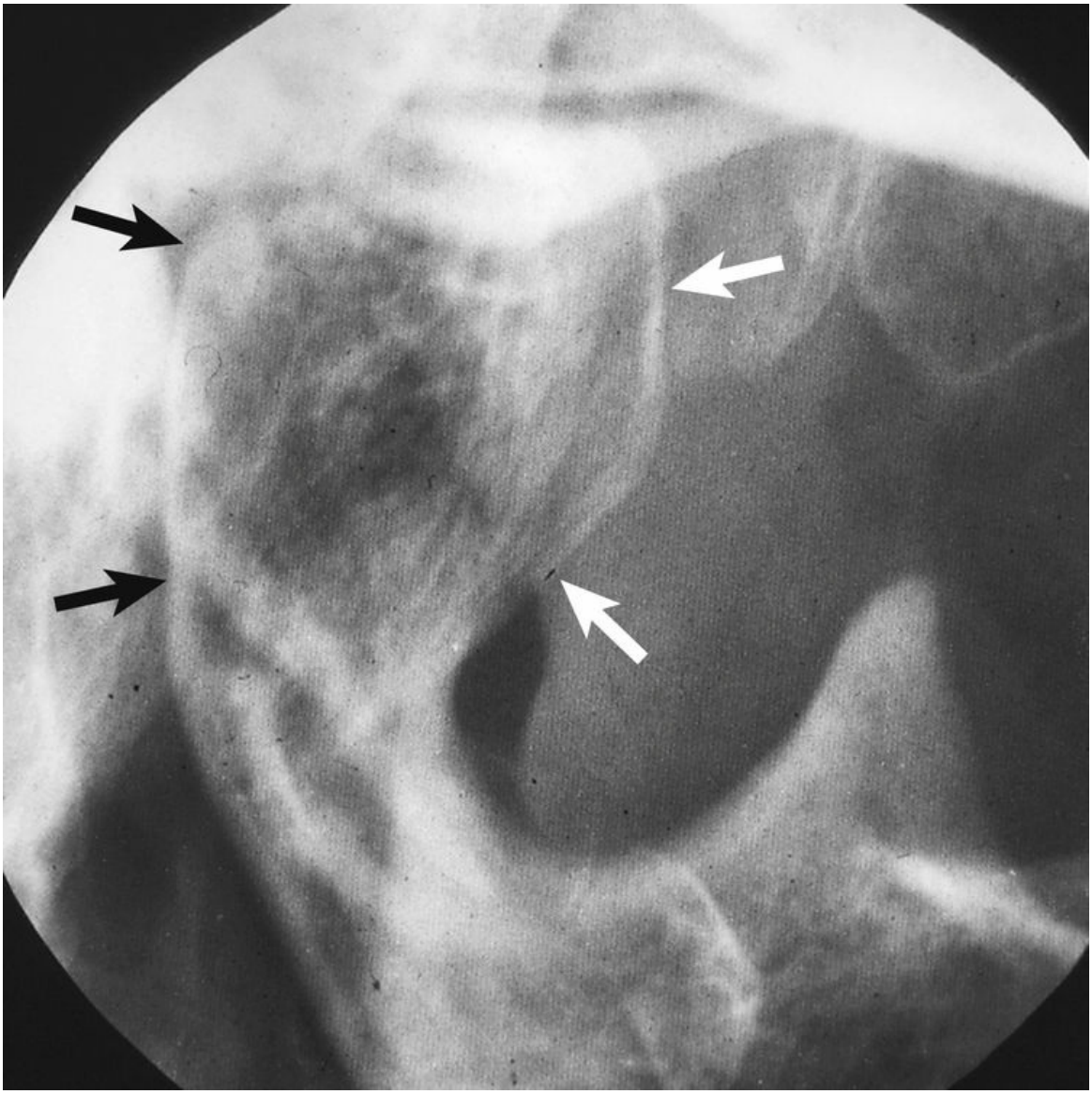


FIG. 30.23 Transpharyngeal of the right condyle showing gross, expansive enlargement of the head (arrowed). The lesion is round, well-defined and with a moderately well-corticated outline – these features all indicate a slow-growing, benign lesion that proved to be a chondroma.

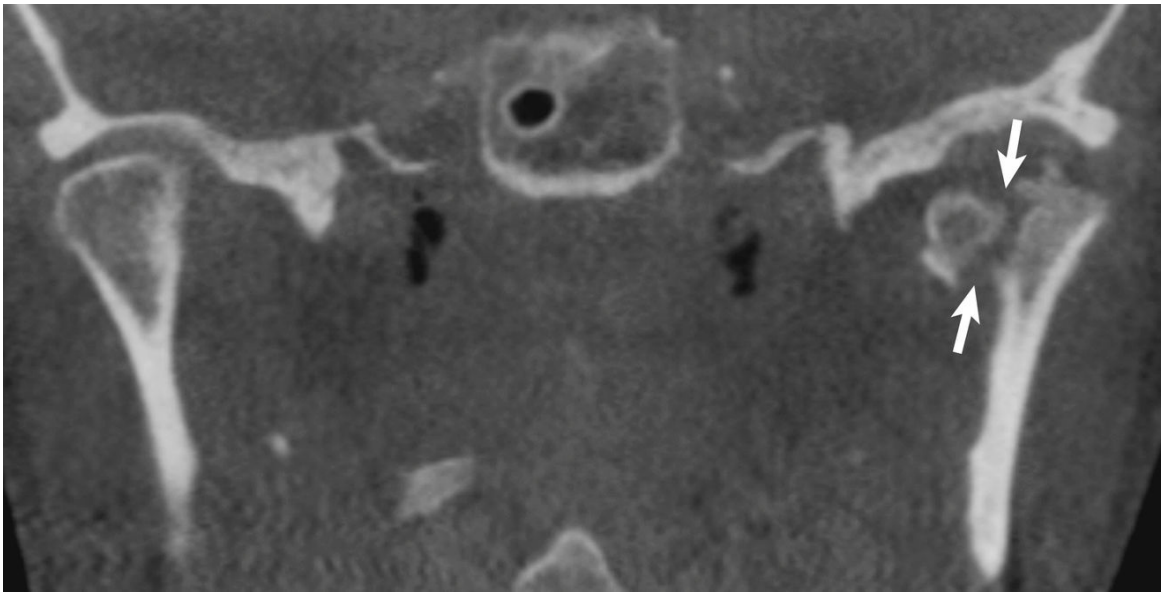


FIG. 30.24 Coronal section CBCT image showing fracture of the left condylar head (arrowed).

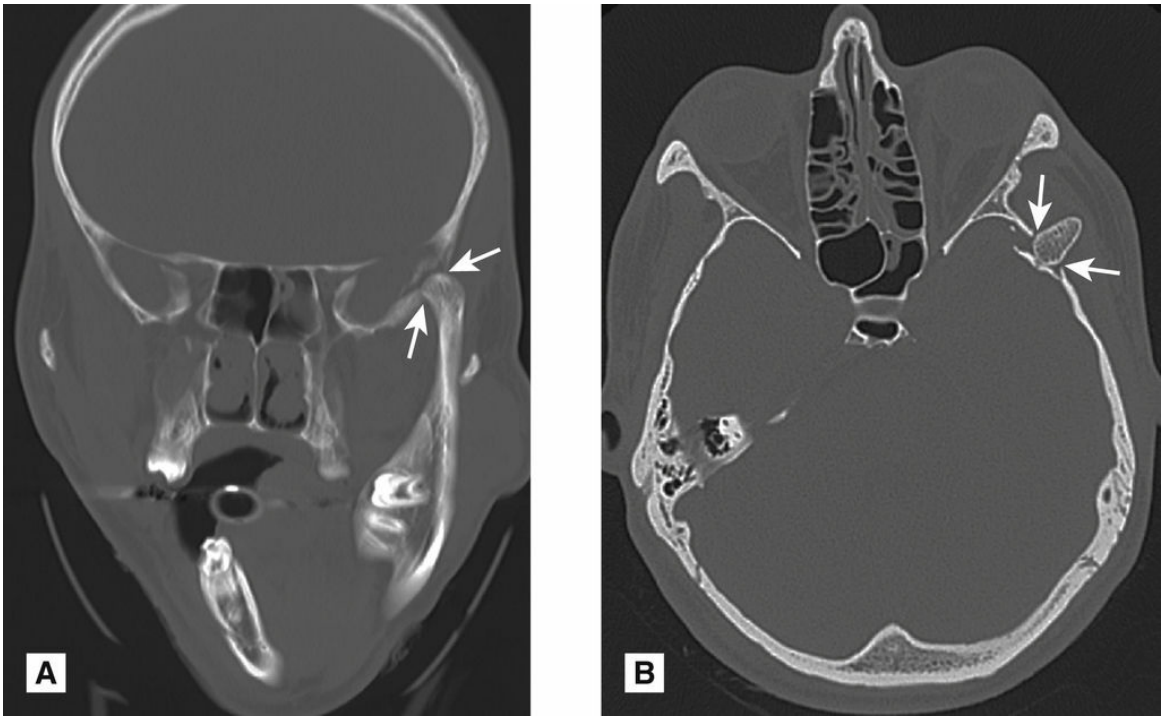


FIG. 30.25 **(A)** Coronal and **(B)** axial CT scans showing dislocation of the left mandibular condyle with impaction into the middle cranial fossa (arrowed).
Courtesy of the Aneurin Bevan Health Board.

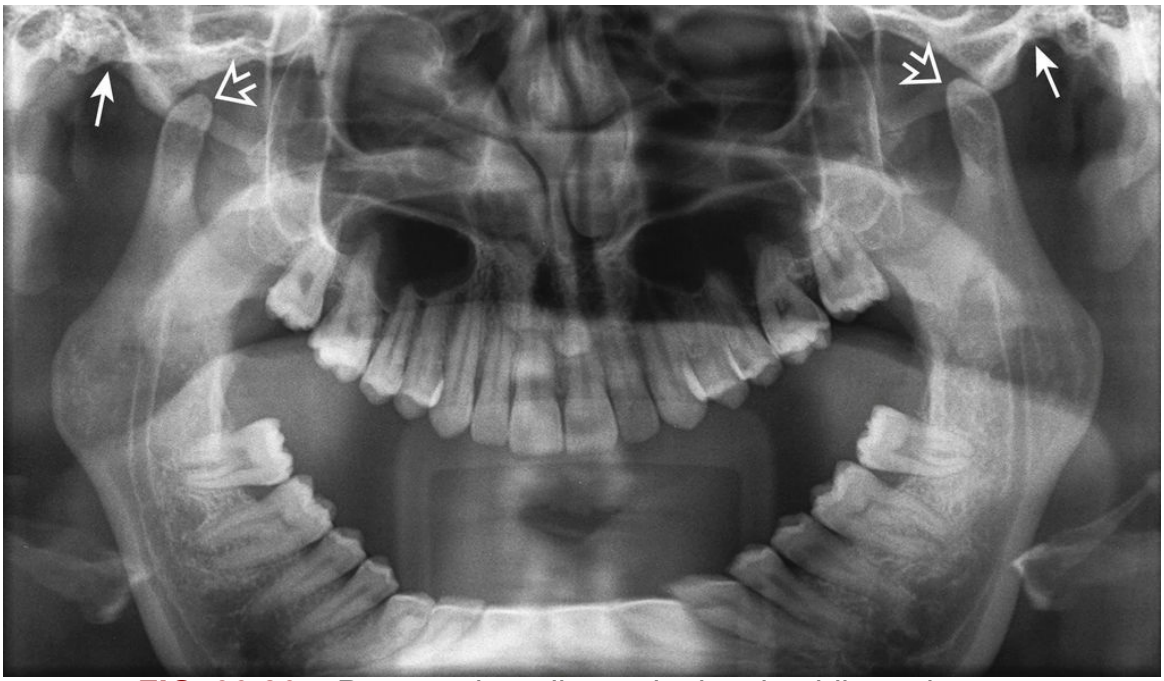


FIG. 30.26 Panoramic radiograph showing bilateral dislocation of the condyles (open arrows) out of the glenoid fossae (arrowed).

Developmental Anomalies

Developmental defects affecting the TMJ are usually investigated using conventional radiography. They can be divided into:

- Condylar hypoplasia (unilateral or bilateral) (see Fig. 30.27)
- Condylar hyperplasia (unilateral or bilateral) (see Fig. 30.28)
- Bifid condyle (see Fig. 24.30)
- Post-radiotherapy
- Defects associated with specific disease or syndromes, for example:
  - First arch syndrome
  - Mandibular facial dysostosis (Treacher-Collins syndrome).

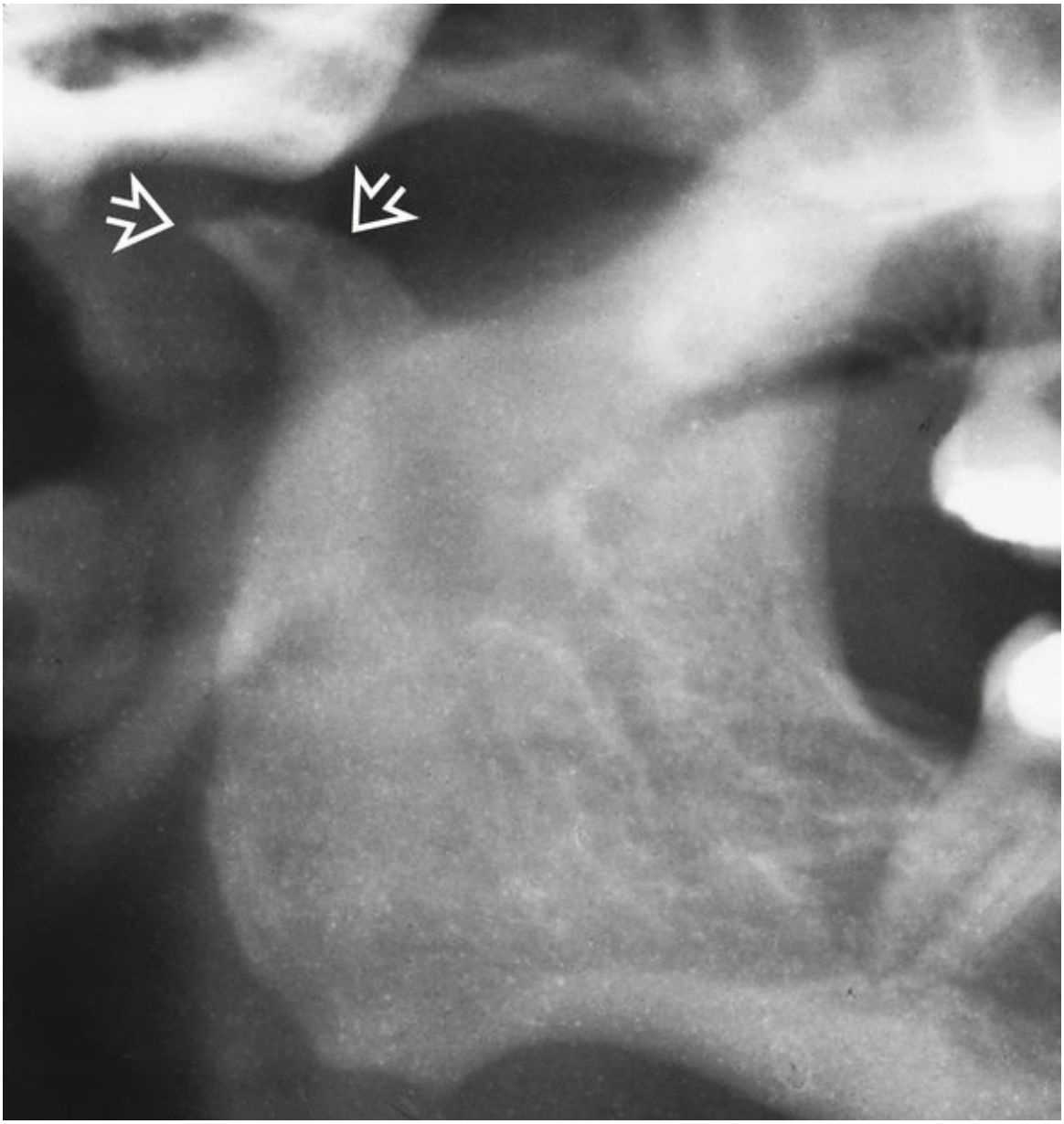


FIG. 30.27 Part of a panoramic radiograph showing marked condylar hypoplasia of the right condyle (arrowed).

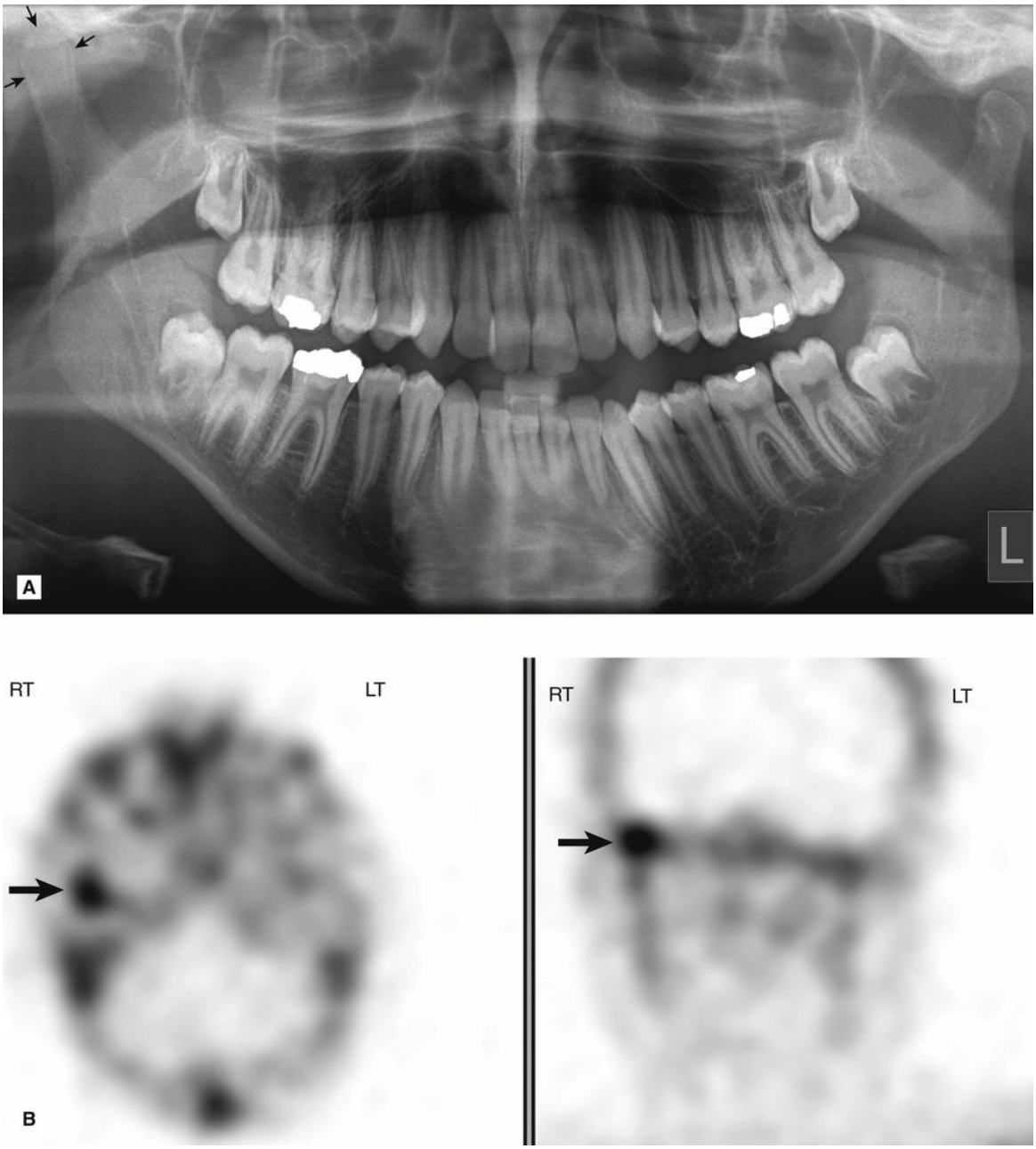


FIG. 30.28 **(A)** Panoramic radiograph showing condylar hyperplasia of the right condyle and elongation of the condylar neck (arrowed). Courtesy of Mr A. Cronin). **(B)** SPECT nuclear medicine scans of the same patient showing increased activity (*hot spot*) in right condyle (arrowed). (Courtesy of Dr J. Rees).

Footnote

The bony abnormalities illustrated are often detected as incidental findings on panoramic radiographs taken for some other clinical condition. For those patients with specific signs and symptoms relating to the TMJ, the type of investigation chosen will depend on the history, the clinical presentation and the facilities available. Knowledge of the respective merits and limitations of the different investigations allows the clinician to use the most appropriate for each patient.

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

31

The Maxillary Antra

Introduction

The maxillary antra, because of their close proximity to the upper teeth, are the most important of the paranasal sinuses in dentistry. Nowadays the imaging modalities of choice to investigate possible disease within the antra are computed tomography (CT), cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) (see Chapters 16 and 18). However, because the antra are often imaged on conventional dental radiographs, as well as on certain skull views, clinicians still need to know:

- The anatomy of the antra, including their shape, size, normal variations and related structures
- How the antra are represented normally on conventional dental and skull radiographs and how these radiographs are assessed
- The radiographic features of disease.

Similar radiographic changes can be seen in the other paranasal sinuses – frontal, ethmoidal and sphenoidal. They are of less clinical relevance in dentistry and are discussed only briefly.

Normal Anatomy

The maxillary antrum or sinus is an approximately pyramidal cavity. It contains air, is lined by mucoperiosteum with a pseudostratified ciliated columnar epithelium and occupies most of the body of the

maxillary bone. It is present at birth, but at that stage it is little more than a slit-like out-pouching of the nasal cavity. It grows rapidly by a process known as pneumatization during the eruption of the deciduous teeth and reaches about half its adult size by 3 years of age. The final size of the antra (like the other air sinuses) is very variable.

Pneumatization in adulthood causes further changes in antral shape and size. The cavity often enlarges downwards into the alveolar process or laterally into the body of the zygoma. The internal surface can be smooth or ridged with prominent bony septa. The lateral wall contains canals or grooves for the nerves and blood vessels supplying the upper posterior teeth.

The main anatomical parts of the antra, as shown in Fig. 31.1 can be divided into:

- A central air-filled cavity
- A roof or upper border, bounded by the orbit
- A medial wall, bounded by the nasal cavity
- A posterior wall, related to the pterygopalatine fossa
- A lateral wall, related to the zygoma and cheek
- An anterior wall, related to the cheek
- A floor, related to the apices of the upper posterior teeth.

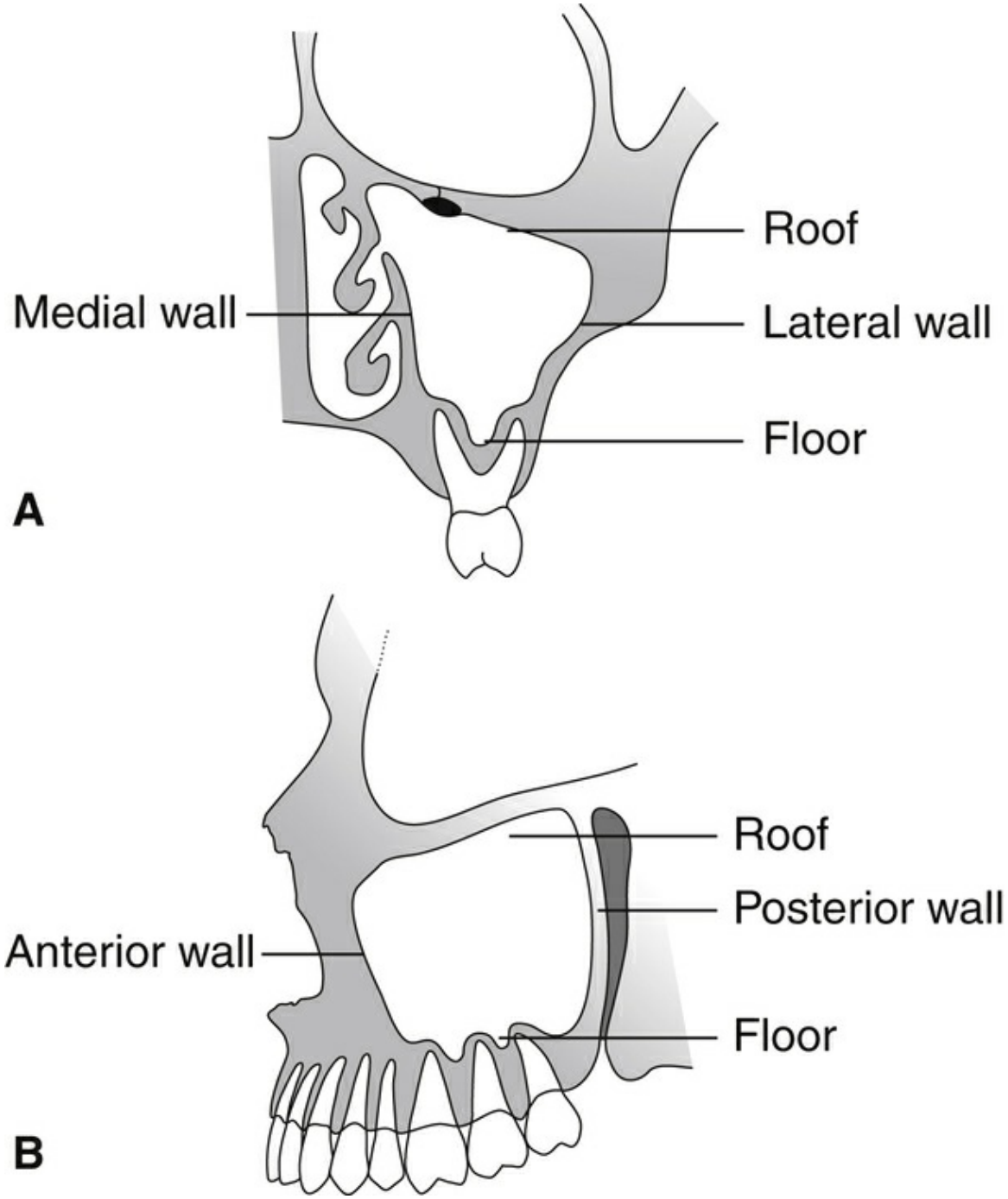


FIG. 31.1 Diagrams of a left antrum showing the basic shape and various walls and margins: **(A)** from the front; **(B)** from the side.

Normal Appearance of the Antra on

Conventional Radiographs

An antrum appears radiographically as a radiolucent cavity in the maxilla, with well-defined, dense, corticated radiopaque margins or walls. In general, the larger the cavity the more radiolucent it will appear. The internal bony septa and blood vessel canals in the walls all produce their own shadows. The thin epithelial lining is not normally seen. The different parts of the antra shown on conventional dental and skull radiographs are summarized in Table 31.1 . Typical normal radiographic appearances are shown in Figs. 31.2 –31.4 . In addition, a suggested systematic approach to viewing the antra on the 0° occipitomental (OM) is shown in Fig. 31.4 .

Table 31.1

Summary of the different parts of the antra shown on conventional dental and skull radiographs

Area of antrum shown	Radiographic projection
Floor	Periapical
	Upper oblique occlusal
	Panoramic
Main antral cavity	0° occipitomental (OM)
	True lateral skull
Lower aspect of antral cavity	Periapical
	Upper oblique occlusal
	Panoramic
Posterior wall	Panoramic
	True lateral skull
Anteromedial wall	Panoramic
	True lateral skull
Lateral wall	0° occipitomental (OM)
Roof	0° occipitomental (OM)
Relationship with upper posterior teeth	Periapical Upper oblique occlusal Panoramic

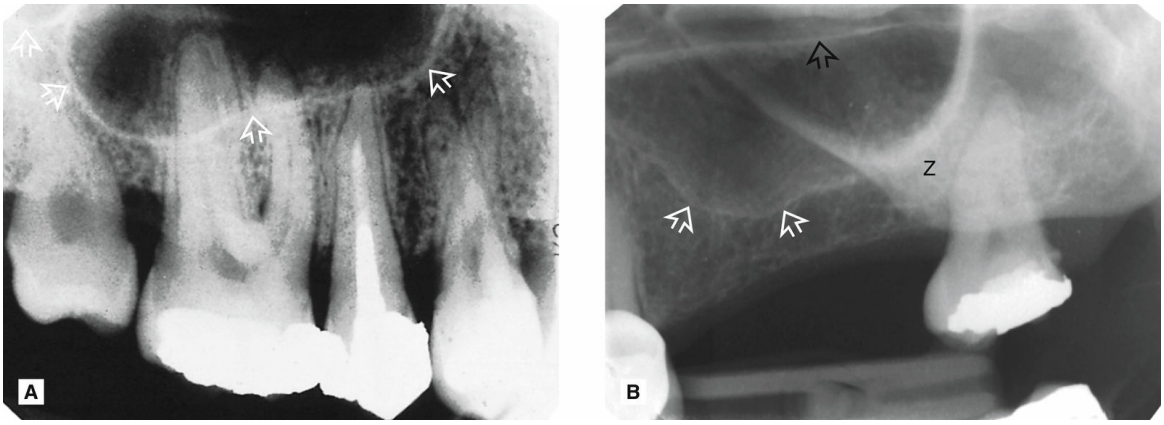


FIG. 31.2 **(A)** Periapical of the upper right quadrant showing the usual appearance of the floor (arrowed) and base of the antral cavity in relation to the upper posterior teeth in a dentate adult. **(B)** Periapical of the upper left quadrant of a partially dentate adult showing various normal anatomical structures. These include the floor of the antrum (open white arrows), the hard palate/floor of the nasal cavity (open black arrows) and the zygomatic buttress (Z).

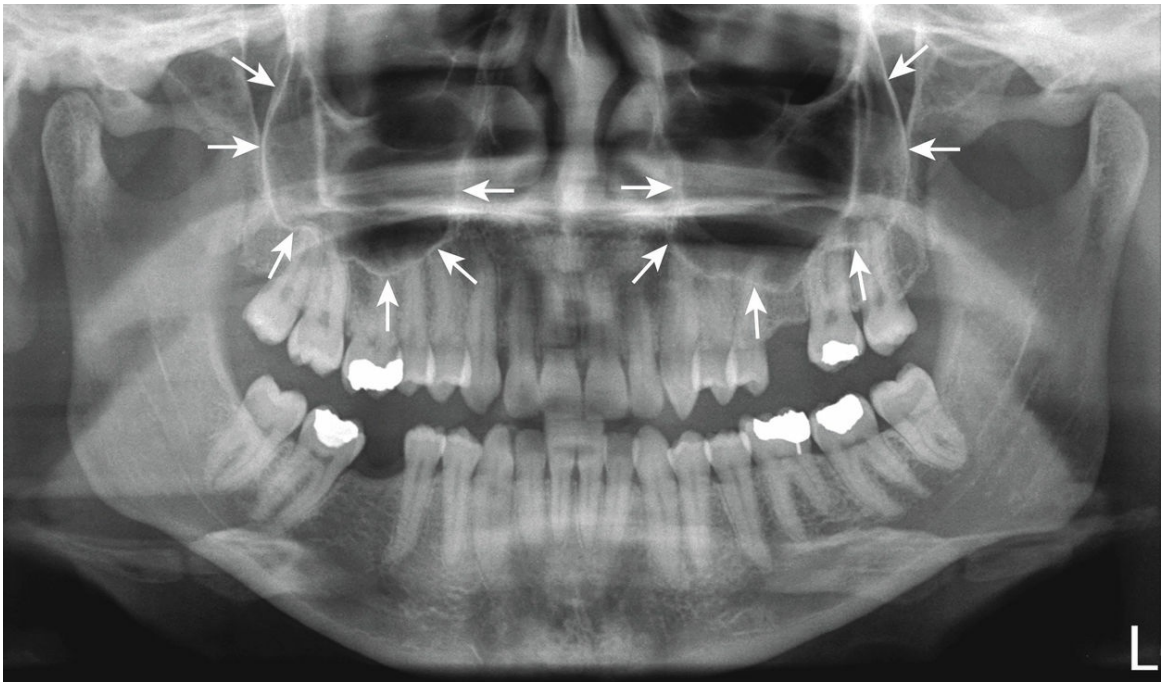


FIG. 31.3 Panoramic radiograph showing the usual appearance of the antral floor, medial and posterior walls (arrowed).

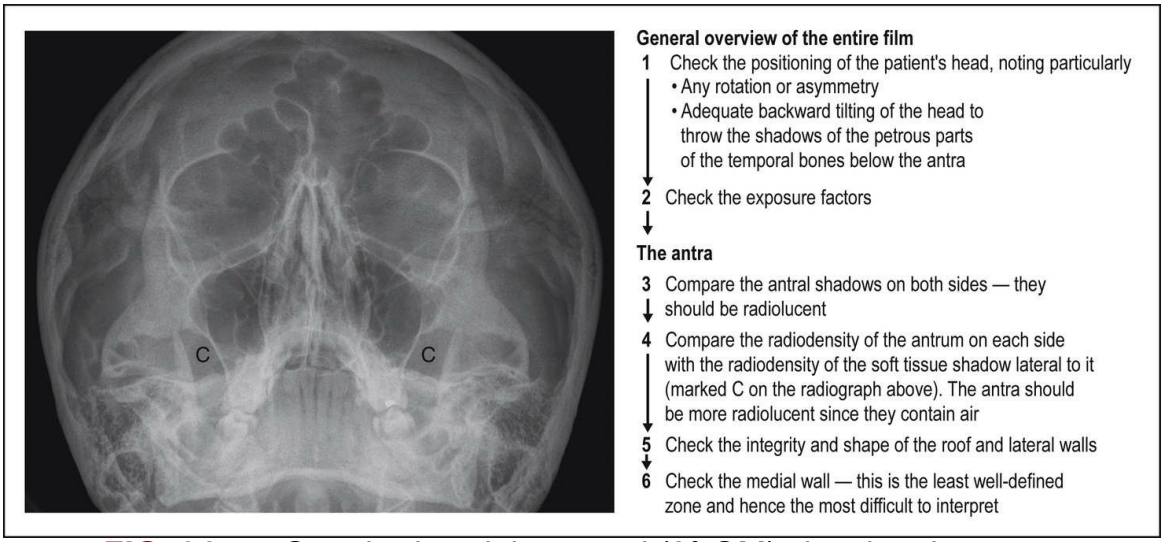


FIG. 31.4 Standard occipitomental (0° OM) showing the normal radiolucent appearance of the antral cavities together with a suggested systematic approach for examining the antra.

Antral Disease

The major pathological conditions that can affect the antra, directly or indirectly, include:

- Infection and inflammation
  - – Acute sinusitis
  - – Chronic sinusitis.
- Trauma
  - – Oro-antral communication
  - – Fractures of the maxillofacial skeleton
  - – Foreign bodies within the antrum.
- Cysts
  - – Intrinsic (mucous retention cyst)
  - – Extrinsic.
- Tumours

    - Intrinsic
    - Extrinsic.
- Other bone abnormalities (see Chapter 28)
    - Fibrous dysplasia
    - Paget's disease of bone
    - Osteopetrosis.

These various disease entities can result in the following radiological changes:

- Total or partial opacity/obliteration of the main antral cavity
- Alteration in the integrity of the antral walls, including discontinuity as a result of a fracture or destruction by an intrinsic or extrinsic tumour
- Alteration in the antral outline, including expansion or compression caused by an intrinsic or extrinsic lesion or disease process
- The presence of a foreign body within the antrum.

Investigation and Appearance of Disease Within the Antra

Various imaging modalities can be used to investigate possible disease within the antra, depending on their availability. These include:

- Computed tomography (CT) – currently recommended by the Royal College of Radiologists in the UK
- Cone beam computed tomography (CBCT)
- Magnetic resonance imaging (MRI)
- Multidirectional (spiral) tomography
- Panoramic radiography
- Intraoral periapical/occlusal radiography
- Skull radiography
    - 0° occipitomental

– True lateral.

Appearances of antral diseases using various imaging modalities are shown in Figs. 31.5 –31.23 .

Infection and Inflammation

Acute Sinusitis

Acute sinusitis is most commonly caused by an upper respiratory tract infection, particularly the common cold. The effects on the antrum include:

- Thickening of the antral mucosal lining
- Increase in secretions
- Formation of pus.

Acute sinusitis can be diagnosed and treated clinically. As a result, the Royal College of Radiologists in the UK in their 2017 publication *iRefer: Making the Best Use of Clinical Radiology* (eighth edition) and the European Paper on Rhinosinusitis and Nasal Polyps 2012 both recommend that radiological imaging is not necessary. The European Paper on Rhinosinusitis and Nasal Polyps 2012 also suggest CT scanning only if there are additional problems such as:

- Very severe disease
- Immunocompromised patients
- Signs of complications.

Chronic Sinusitis

Important Causes

- Prolonged antral infection (10 days)
- Trauma, including roots or teeth displaced into the antrum or

the formation of an oro-antral communication (see Fig. 31.5)
- Apical infection associated with an upper posterior tooth (rare).

Typical Effects on the Antrum

- Some shrinkage of the thickened mucosal lining from the acute phase

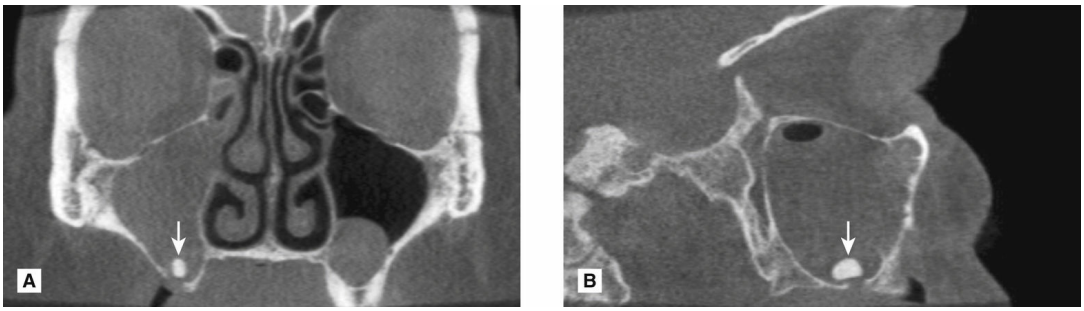


FIG. 31.5 **(A)** Coronal and **(B)** sagittal CBCT images showing an oro-antral communication and a displaced root in the right antrum (arrowed). Note also the domed mucous retention cyst in the left antrum.

- Continued formation of secretions and pus
- Sometimes mucosal polyp formation
- Sometimes thickening of the antral walls
- Destruction and remodelling of the antral floor associated with an infected tooth apex.

Main Radiological Features

- Total or partial opacity within the antral cavity
- Fluid level – usually in the base of antral cavity with a characteristic meniscus shape
- Round, domed opacity produced by a mucosal polyp
- Occasionally thickening of the bony antral walls
- Typical inflammatory changes if infected teeth are involved –

this may lead to resorption and remodelling to produce the appearance described as *antral halo* (see also Chapter 21 and Fig. 31.8)

- Evidence of a foreign body (if applicable).

Plain radiographs and CT scans are also not recommended in routine cases of chronic sinusitis. A specialist may consider a CT scan before surgery.

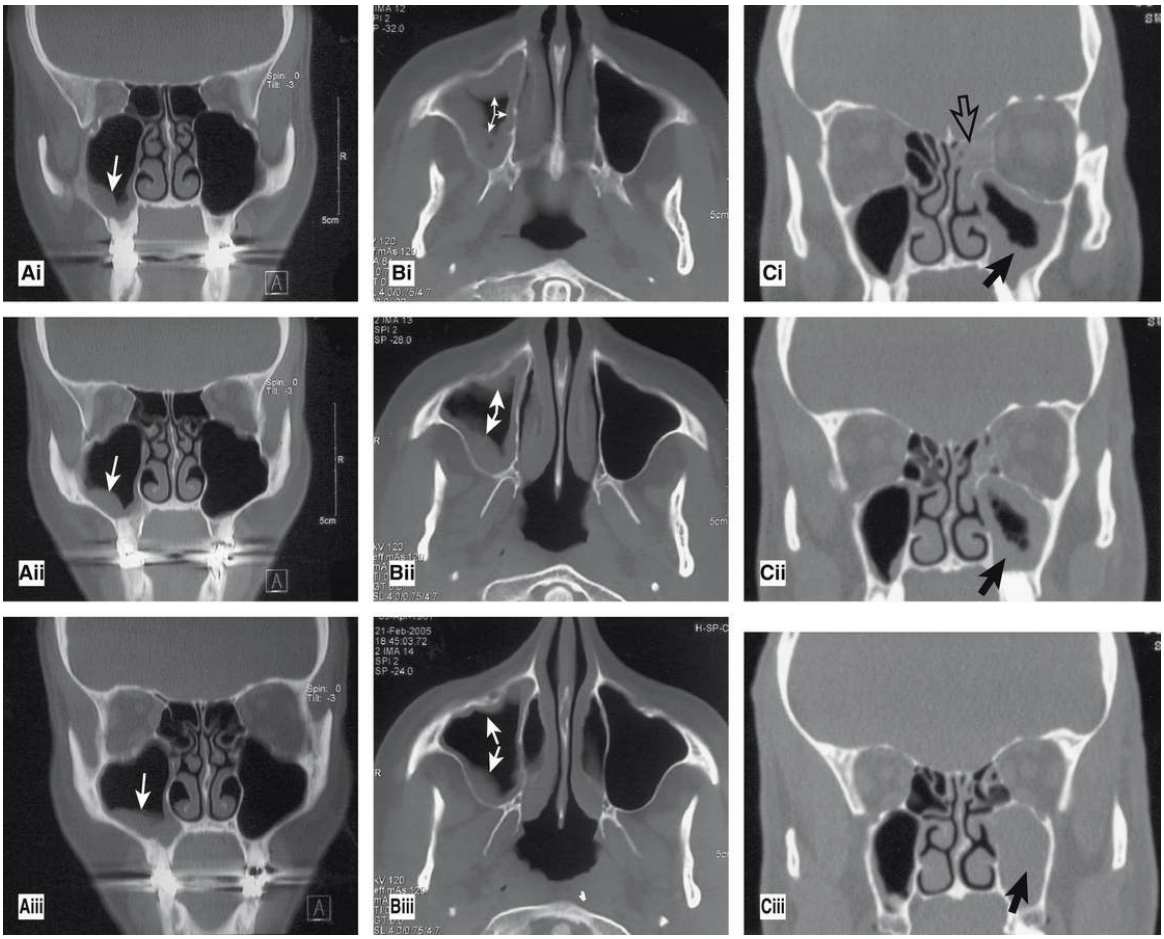


FIG. 31.6 Various appearances of the effects of chronic sinusitis shown on computed tomography (CT). **(A)** Contiguous coronal CT scans showing mucosal thickening in the base of the antrum (arrowed). **(B)** Contiguous axial CT scans showing mucosal thickening on the medial and lateral walls of the antrum (arrowed). **(C)** Contiguous coronal CT scans showing mucosal thickening and total opacity of the left antrum (arrowed) and the left ethmoidal sinuses (open black arrow).

((A) and (B) courtesy of Drs J. Kabala and J. Luker.)

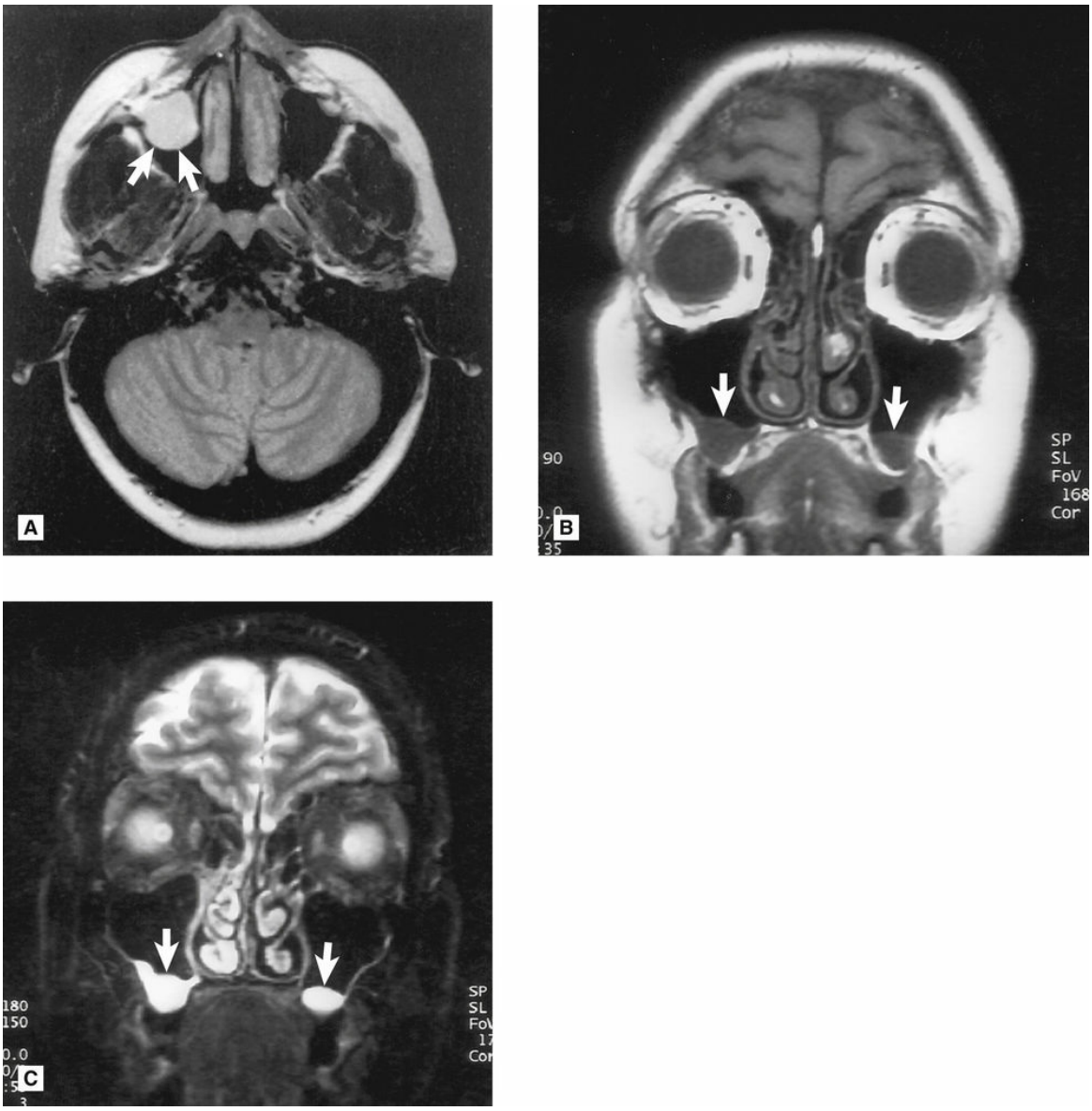


FIG. 31.7 Various appearances of the effects of chronic sinusitis shown on magnetic resonance imaging (MRI). **(A)** Axial MRI scan showing a round antral mucous retention cyst (arrowed) arising from the anterolateral wall. **(B)** T1-weighted and **(C)** T2-weighted coronal MRI images of the same patient with bilateral mucous retention cysts (arrowed).

Courtesy of Drs J. Kabala and J. Luker

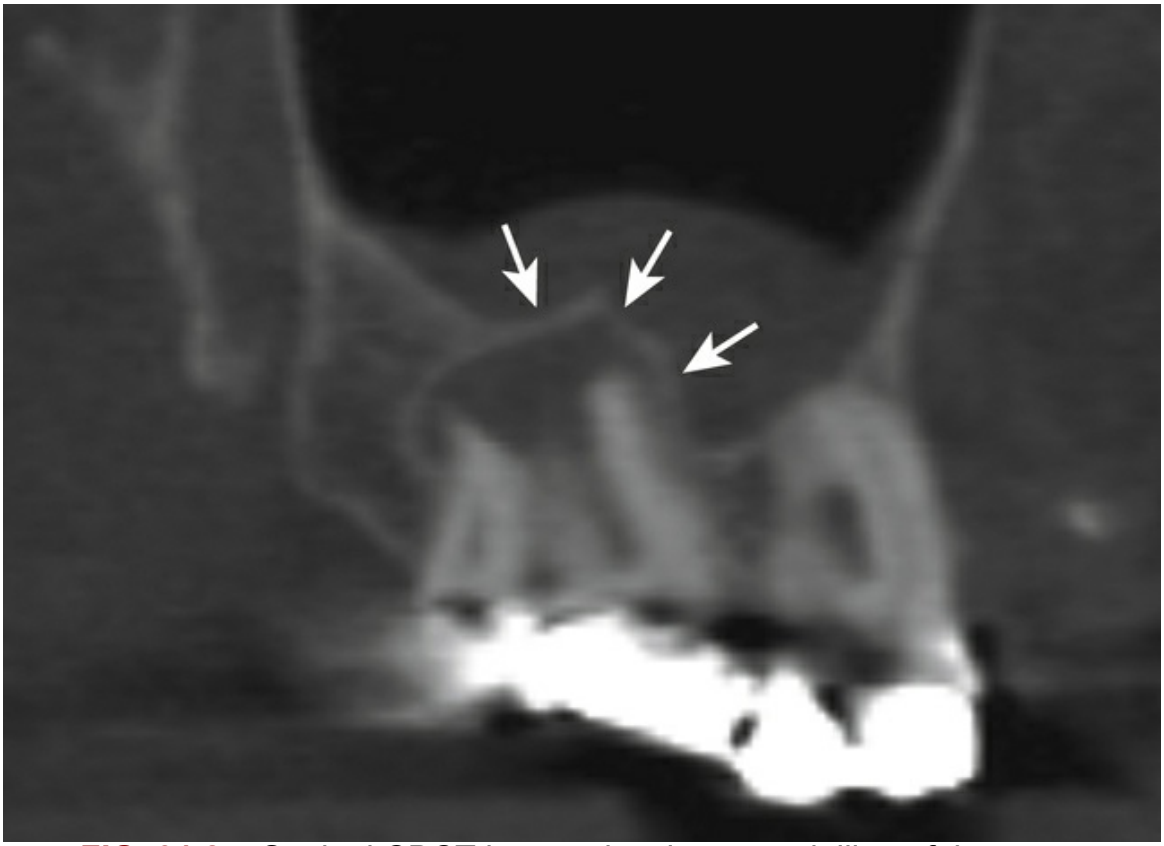


FIG. 31.8 Sagittal CBCT image showing remodelling of the antral floor associated with non-vital infected molars producing the *antral halo* appearance (arrowed).

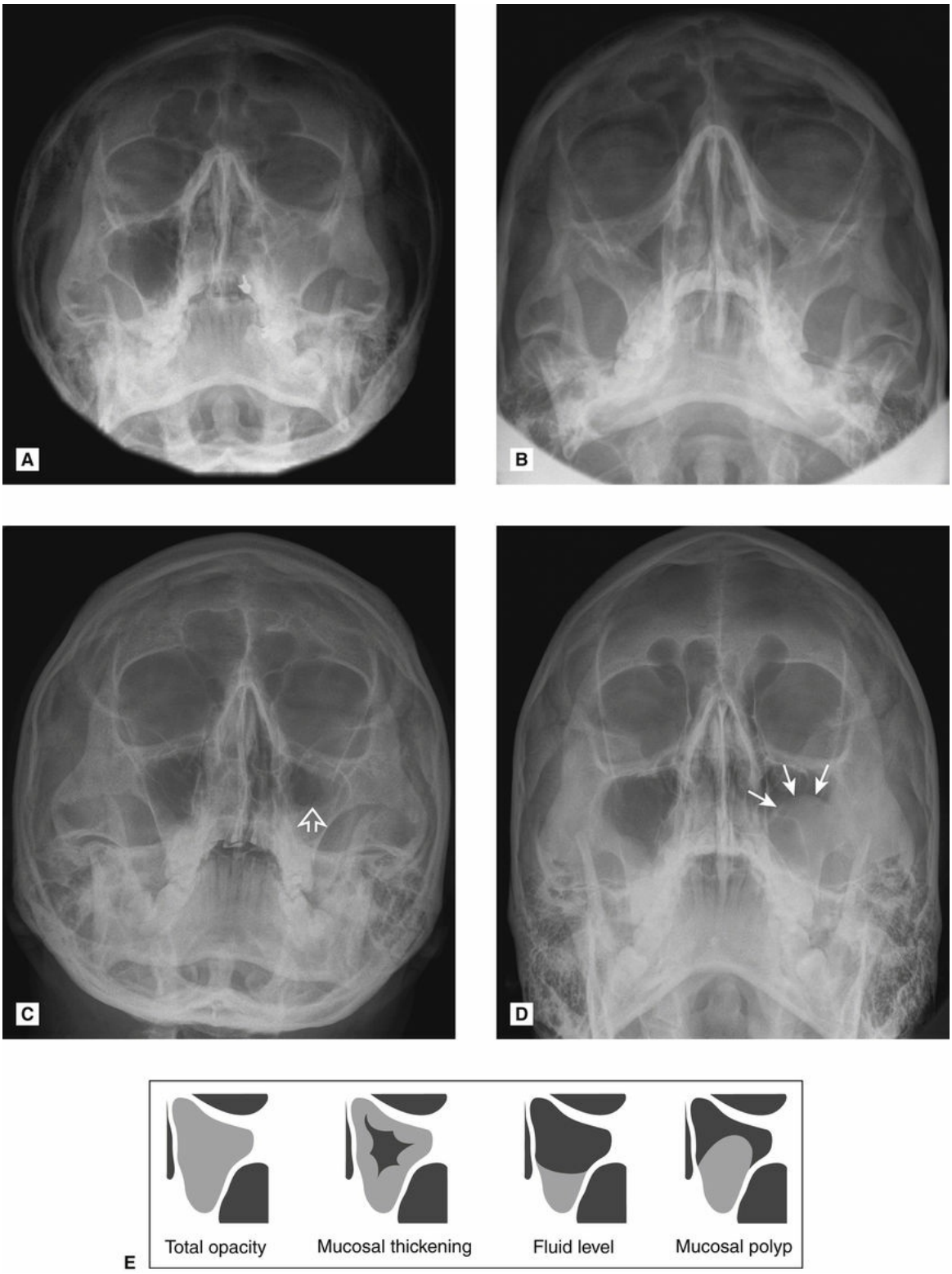


FIG. 31.9 Various appearances of chronic sinusitis evident on conventional occipitomental radiographs. **(A)** Totally opaque left antrum. **(B)** Bilateral mucosal thickening. **(C)** Fluid level in left antrum (arrowed). **(D)** Round, domed antral polyp

in the base of the left antrum (arrowed). **(E)** Simplified line diagrams of the left antrum (as depicted on a 0° OM) illustrating the various appearances.

Trauma

Oro-antral Communication

Important causes

- Extraction of closely related upper posterior teeth can remove part of the antral floor or fracture the tuberosity
- Inappropriate or incorrect use of elevators during root or tooth removal – may also cause the root, or rarely the tooth, to be displaced into the antrum.

Main radiographic features

- Break in the continuity of the floor may be evident (see Fig. 31.10); however, the diagnosis of an oro-antral communication is made clinically, not radiographically, because the defect in the floor of the antrum may not be evident on the two-dimensional radiograph
- Characteristic features of acute or chronic sinusitis owing to the ingress of bacteria
- Evidence of the displaced root or tooth – a second view of the antrum with the head in a different position or CBCT scan may be required to ascertain the exact location of the displaced object (see Fig. 31.5).

Fractures of the Maxillofacial Skeleton

Fractures are discussed in detail in Chapter 29 and only a brief summary is provided here.

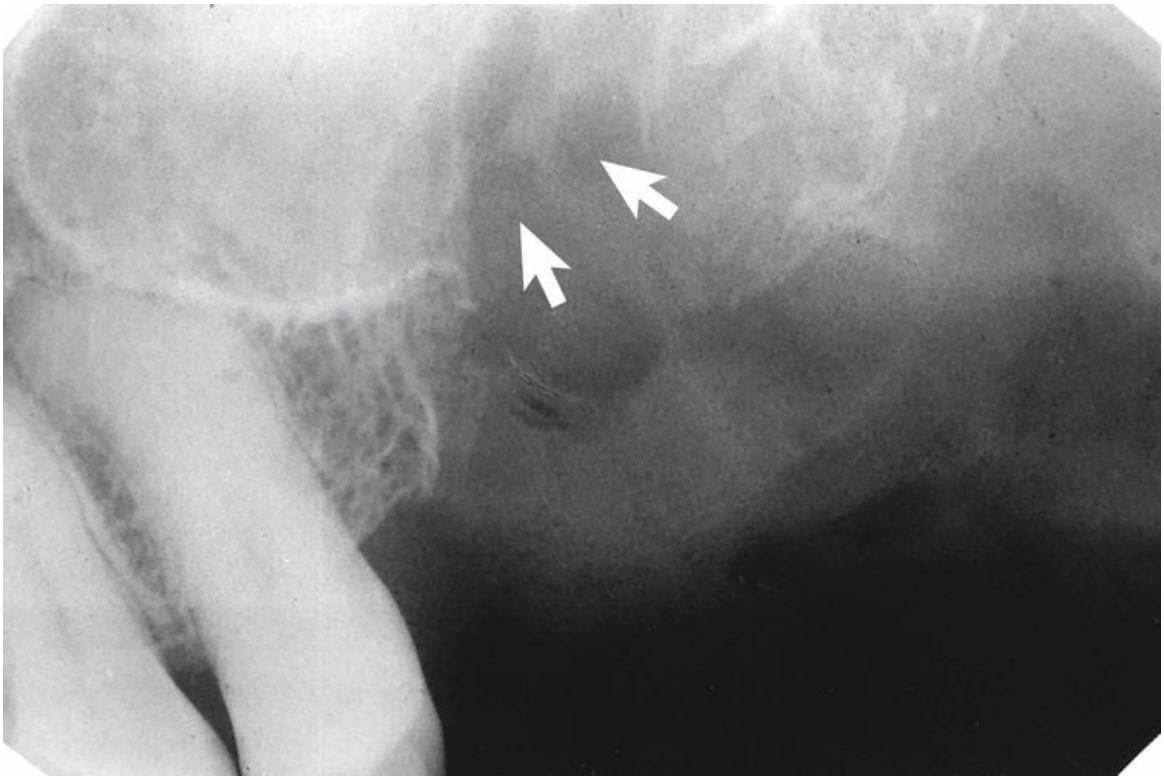


FIG. 31.10 Periapical of the left posterior maxilla showing a discontinuity of the antral floor (arrowed) after the extraction of the molar tooth that resulted in a clinical oro-antral communication. Note this break in continuity of the floor is not always evident radiographically in cases of oro-antral communication.

Important sites possibly involving the antra

- Le Fort I
- Le Fort II
- Le Fort III
- Zygomatic complex
- Naso-ethmoidal complex
- Orbit
  - Rim
  - Blow-out
- Dento-alveolar.

Main radiographic features

- Break in the continuity of one or more of the antral walls depending on the type of fracture.
- Total opacity or fluid level within the antral cavity caused by haemorrhage (see Figs 31.11 and 31.12).
- Features of sinusitis if subsequent infection develops (this is in fact surprisingly rare).
- The orbital blow-out fracture classically produces a tear-drop-shaped opacity in the upper part of the antrum, the *hanging drop* appearance, caused by herniation of the orbital contents downwards into the antrum following collapse of the antral roof (see Fig. 31.13). The infraorbital margin remains intact. See also Fig. 29.30 .

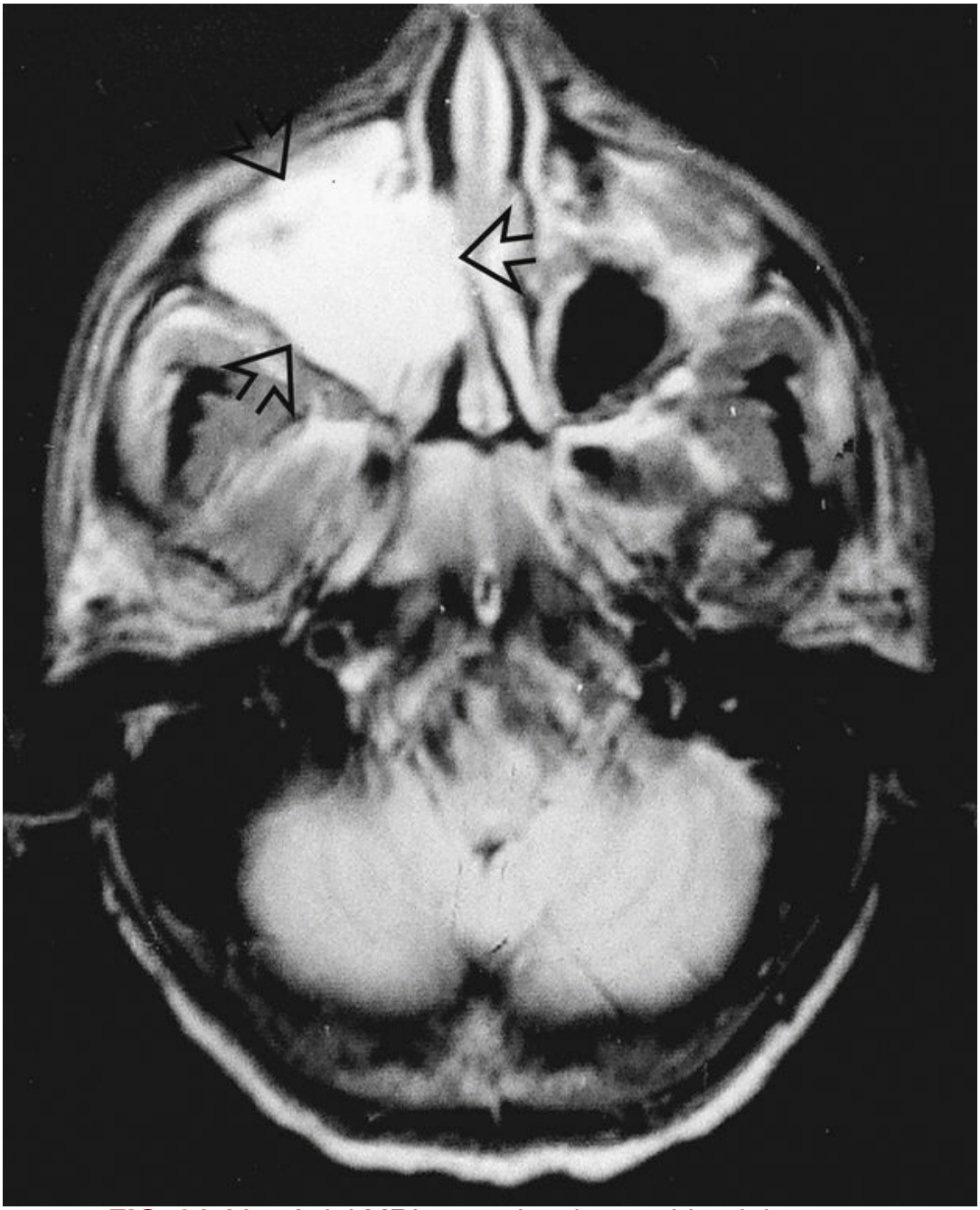


FIG. 31.11 Axial MRI scan showing a white right antrum (arrowed) that was filled with blood following a middle third facial fracture.
Courtesy of Mrs J.E. Brown.

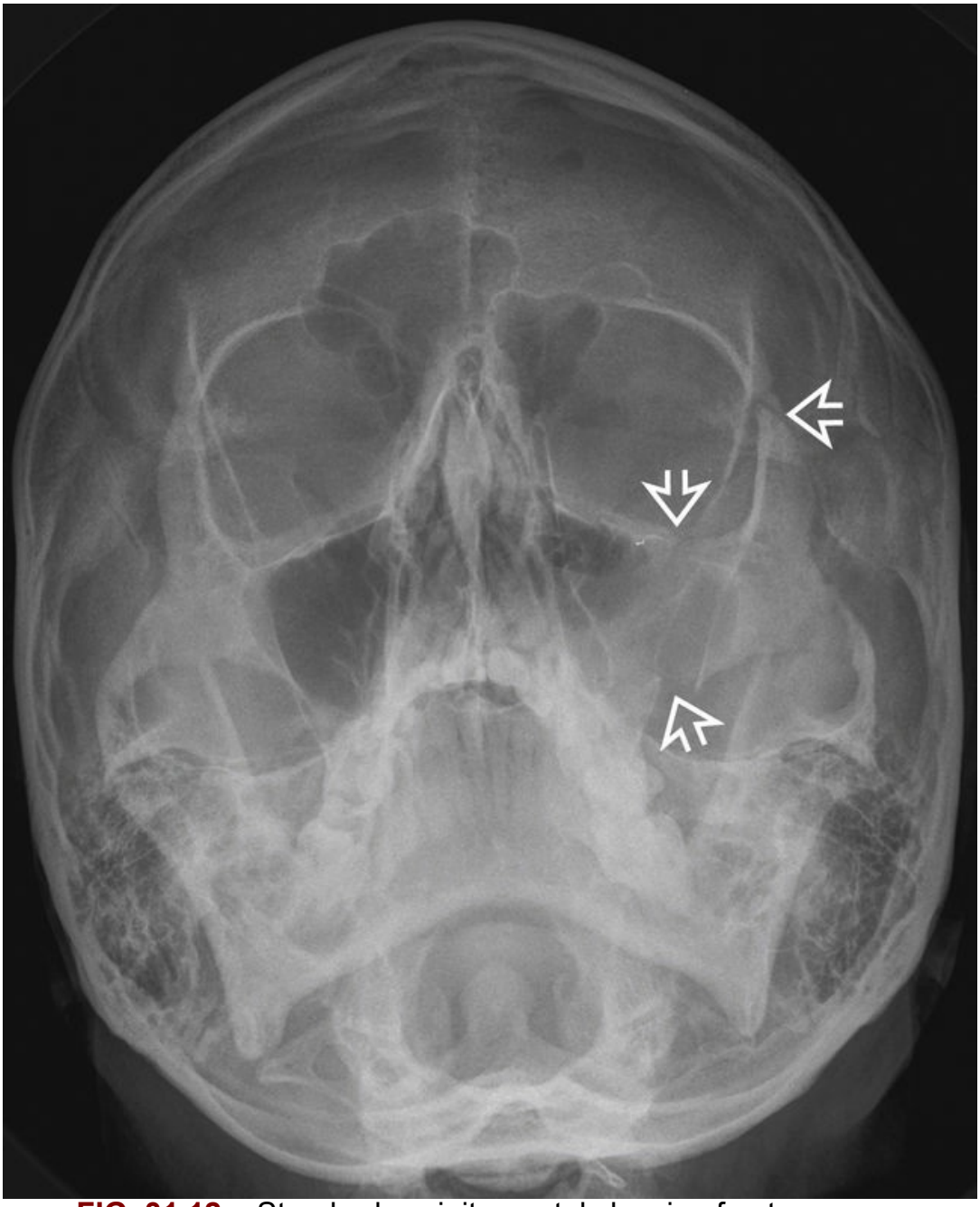


FIG. 31.12 Standard occipitomental showing fracture of the left zygomatic complex (arrowed) and resultant opacity of the left antrum.

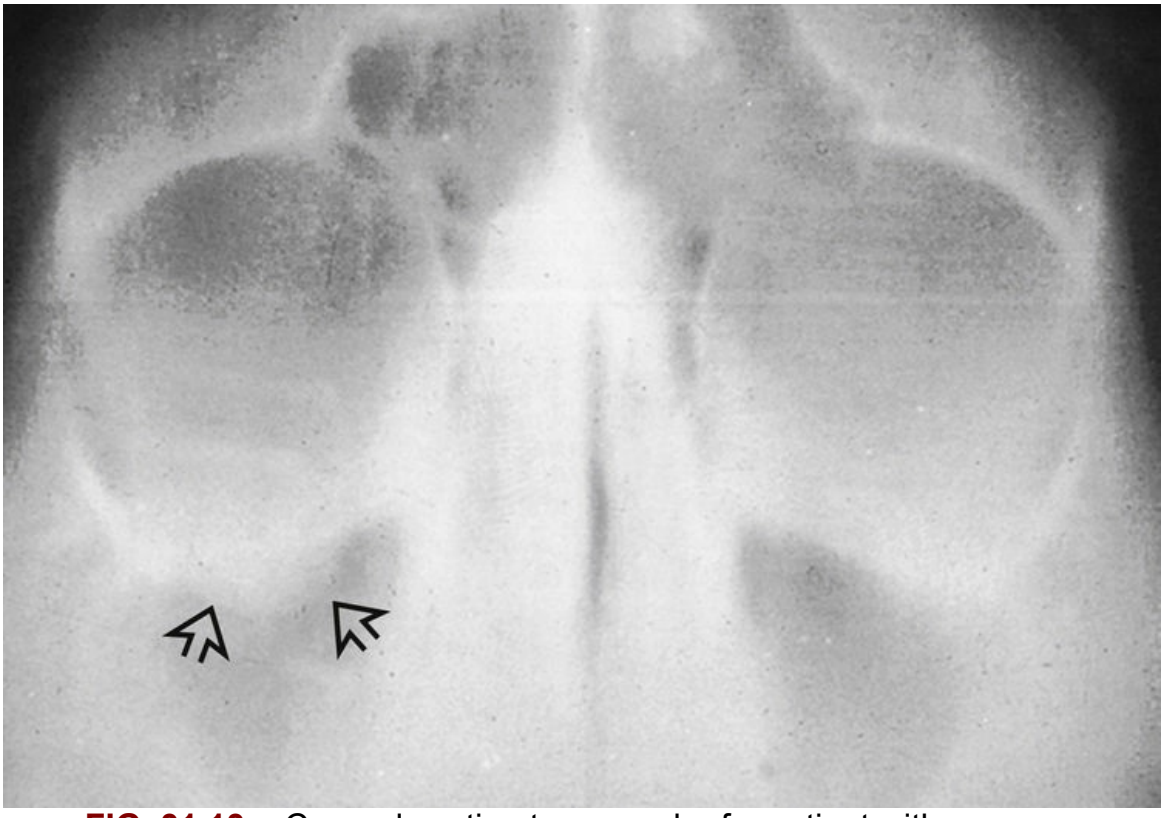


FIG. 31.13 Coronal section tomograph of a patient with an orbital blow-out fracture of the right orbital floor/antral roof showing the downward herniated contents of the orbit into the antrum (arrowed), the so-called *hanging drop* appearance.

Foreign Bodies in the Antrum

Important Causes

- Displaced root fragments or teeth (see Fig. 31.5)
- Excess root canal filling material forced through the apex of an upper posterior tooth during endodontics
- Antrolith – calcification within the antrum
- Foreign material pushed into the antrum through an existing oro-antral communication.

Main Radiographic Features

- The presence, position and often the nature of the foreign body
- Occasionally, associated sinusitis.

Cysts

The more important cysts that can affect the antra include the following:

- Intrinsic mucous retention cyst
- Extrinsic – odontogenic cysts, e.g.:
  - Radicular (dental) cysts
  - Residual cysts
  - Dentigerous cysts

  } associated with upper posterior teeth.

Mucous Retention Cyst

Cause

The cause is unknown, but is presumably due to blockage of a mucous-secreting cell in the antral lining.

Main Radiographic Features

- Incidental finding
- Well-defined, round, dome-shaped opacity within the antrum varying in size from a tiny lesion to one completely filling the antrum (see Figs. 31.5 and 31.7)
- Usually no evidence of thickening of the remainder of the epithelial lining
- Usually no alteration of the antral outline
- Occasionally bilateral (see Fig. 31.14).

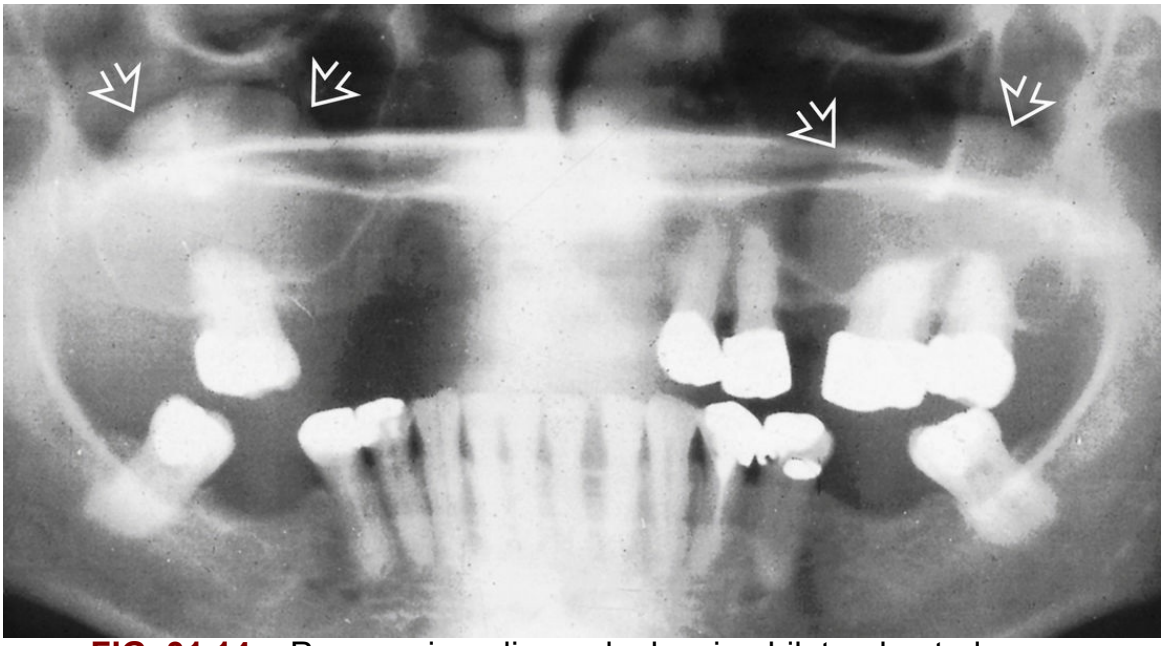


FIG. 31.14 Panoramic radiograph showing bilateral antral mucous retention cysts (arrowed).

Odontogenic Cysts

These cysts are extrinsic to the antra developing in the alveolar bone beneath the antral floor.

Main radiographic features of a small cyst

- Round, dome-shaped opacity in the base of the antrum with a well-defined, radiopaque corticated margin to the edge of the meniscus, i.e. the odontogenic cyst has a bony margin and so can be differentiated from the soft tissue mucous retention cyst or antral polyp (see Figs 31.15 and 31.16)
- Lateral expansion of the alveolar bone
- Sometimes displacement of the associated tooth.

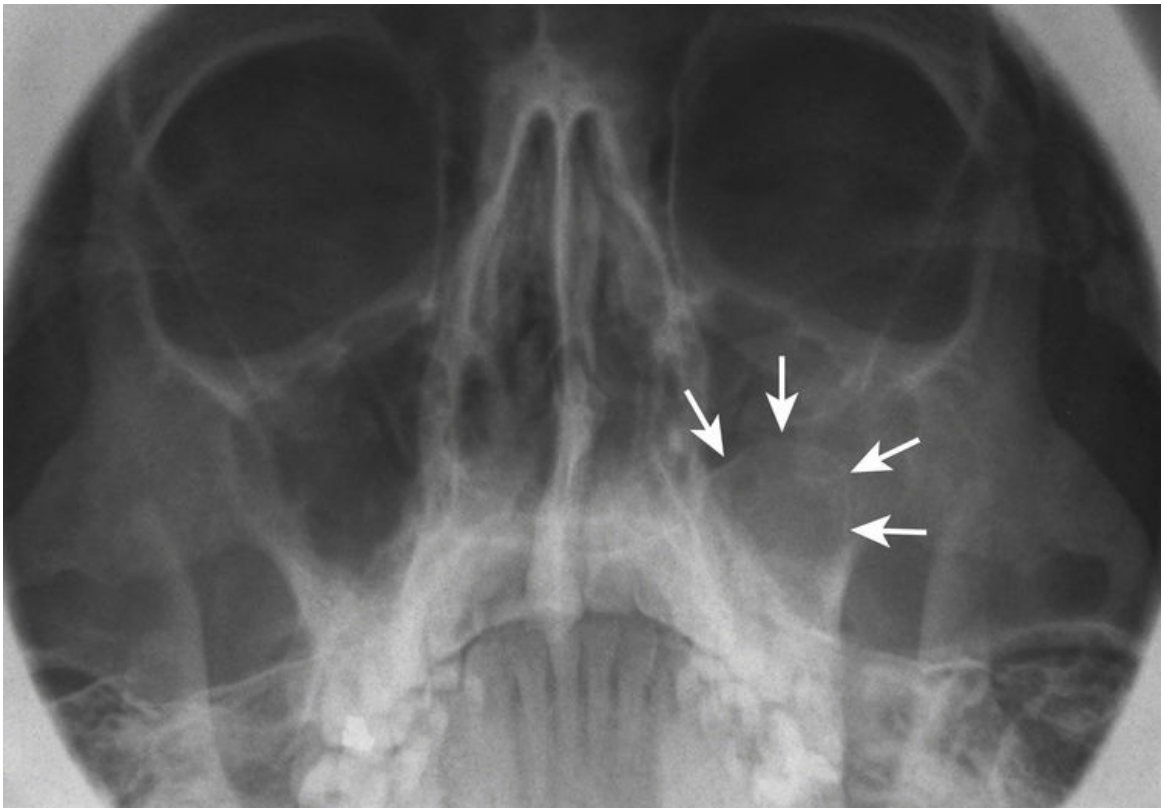


FIG. 31.15 Central part of an occipitomental showing a round, domed opacity on the left side (arrowed) caused by a radicular (dental) cyst arising from ⌊6 , which has displaced the antral floor.

Main radiographic features of a large cyst

- Total opacity of the antral region owing to complete compression of the antral cavity
- Loss of antral outline
- Sometimes displacement of the associated tooth (see Figs 31.17 and 31.18).

NOTE: Subsequent marsupialization or decompression of the cyst will usually result in the reformation of the antral cavity.

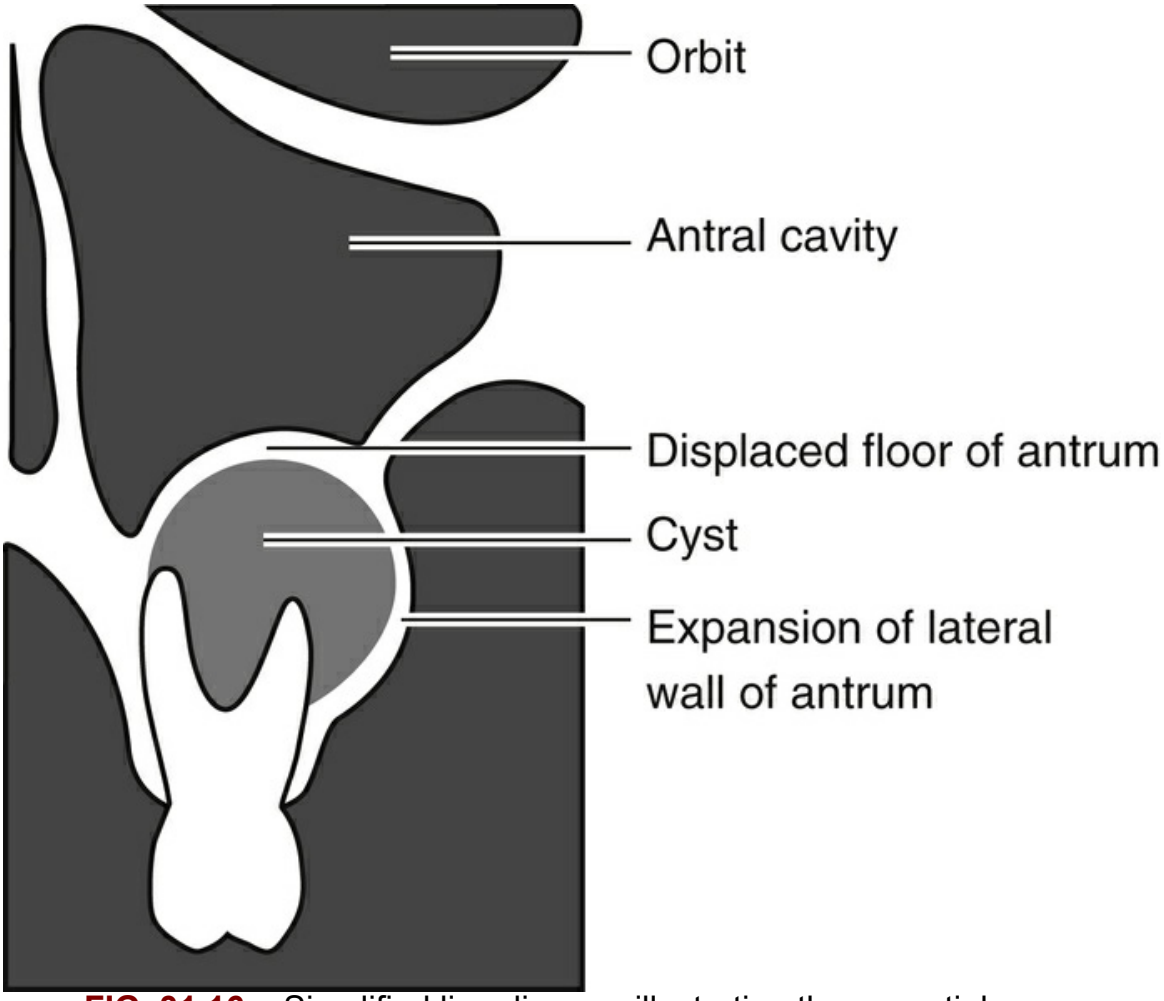


FIG. 31.16 Simplified line diagram illustrating the essential radiographic features of a small odontogenic cyst and its effects on the antrum (as depicted on an 0° occipitomental).



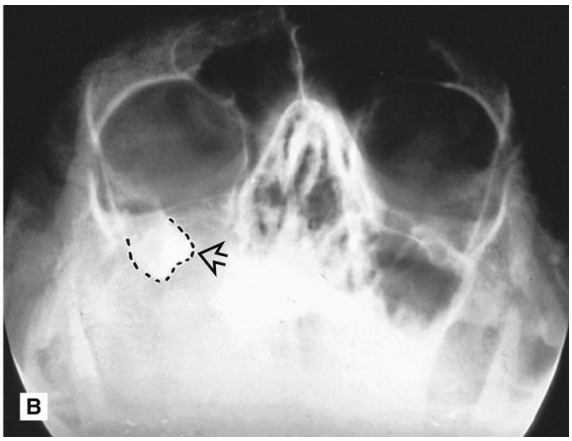


FIG. 31.17 Large dentigerous cyst associated with 8. **(A)** Periapical of the upper right posterior teeth. Note the lack of antral floor outline and absence of 8. **(B)** Occipitomental of the same patient showing total opacity of the right antral region with no evidence of the lateral antral margin. The displaced upper wisdom tooth is evident underneath the orbit (outlined and arrowed).

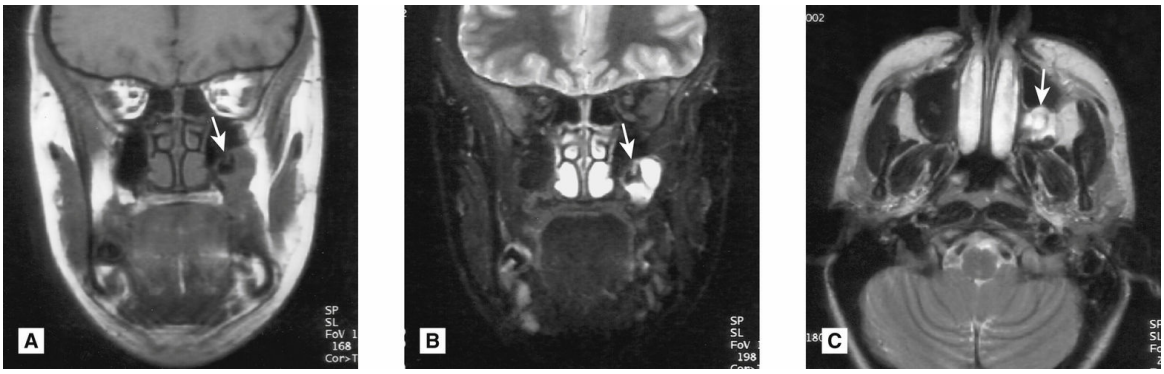


FIG. 31.18 MRI of a dentigerous cyst associated with an unerupted displaced third molar expanding into the antrum. **(A)** A T1-weighted coronal image showing the cyst and unerupted tooth (arrowed). **(B)** A T2-weighted coronal image – the cyst fluid appears white (arrowed). **(C)** A T2-weighted axial image showing the cyst (arrowed).
Courtesy of Drs J. Kabala and J. Luker

Tumours

Benign Intrinsic Tumours

These are all rare but can include:

- *Papilloma* – this produces, radiographically, a well-defined, non-specific, soft tissue opacity within the antrum
- *Osteoma* – this produces, radiographically, a well-defined, round or lobulated, homogeneous, densely opaque mass within the antrum. The osteoma is most common in the frontal sinus.

Malignant Intrinsic Tumours

Squamous cell carcinoma and *adenocarcinoma* – these uncommon but important tumours produce a rapidly growing, aggressive soft tissue mass within the antrum causing destruction of one or more of the antral walls.

Main radiographic features of a small early lesion

- Non-specific, well-defined, round soft tissue opacity within the antrum
- Variable destruction of the bony antral walls.

Main radiographic features of a large well-established lesion

- Total opacity of the antral cavity (see Fig. 31.19) – in the absence of symptoms suggesting infection, or a history of trauma, a totally opaque antrum is a cause for serious concern and further investigation is necessary.
- Destruction of one or more of the antral walls (see Fig. 31.20) and invasion of surrounding hard and soft tissues – hence the need for CT
- Occasional displacement or resorption of teeth.

Extrinsic Tumours

Any tumour that can affect the maxilla – whether benign or malignant – can have an effect on the antra with the typical associated bony changes. All are uncommon but three of the more important tumours are:



FIG. 31.19 Occipitomental showing a totally opaque right antrum caused by a large squamous cell carcinoma, with destruction of the lateral antral wall (large arrow) and zygoma (small arrow).

- Ameloblastoma
- Osteosarcoma
- Squamous cell carcinoma.

The main radiographic features of concern are those indicating malignancy and include:

- Total or partial opacity of the antral cavity

- Destruction of one or more of the walls of the antrum
- Expansion of the maxilla
- Occasional displacement or resorption and loosening of the adjacent teeth (see Figs 31.21 and 31.22).

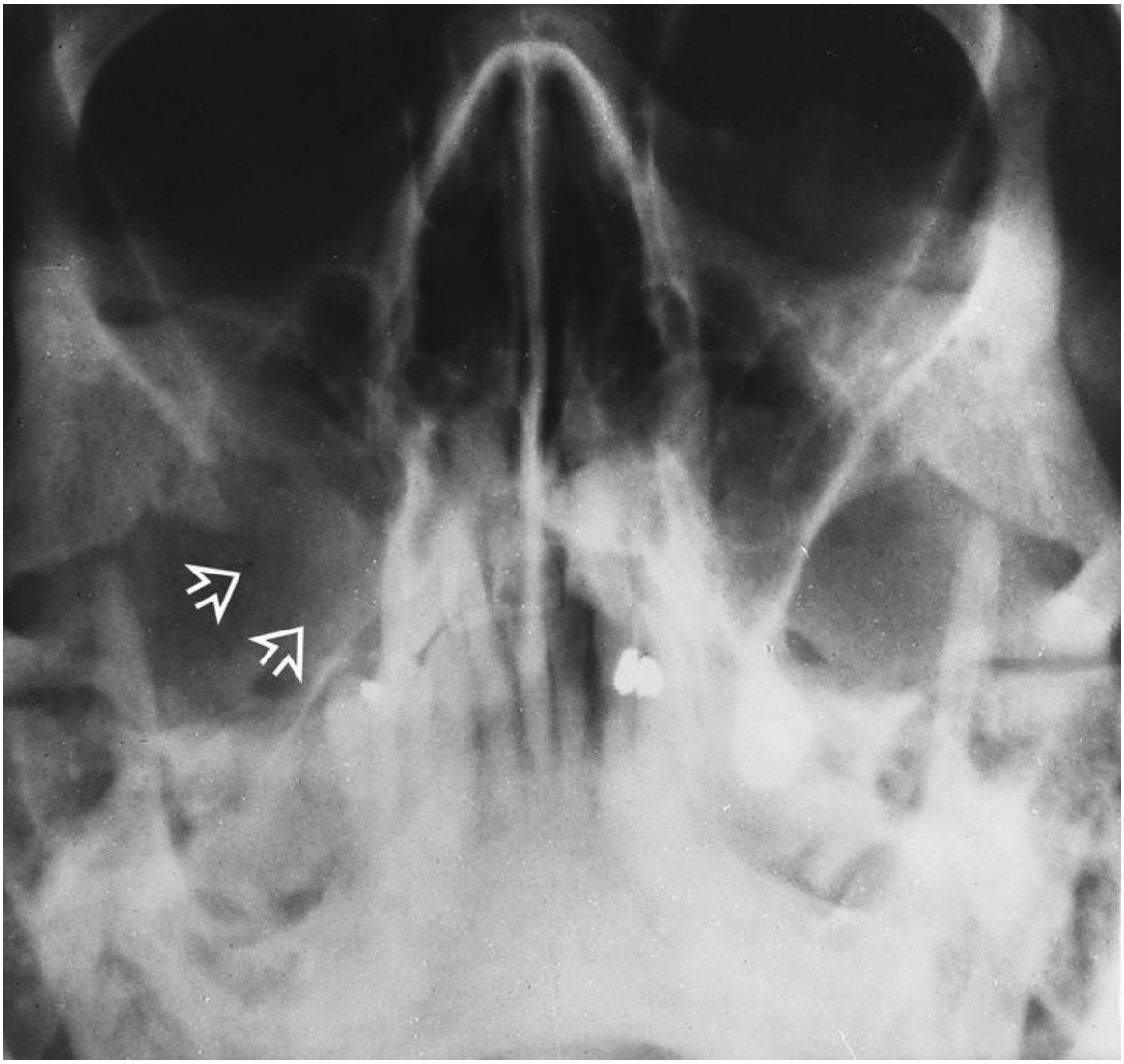


FIG. 31.20 Occipitomental showing destruction of the lateral wall of the right antrum (arrowed) by a squamous cell carcinoma. In this case, there is little evidence of increased opacity within the antrum.

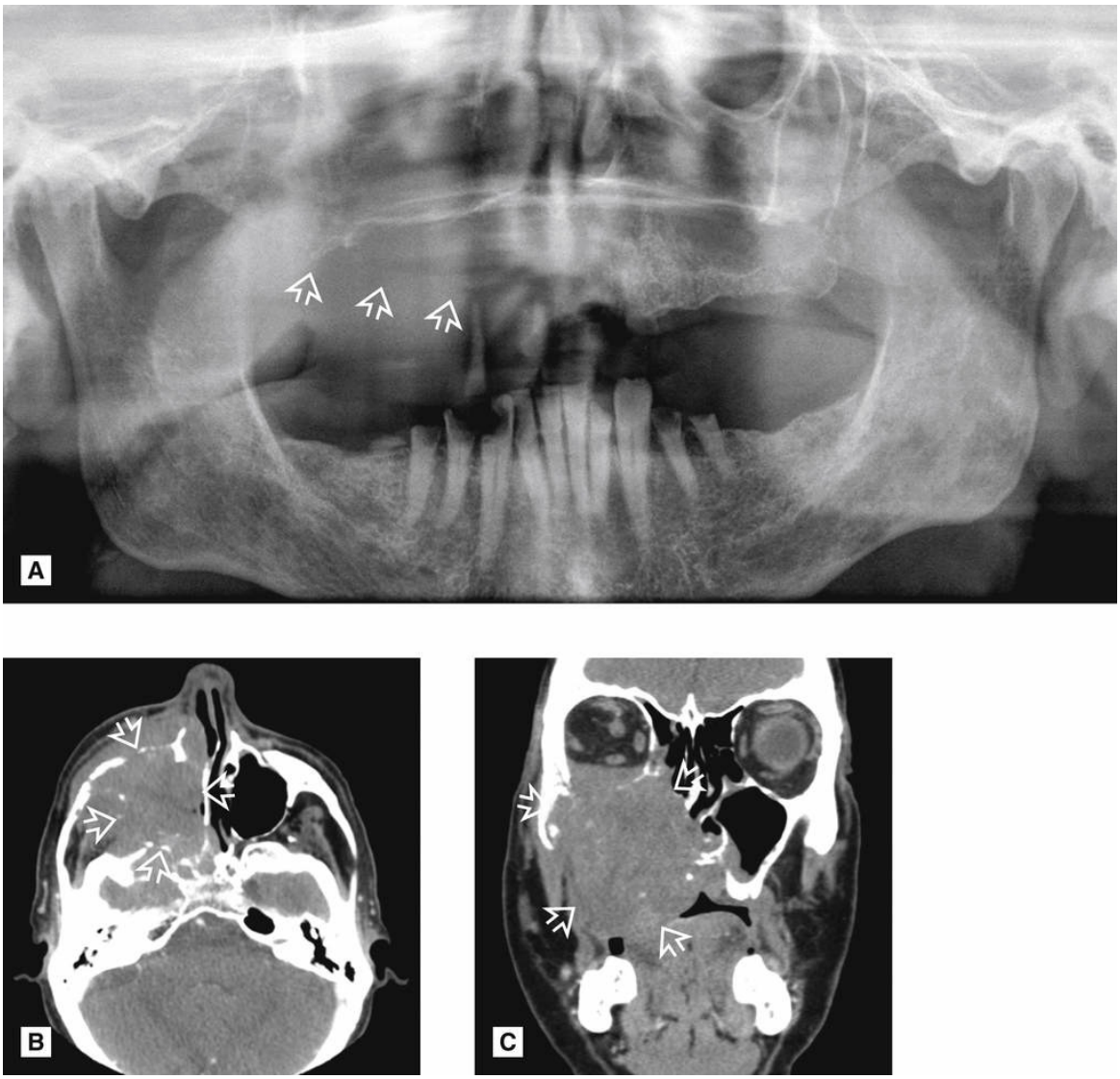


FIG. 31.21 **(A)** Panoramic radiograph showing gross destruction of right maxilla (arrowed). **(B)** Axial CT and **(C)** coronal CT images of the same patient showing the large destructive mass of an adenocarcinoma (arrowed).
Courtesy of Mr M. Fardy.

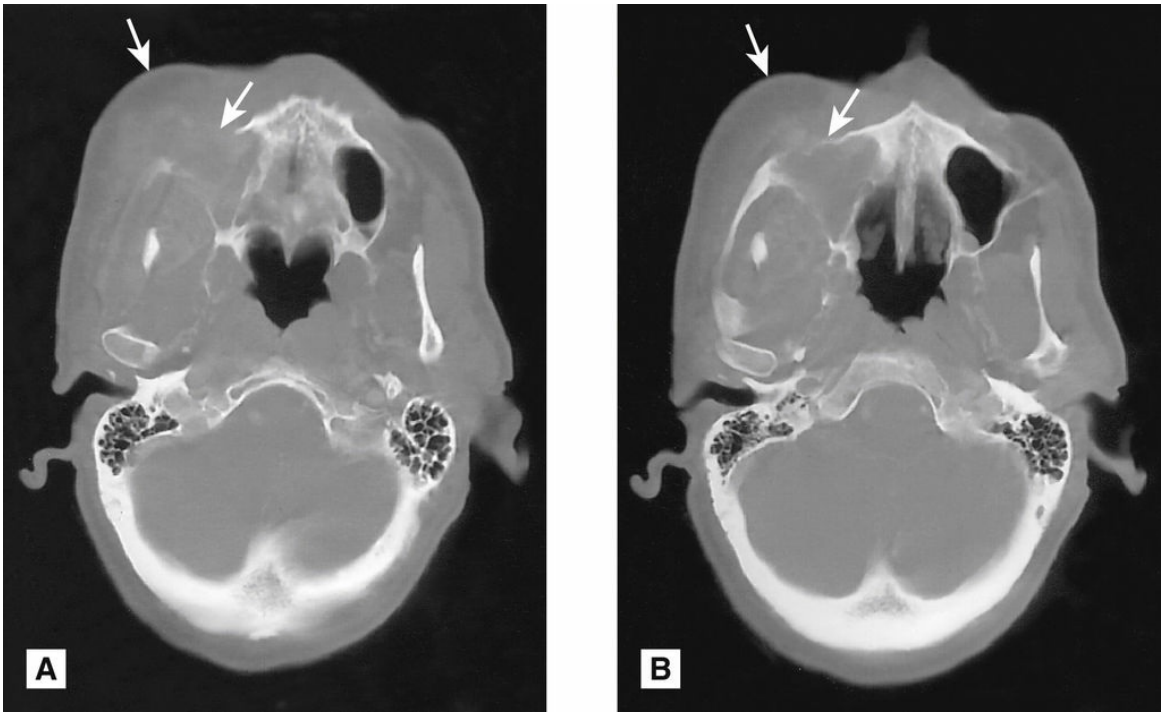


FIG. 31.22 Two axial CT slices showing a very large mass (arrowed) of a squamous cell carcinoma probably arising in the cheek showing extensive local destruction including the lateral wall of the antrum and extension into the antrum.
Courtesy of Drs J. Kabala and J. Luker.

Other Paranasal Air Sinuses

As mentioned, the frontal, ethmoidal and sphenoidal air sinuses are of limited importance in routine dentistry. Many of the conditions described in relation to the maxillary antra can affect these paranasal sinuses and produce similar effects. Occasionally routine skull radiography reveals unusual abnormalities, such as the *ivory osteoma* in the frontal sinus (see Fig. 31.23). But generally the investigation of choice for the paranasal air sinuses is computed tomography (CT) as shown in Fig. 31.24 .

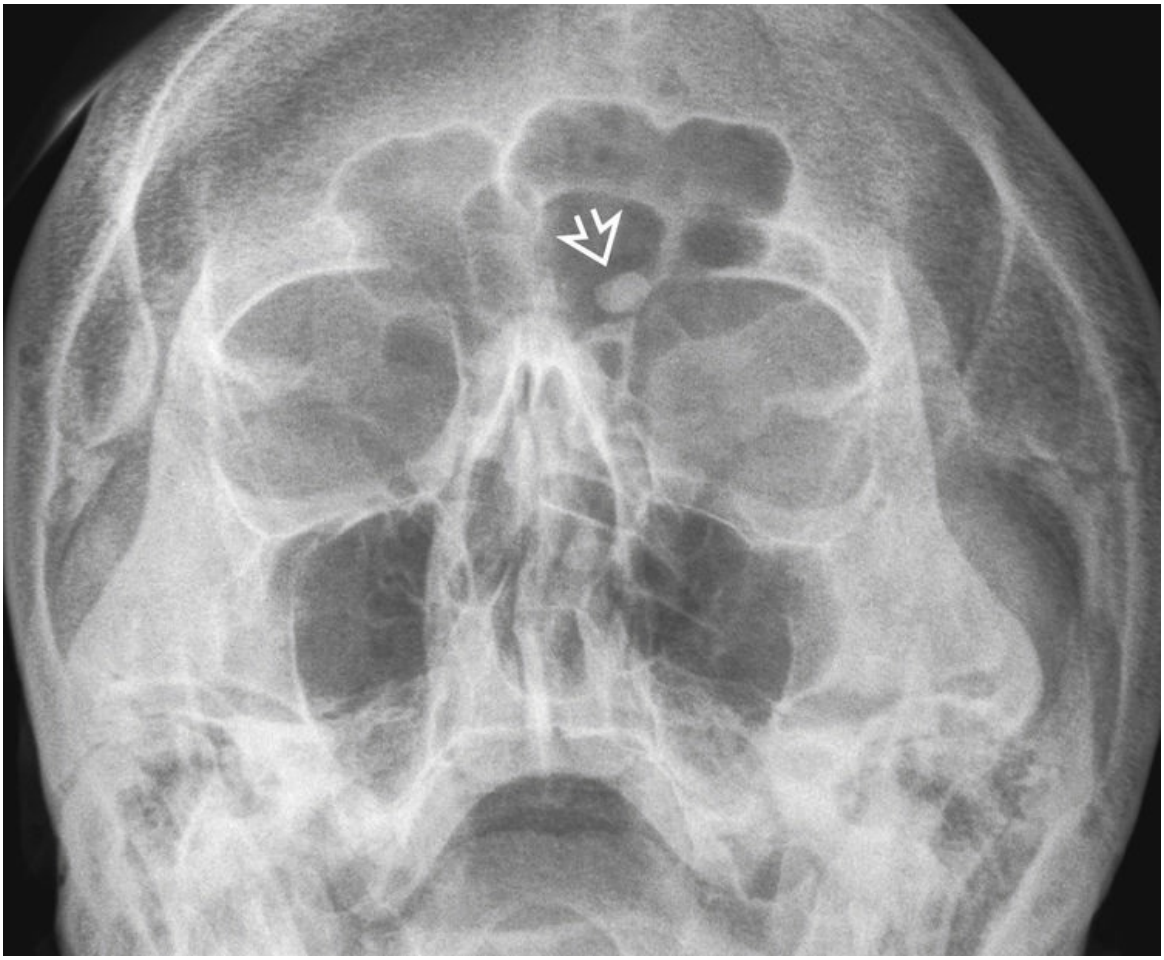
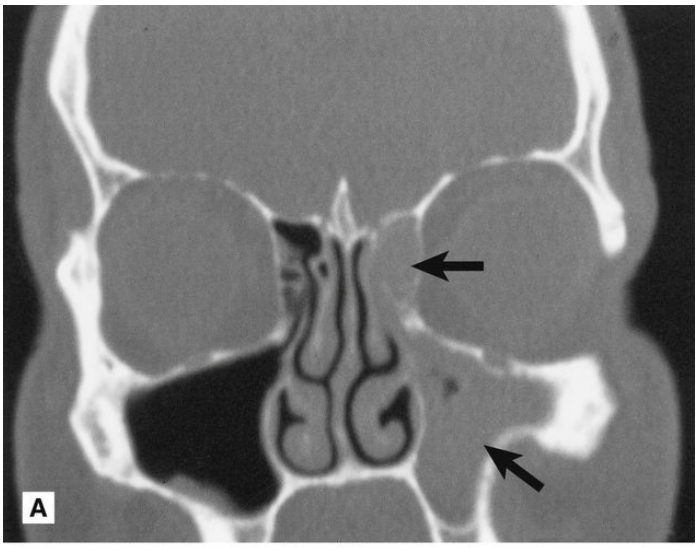
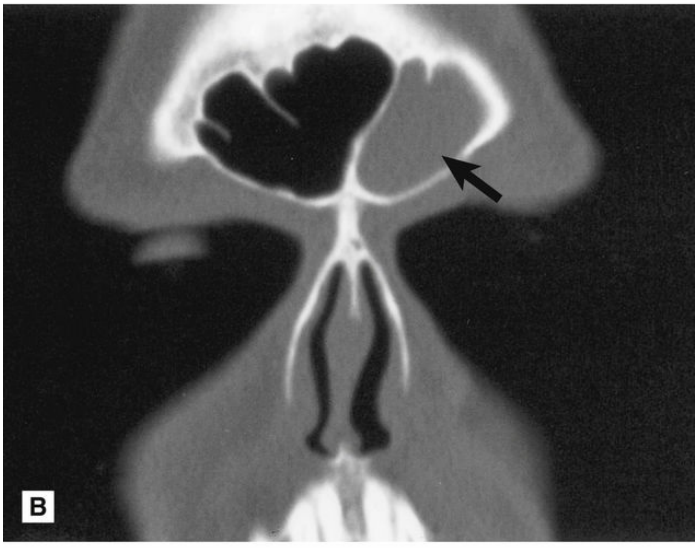


FIG. 31.23 Occipitomental showing the characteristic opacity of a benign ivory osteoma (arrowed) in the frontal sinus.


A


B

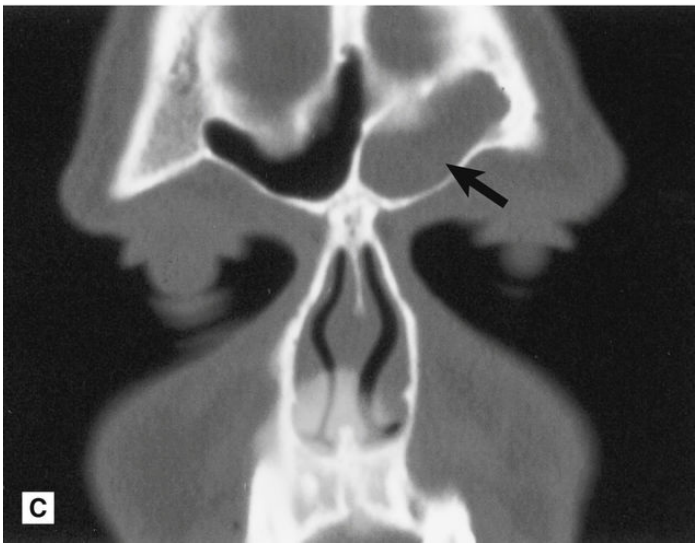

C

FIG. 31.24 Three coronal CT scans of the same patient showing **(A)** total opacity of the maxillary, ethmoidal and **(B, C)** frontal sinuses (arrowed) on the left side as a result of acute infection and inflammation.

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

32

The Salivary Glands

Salivary Gland Disorders

Disorders of the major salivary glands are relatively common, with a large spectrum of underlying diseases. This has led to a variety of classifications. However, the presenting symptoms and complaints allow a broad division into six main categories:

- Acute intermittent generalized swelling of a gland, often related to meals
- Acute generalized swelling of one or more glands
- Chronic generalized swelling, often involving more than one gland
- Discrete swelling within or adjacent to a gland
- Dry mouth
- Excess salivation.

The important causes of these complaints are summarized in Table 32.1 .

Investigations

Several investigations can be used on the salivary glands, the most appropriate often being decided by the patient's presenting symptoms. The main investigations include:

- Plain radiography
- Sialography (using conventional radiography or fluoroscopy)

- Ultrasound examination
- Magnetic resonance imaging (MRI)
- Radioisotope imaging
- Computed tomography (CT)
- Flow rate studies
- Biopsy.

TABLE 32.1

A summary of the main salivary gland complaints and their causes

Salivary gland complaint	Cause
Acute intermittent generalized swelling	Obstructive disorders including: • Sialolithiasis – salivary stones • Stricture or stenosis of the duct, usually secondary to surgery, stones or infection • Recurrent parotitis of childhood
Acute generalized swelling	Infection, either: • Viral, e.g. mumps • Bacterial-ascending sialadenitis
Chronic generalized swelling	Sjögren's syndrome, either primary or secondary Sialosis Chronic infection HIV disease Cystic fibrosis Sarcoidosis
Discrete swelling	Intrinsic tumour, benign or malignant Extrinsic tumour Cysts Overlying lymph nodes
Dry mouth	Sjögren's syndrome Post-radiation damage Mouth breathing Dehydration Functional disorders, including: • Drugs, such as tricyclic antidepressants • Neuroses, particularly chronic anxiety states
Excess salivation	Psychological (false ptyalism) Reflex, e.g. owing to local stimulation Heavy metal poisoning

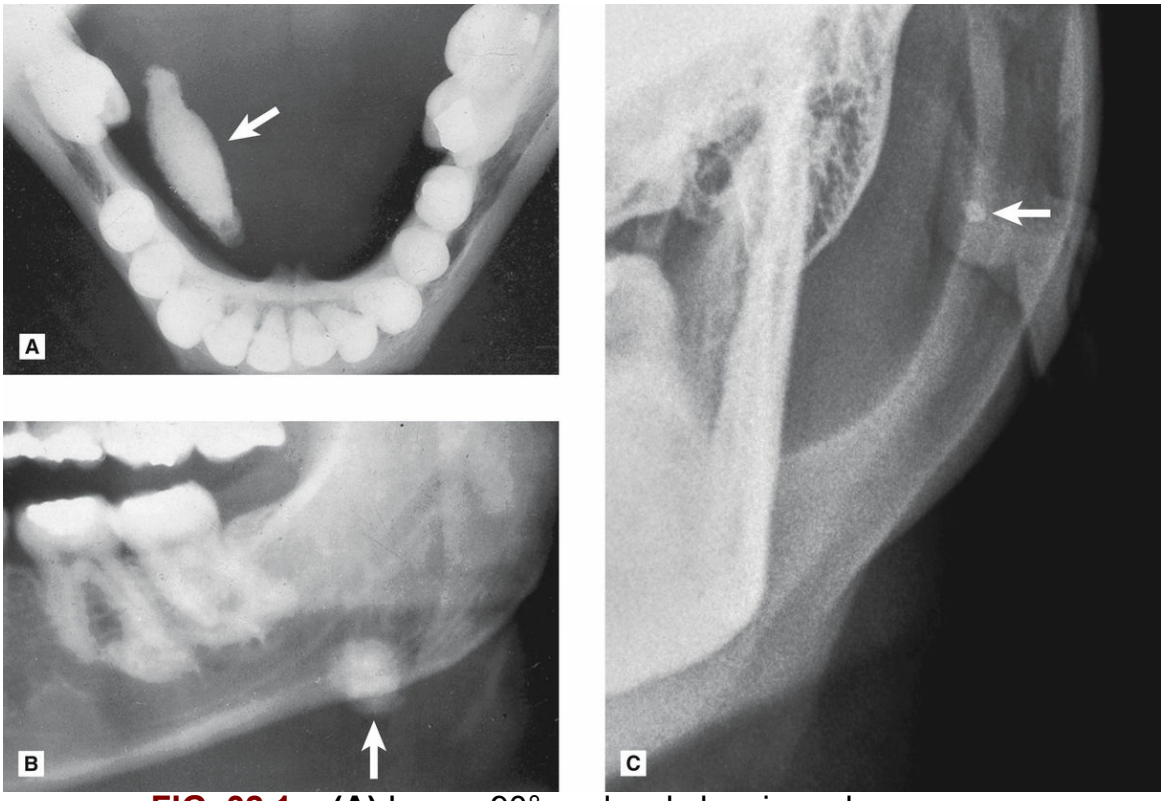


FIG. 32.1 **(A)** Lower 90° occlusal showing a large radiopaque calculus (arrowed) in the right submandibular duct. **(B)** Part of a panoramic radiograph showing another calculus (arrowed) in the left submandibular gland. **(C)** Rotated AP view with the left cheek blown out to ensure the calculus (arrowed) is not superimposed on the underlying bones.

Plain Radiography

The most common disorder of the major salivary glands is obstruction caused either by salivary stones (calculi) or stricture of the ducts. A large proportion of salivary calculi are radiopaque (approximately 40%–60% in the parotid and 80% in the submandibular glands) so patients presenting with obstructive symptoms of acute intermittent swelling require routine radiographs to determine the presence and position of the stone(s) (see Fig. 32.1).

The radiographic projections used commonly for the parotid and submandibular glands are summarized in Table 32.2 .

TABLE 32.2

A summary of the commonly used radiographic projections for the parotid and submandibular glands

Salivary gland	Radiographic projections used
Parotid	Panoramic radiograph Oblique lateral Rotated PA or AP with cheek blown out Intraoral view of the cheek
Submandibular	Panoramic radiograph Oblique lateral Lower 90° occlusal (to show the duct) Lower oblique occlusal (to show the gland) True lateral skull with the tongue depressed Rotated AP (below mandible)

Sialography

Sialography can be defined as the radiographic demonstration of the major salivary glands by introducing a radiopaque contrast medium into their ductal system. It is also very effective for the diagnosis of obstruction whether caused by stones or strictures. Conventional sialography is widely used and is probably still the most common specialized salivary gland investigation.

The procedure is divided into three phases:

- The preoperative phase
- The filling phase
- The emptying phase.

Preoperative Phase

This involves taking preoperative (scout) radiographs, if not already taken, before the introduction of the contrast medium, for the following reasons:

- To note the position and/or presence of any radiopaque obstruction

- To assess the position of shadows cast by normal anatomical structures that may overlie the gland, such as the hyoid bone
- To assess the exposure factors.

Filling Phase

The relevant duct orifice needs to be found clinically, probed and dilated, and then cannulated. This is shown in Fig. 32.2 together with a diagram of the normal anatomy of the major salivary glands and ducts. The contrast medium can then be introduced.

Three main techniques are available for introducing the contrast medium. When this is complete, the filling phase radiographs are taken, ideally at least two different views at right angles to one another.

Emptying Phase

The cannula is removed and the patient allowed to rinse out. The use of lemon juice at this stage to aid excretion of the contrast medium is often advocated but is seldom necessary. After 1 and 5 minutes, the emptying phase radiographs are taken, usually oblique laterals. These films can be used as a crude assessment of function.

Sialography using Fluoroscopy

Fluoroscopy is a specialized imaging modality that uses low dose X-rays to show a continuous real-time X-ray image on a monitor – much like an X-ray movie. In sialography, it allows the contrast to be visualized in real time during the filling and emptying phases.

Contrast Media Used

The types of contrast media (see Chapter 18) suitable for sialography are all iodine-based, and include:

- Ionic aqueous solutions, including:
  - Diatrizoate (Urografin®)

– Metrizoate (Triosil®)
- Non-ionic aqueous solutions, including:
  – Iohexol (Omnipaque®)
  – Iodixanol (Visipaque320®).

Advantages

- Low viscosity
- Easily introduced
- Easily and rapidly removed from the gland
- Easily absorbed and excreted if extravasated.

Disadvantages

- Excretion from the gland can be very rapid unless used in a closed system
- Fine duct structures are sometimes difficult to visualize
- Ionic solutions – poor taste
- Non-ionic solutions – expensive but safer.

NOTE: In sialography, unlike with intravenous contrast studies, taste is an important factor in choosing a contrast medium. This is particularly important when undertaking sialography using fluoroscopy because patients may move if not tolerating the taste. In these circumstances, it is preferable to use non-ionic aqueous solutions.

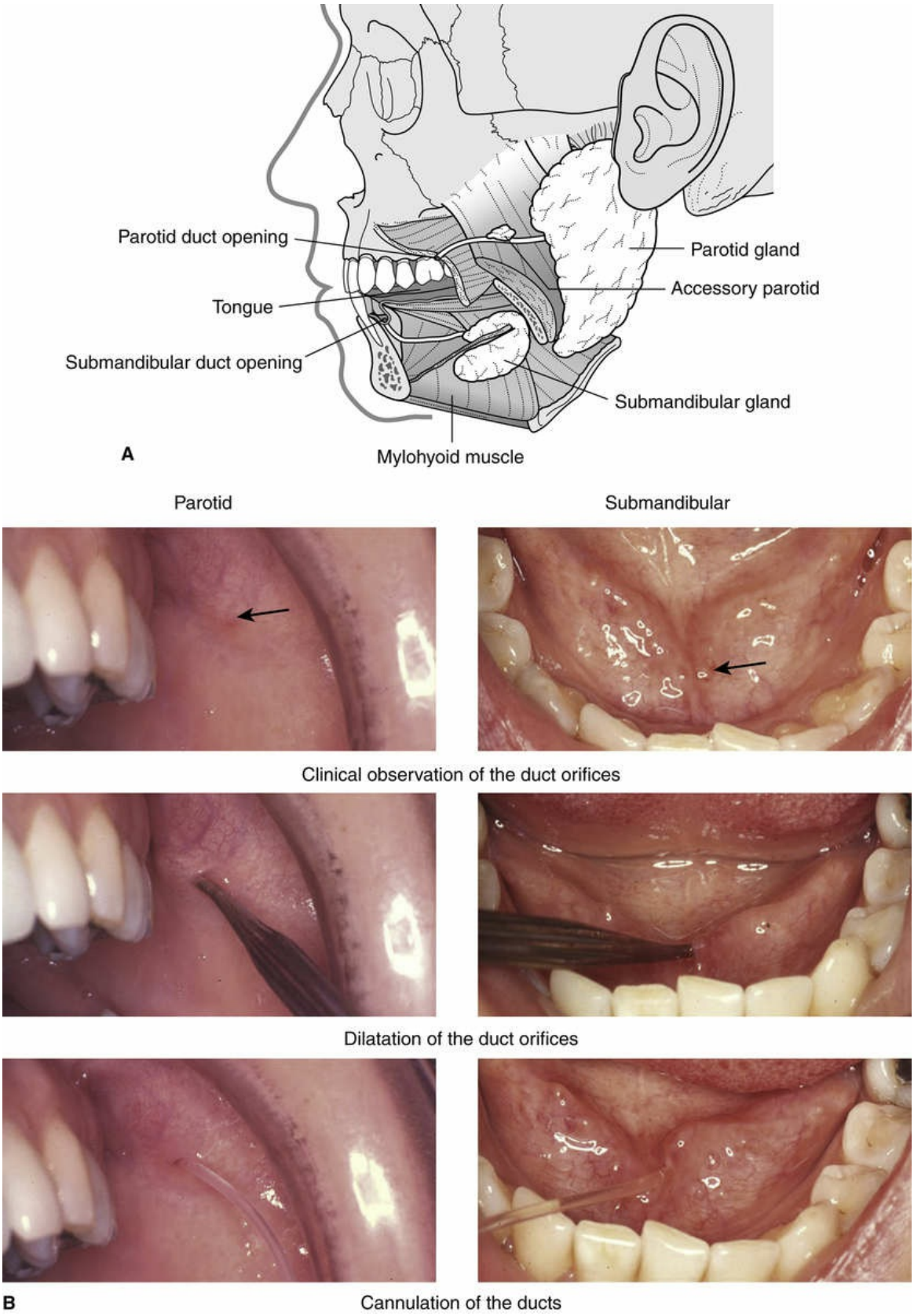


FIG. 32.2 **(A)** Diagram showing the normal anatomy of the

parotid and submandibular salivary glands, ducts and duct orifices. **(B)** Clinical photographs showing these duct orifices (arrowed), being dilated and cannulated.

Main Indications

The main clinical indications for sialography include:

- To determine the presence and/or position of calculi or other blockages, whatever their radiodensity
- To assess the extent of ductal and glandular destruction secondary to an obstruction
- To determine the extent of glandular breakdown and as a crude assessment of function in cases of dry mouth.

Contraindications

The main contraindications include:

- Allergy to compounds containing iodine in atopic individuals, although gadolinium may be used as an alternative
- Periods of acute infection/inflammation, when there is discharge of pus from the duct opening
- When clinical examination or routine radiographs have shown a calculus close to the duct opening, as injection of the contrast medium may push the calculus back down the main duct where it may be inaccessible.

Conventional Sialographic Techniques

The control of infection measures detailed in Chapter 7 are of particular importance, and should be adhered to during sialography. In addition, the wearing of eye protection glasses and a mask by operators is recommended.

The three main techniques available for introducing the contrast medium into the ductal system, having cannulated the relevant duct

orifice, include:

- Simple injection
- Hydrostatic
- Continuous infusion pressure-monitored.

These techniques can be summarized as follows.

Simple injection technique

Aqueous contrast medium is introduced using gentle hand pressure until the patient experiences tightness or discomfort in the gland (about 2.0 ml for the parotid gland, 1.0 ml for the submandibular gland).

Advantages

- Simple
- Inexpensive.

Disadvantages

- The arbitrary pressure which is applied may cause damage to the gland
- Reliance on patient's responses may lead to underfilling or overfilling of the gland.

Hydrostatic technique

Aqueous contrast medium is allowed to flow freely from an overhead reservoir into the gland under the force of gravity until the patient experiences discomfort.

Advantages

- The controlled introduction of contrast medium is less likely to cause damage or give an artefactual picture

- Simple
- Inexpensive.

Disadvantages

- Reliant on the patient's responses
- Patients have to lie down during the procedure, so they need to be positioned in advance for the filling-phase radiographs.

Continuous infusion pressure-monitored technique

Using aqueous contrast medium, a constant flow rate is adopted and the ductal pressure monitored throughout the procedure.

Advantages

- The controlled introduction of contrast media at known pressures is not likely to cause damage
- Does not cause overfilling of the gland
- Does not rely on the patient's responses
- May give information on the presence of obstruction.

Disadvantages

- Complex equipment is required
- Time consuming.

Each of these techniques has its advocates, and with experience, each produces satisfactory results. The technique used therefore depends on the operator and the facilities available.

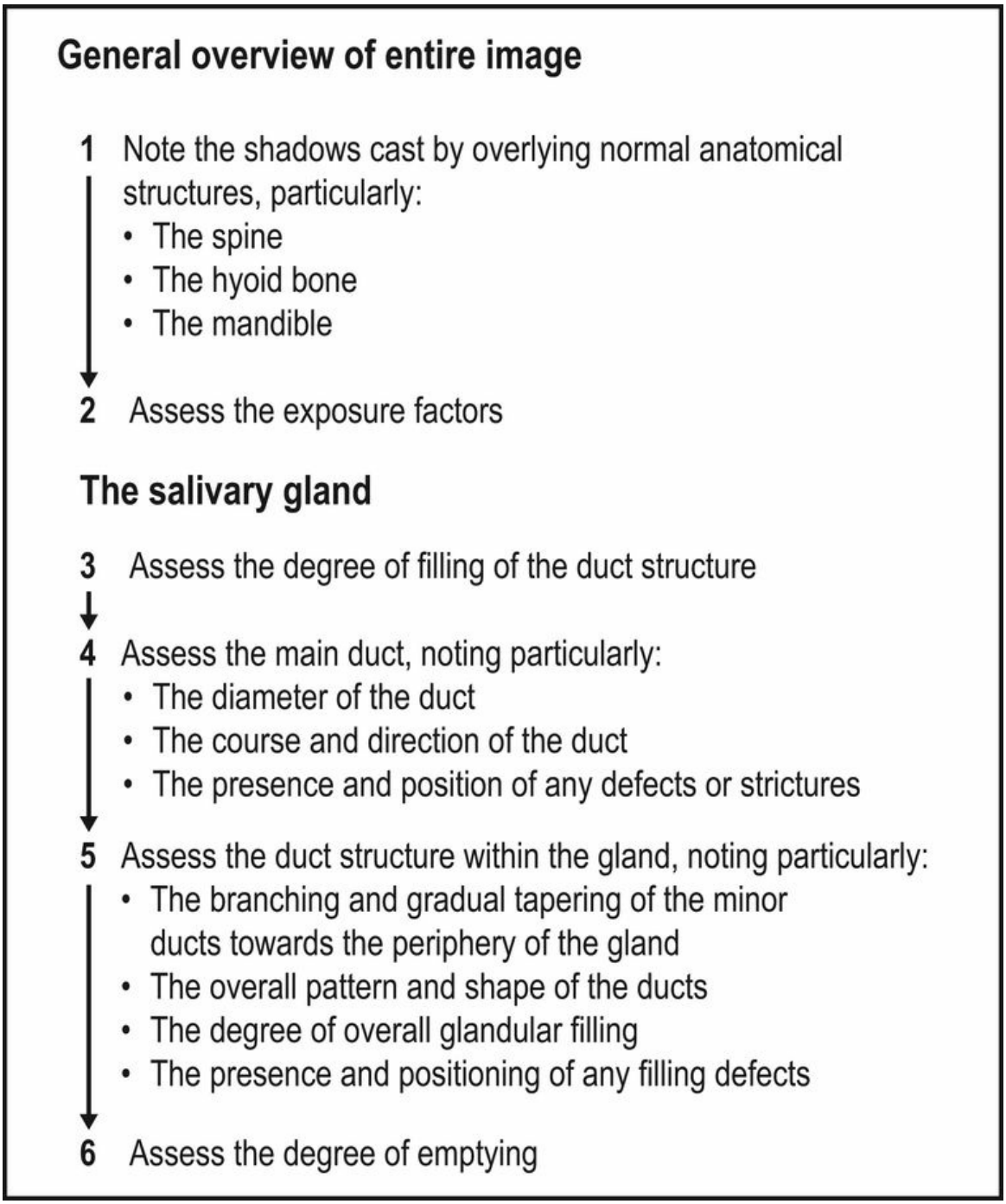


FIG. 32.3 A systematic approach for viewing sialographs.

In addition, sialography may also be performed using advanced imaging modalities, e.g. fluoroscopy, CT or MRI (see Fig. 32.20).

Sialographic Interpretation

Once again, the essential requirements include:

- A systematic approach (see Fig. 32.3)
- A detailed knowledge of the radiographic appearances of normal salivary glands
- A detailed knowledge of the pathological conditions affecting the salivary glands.

Normal sialographic appearances of the parotid gland

These include:

- The main duct is of even diameter (1–2 mm wide) and should be filled completely and uniformly.
- The duct structure within the gland branches regularly and tapers gradually towards the periphery of the gland, the so-called *tree in winter* or *leafless tree* appearance (see Fig. 32.4).

Normal sialographic appearances of the submandibular gland

These include:

- The main duct is of even diameter (3–4 mm wide) and should be filled completely and uniformly
- This gland is smaller than the parotid, but the overall appearance is similar to the branching duct structure tapering gradually towards the periphery – the so-called *bush in winter* appearance (see Fig. 32.5).

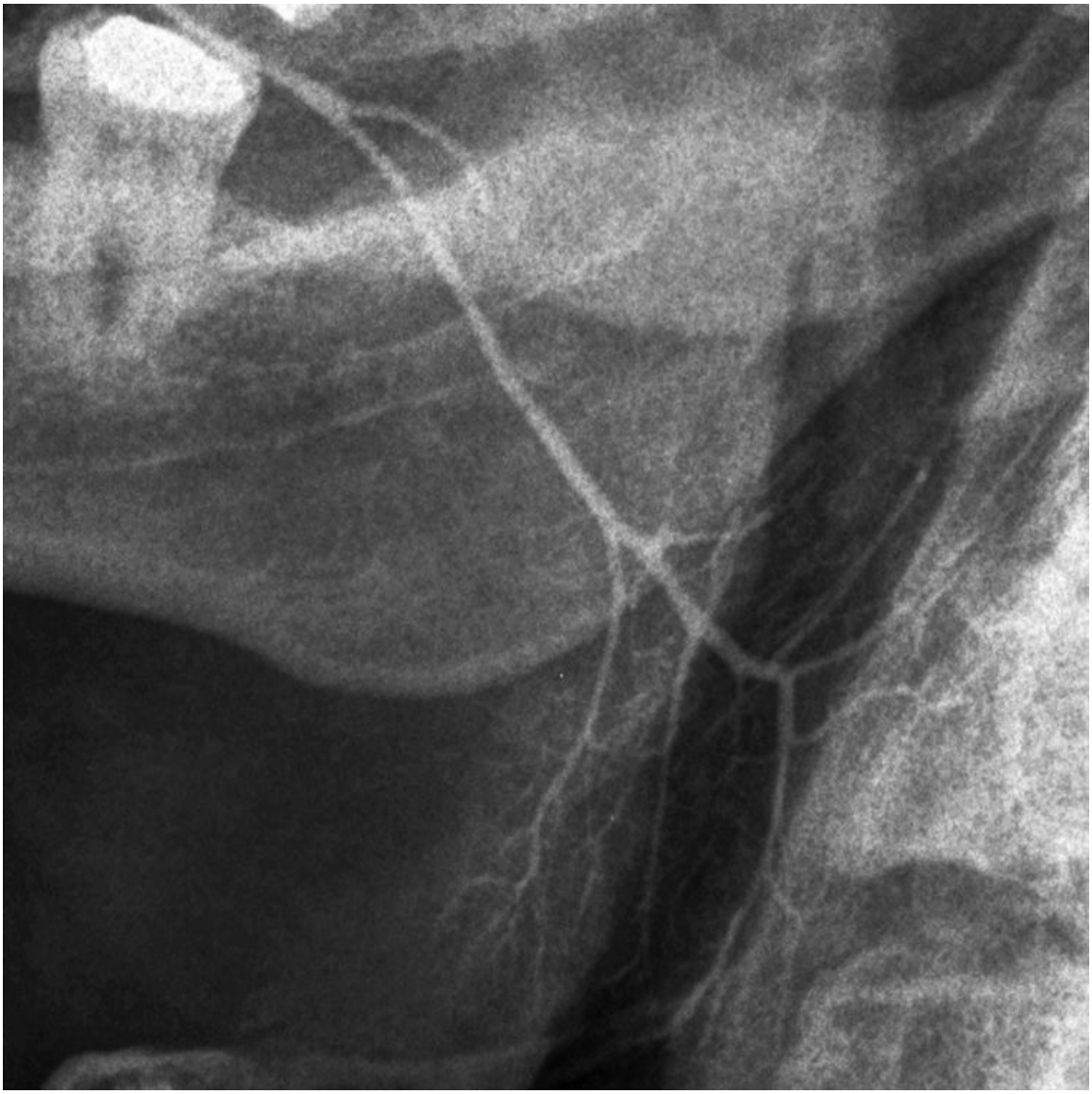


FIG. 32.4 Sialograph showing a normal left parotid gland, the *tree in winter* or *leafless tree* appearance.

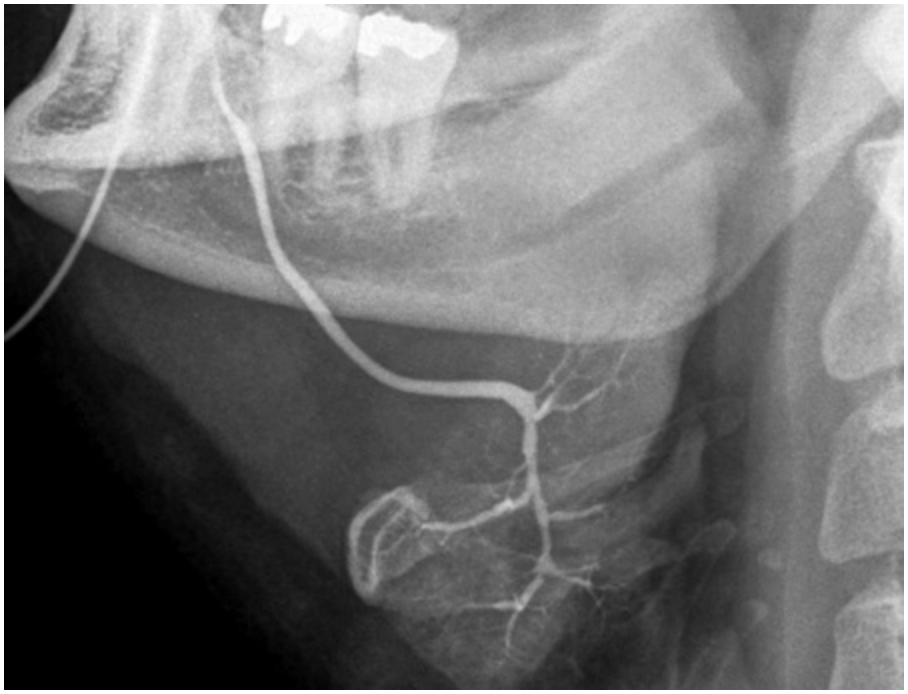


FIG. 32.5 Sialograph showing a normal left submandibular gland, the *bush in winter* appearance.

Pathological appearances

Based on the suggested systematic approach to sialographic assessment, the main pathological changes can be divided into:

- Ductal changes associated with:
  - Calculi
  - Sialodochitis (ductal inflammation/infection)
- Glandular changes associated with:
  - Sialadenitis (glandular inflammation/ infection)
  - Sjögren's syndrome
  - Intrinsic tumours.

Sialographic appearances of calculi

These are shown in Figs. 32.6 –32.8 and include:

- Filling defect(s) in the main duct
- Ductal dilatation proximal to the calculus

- The emptying film usually shows contrast medium retained behind the stone.

Sialographic appearances of sialodochitis

These are shown in Figs. 32.7 and 32.8 and include:

- Segmented sacculation or dilatation and stricture of the main duct, the so-called *sausage link* appearance
- Associated calculi or ductal stenosis.

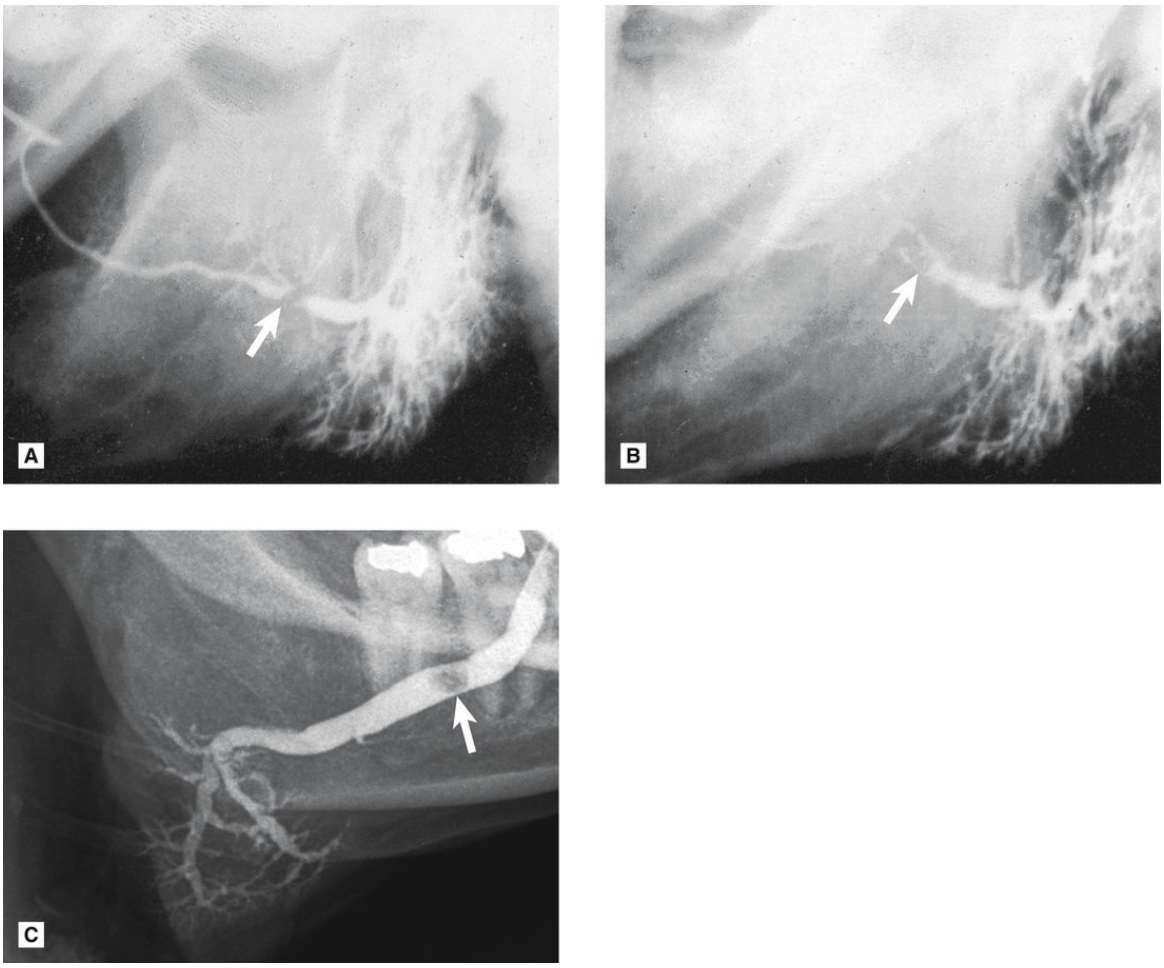


FIG. 32.6 **(A)** Sialograph of a left parotid gland showing a filling defect at the posterior end of the main duct (arrowed), caused by a stone in the duct. Ductal dilatation is evident beyond the stone. **(B)** Emptying image of the same gland showing the contrast medium retained behind the filling defect (arrowed), confirming the diagnosis of salivary calculus in the main duct. **(C)** Sialograph of right submandibular gland showing a filling defect in the main duct (arrowed) caused by a stone.

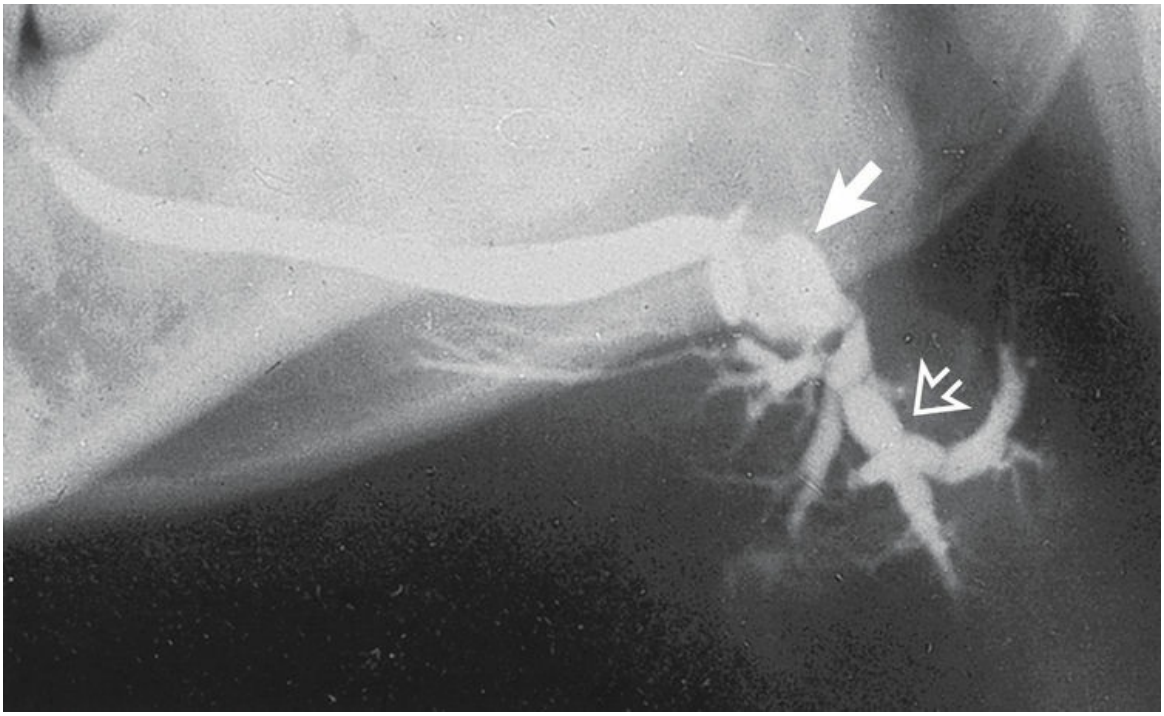


FIG. 32.7 Sialograph of a left submandibular gland, showing a normal main duct, a large calculus (solid arrow) at the posterior end of the main duct and associated segmental sacculation or dilatation and stricture of the ducts beyond the stone. Within the gland (open arrow) the *sausage-link* appearance is caused by sialodochitis.



FIG. 32.8 Sialograph of a left parotid gland showing stricture and dilatation of the main duct caused by sialodochitis secondary to stenosis at the orifice – the *sausage-link* appearance.

Sialographic appearances of sialadenitis

These include:

- Dots or blobs of contrast medium within the gland, an

appearance known as *sialectasis* (see Fig. 32.9) caused by the inflammation of the glandular tissue producing saccular dilatation of the acini

- The main duct is usually normal.



FIG. 32.9 Sialograph of a right parotid gland showing the dots or blobs of contrast medium within the gland – the appearance known as *sialectasis* , caused by sialadenitis. Note the main duct is normal.

Sialographic appearances in Sjögren's syndrome

These include:

- Widespread dots or blobs of contrast medium within the gland, an appearance known as *punctate sialectasis* or *snowstorm* (see Fig. 32.10). This is caused by a weakening of the epithelium lining the intercalated ducts, allowing the

escape of the contrast medium out of the ducts
- Considerable retention of the contrast medium during the emptying phase
- The main duct is usually normal.

An understanding of the underlying disease processes explains why the sialographic appearances of sialadenitis and Sjögren's syndrome (two totally different conditions) are so similar. This is shown diagrammatically in Fig. 32.11 .

Sialographic appearances of intrinsic tumours

These include:

- An area of underfilling within the gland, owing to ductal compression by the tumour
- Ductal displacement – the ducts adjacent to the tumour are usually stretched around it, an appearance known as *ball in hand* (see Figs. 32.12 and 32.13)
- Retention of contrast medium in the displaced ducts during the emptying phase.

NOTE: If modern imaging, e.g. ultrasound imaging or CT scan, is available, sialography for intrinsic tumours is no longer performed.



FIG. 32.10 Sialograph of a right parotid gland of a patient with Sjögren's syndrome. The main duct is normal and there are widespread dots or blobs of contrast medium throughout the gland, the *snowstorm* appearance of *punctate sialectasis* .

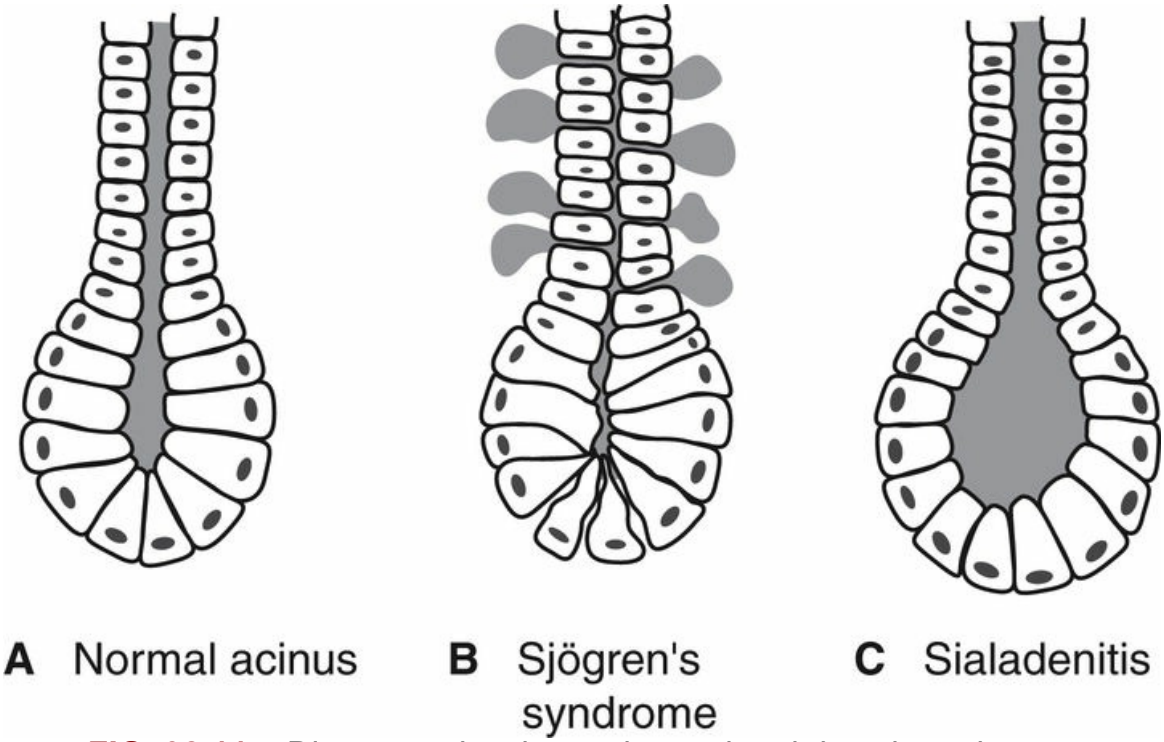


FIG. 32.11 Diagrams showing an intercalated ductule and acinus. **(A)** In a normal gland. **(B)** In Sjögren's syndrome, the epithelium lining the intercalated ductule becomes weakened allowing escape of the contrast medium out of the duct so producing the dots or blobs. **(C)** In sialadenitis, the acinus becomes dilated allowing the collection of contrast into a dot or blob.

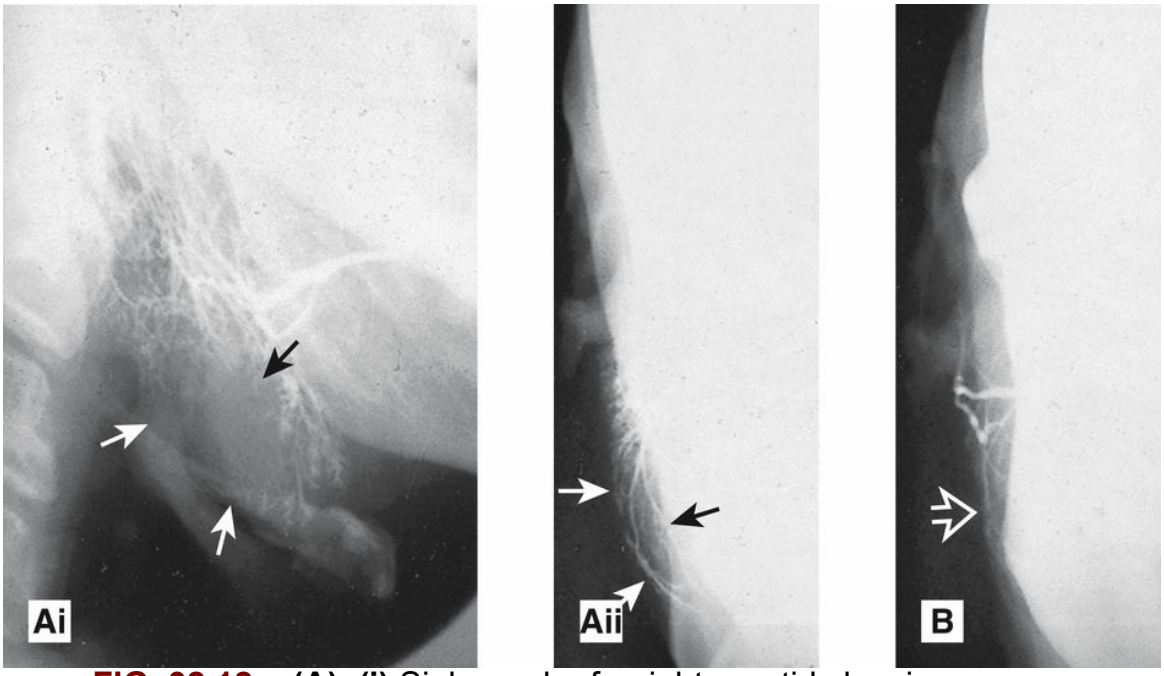


FIG. 32.12 **(A) (i)** Sialograph of a right parotid showing a large area of underfilling in the lower lobe (arrowed) caused by an intrinsic tumour (biopsy confirmed a pleomorphic adenoma). **(A) (ii)** Rotated AP view showing the lateral bowing and displacement of the ducts (arrowed) around the tumour. **(B)** Rotated AP view of a normal parotid gland for comparison (arrowed).

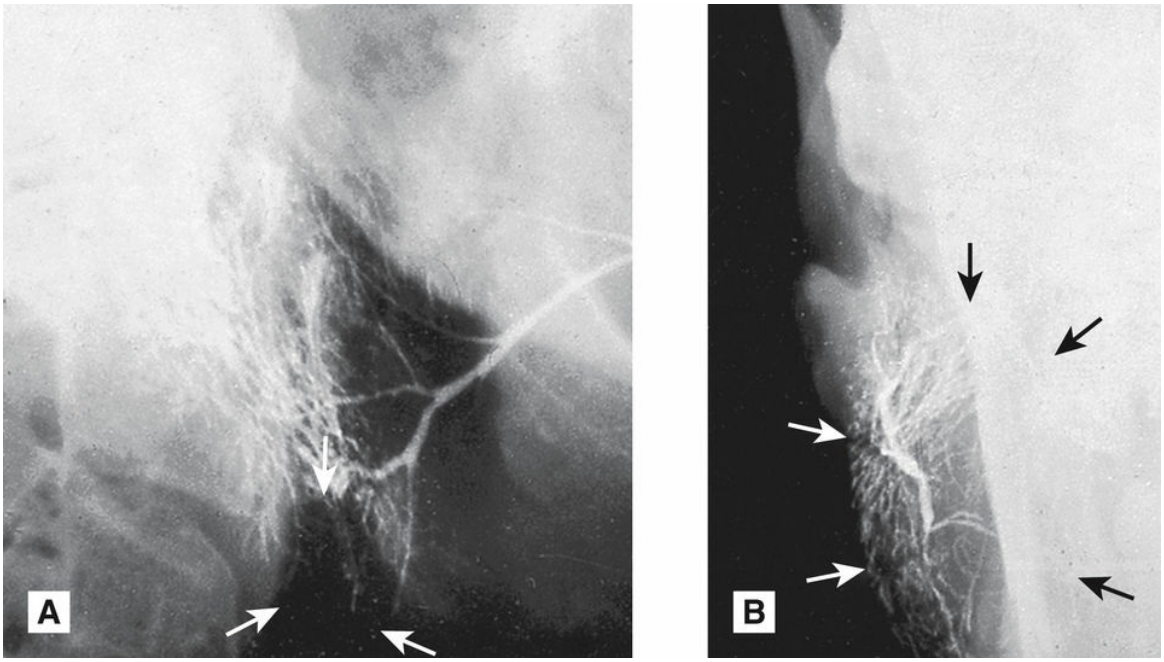


FIG. 32.13 **(A)** Sialograph of a right parotid gland showing a large area of underfilling in the lower lobe (arrowed) caused by an intrinsic tumour (pleomorphic adenoma). **(B)** Rotated AP view showing extensive ductal displacement, the appearance described as *ball in hand* (arrowed).

Interventional sialography

Conventional sialographic techniques can be supplemented and expanded into minimally invasive interventional procedures by using *balloon catheters* and small *Dormia baskets* under fluoroscopic guidance. The *balloon catheter* , as the name implies, can be inflated once positioned within a duct to produce dilatation of ductal strictures. The *Dormia basket* may be used to retrieve mobile ductal salivary stones as shown in Fig. 32.14 . Both of these procedures are now being used successfully to relieve salivary gland obstruction without the need for surgery.

Ultrasound Imaging

Ultrasound imaging of the salivary glands (see Fig. 32.15) is becoming increasingly common. Modern high-resolution scanners produce excellent images and that, coupled with the numerous advantages

shown below, has elevated ultrasound imaging to the imaging modality of choice for many patients with salivary gland disorders as shown in Figs. 32.16 –32.18 .

Indications

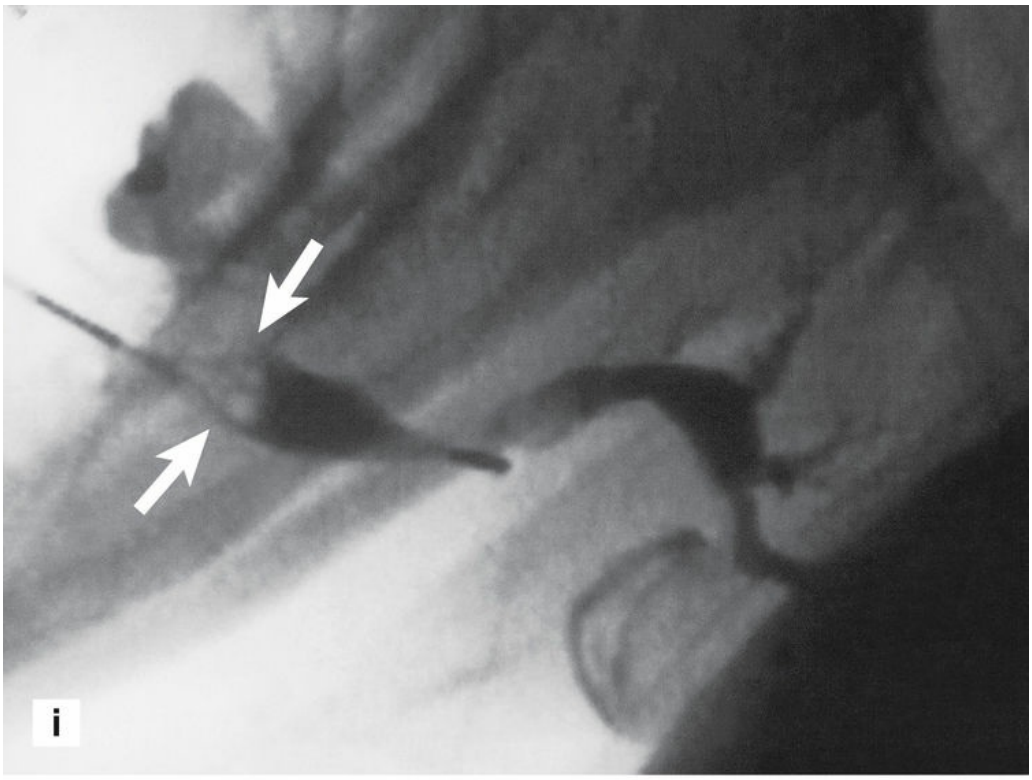
- Discrete and generalized swellings both intrinsic and extrinsic to the salivary glands
- Salivary obstruction.

Advantages

- Ionizing radiation is not used
- Provides good imaging of superficial masses
- Useful for differentiating between solid and cystic masses and for identifying the nature and location of the margins of a lesion
- Different echo signals from different tumours
- Assessment of blood flow using colour Doppler
- Identification of radiolucent stones
- Lithotripsy of salivary stones
- Ultrasound-guided fine-needle aspiration (FNA) biopsy is possible
- Intraoral ultrasound imaging is possible with small probes.

Disadvantages

- The sound waves used are blocked by bone, thus limiting the areas available for investigation
- Provides no information on fine ductal architecture.


i

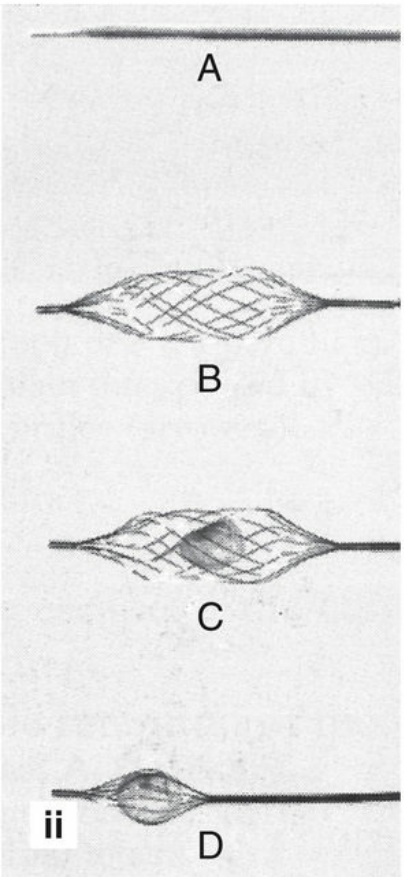

A
B
C
ii
D

FIG. 32.14 **(i)** Fluoroscopic sialograph showing an open Dormia basket in the left submandibular duct. The stone has been captured and is inside the basket (white arrows). Contrast media is evident in the dilated main duct within the gland. **(ii)** The Meditech (Boston Scientific) Dormia basket: **(A)** closed for insertion beyond the stone; **(B)** open ready to draw back; **(C)** open with the stone inside; and **(D)** closed around the stone ready for withdrawal.
Courtesy of Mrs J.E. Brown.



FIG. 32.15 Patient undergoing ultrasound investigation of the left submandibular gland.

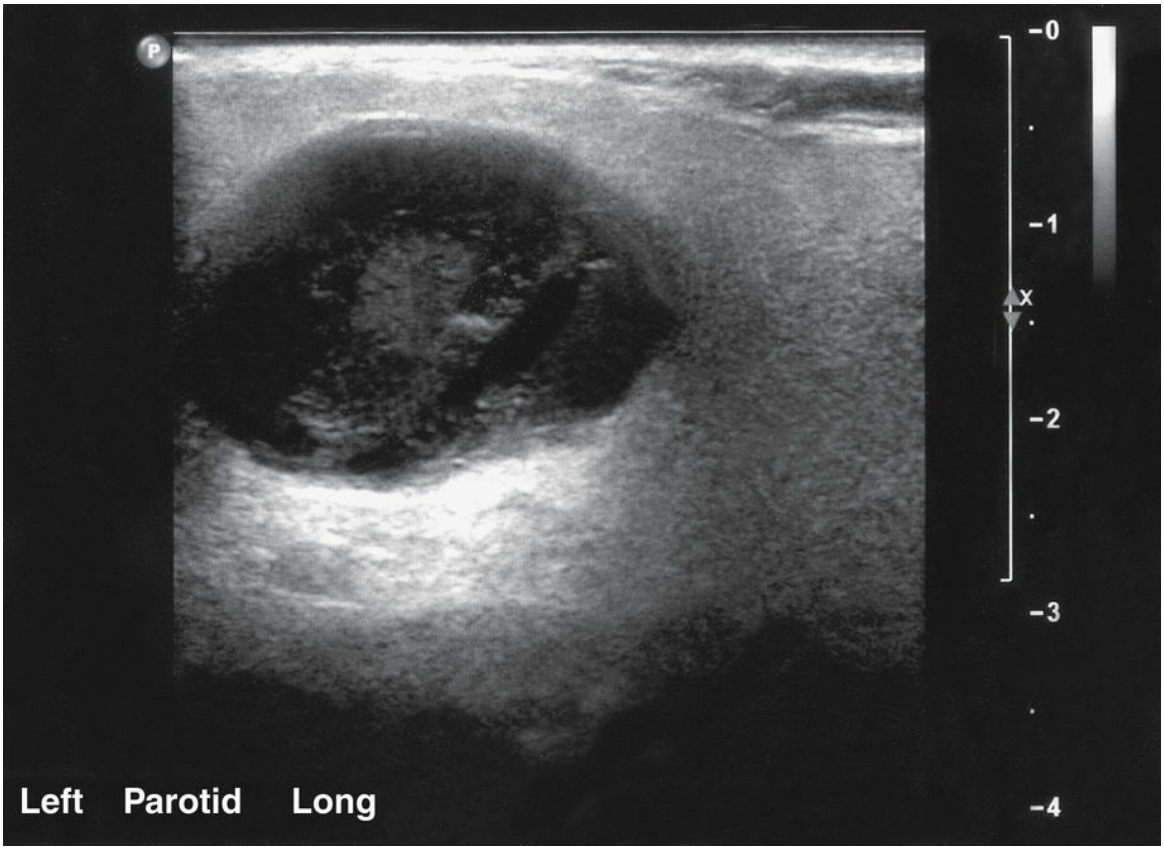


FIG. 32.16 Ultrasound image of a pleomorphic adenoma in the parotid gland. The benign tumour shows well-defined margins and is generally hypoechoic (dark) with *through transmission* (bright echoes beyond the tumour).
Courtesy of Mrs J.E. Brown.

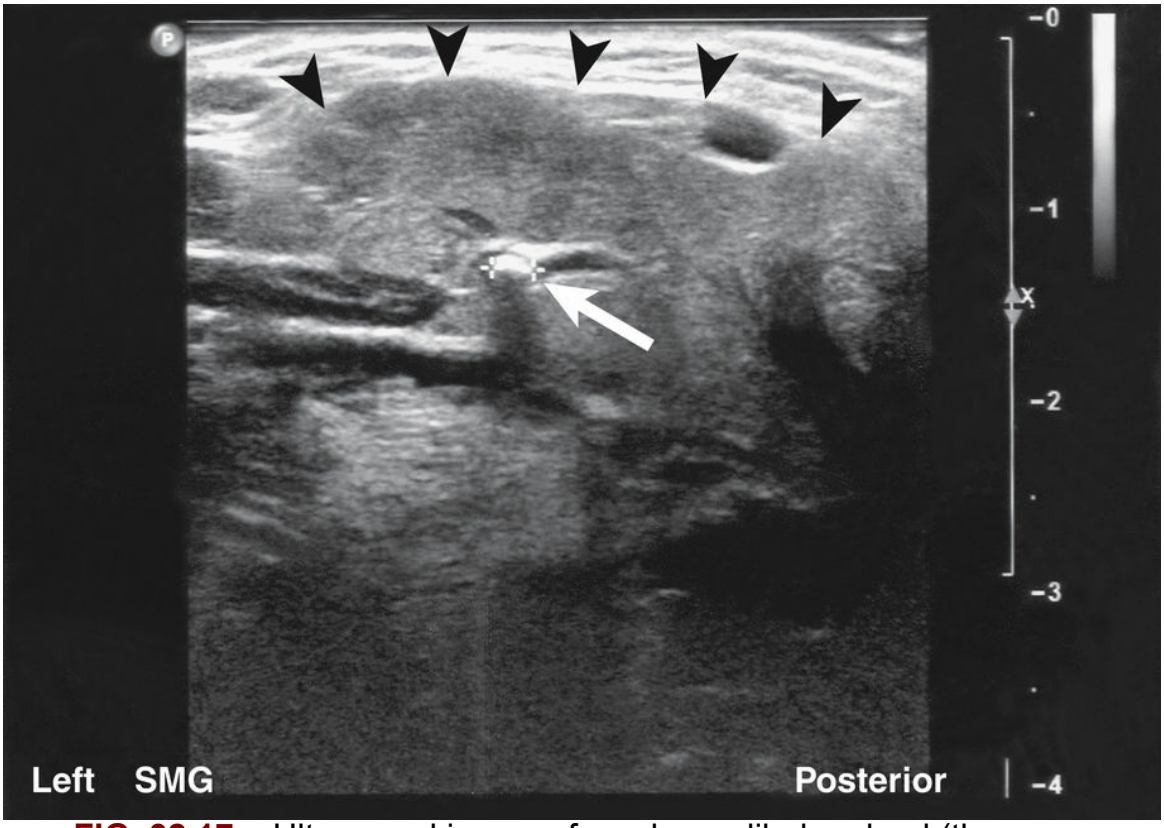


FIG. 32.17 Ultrasound image of a submandibular gland (the margin of the gland is marked by the black arrow heads) containing a small calculus (white arrow) within the hilum of the main duct. The stone measured 2.2 mm in diameter and was radiolucent on plain radiography. The dilated duct to the right of the stone is also evident.

Courtesy of Mrs J.E. Brown.

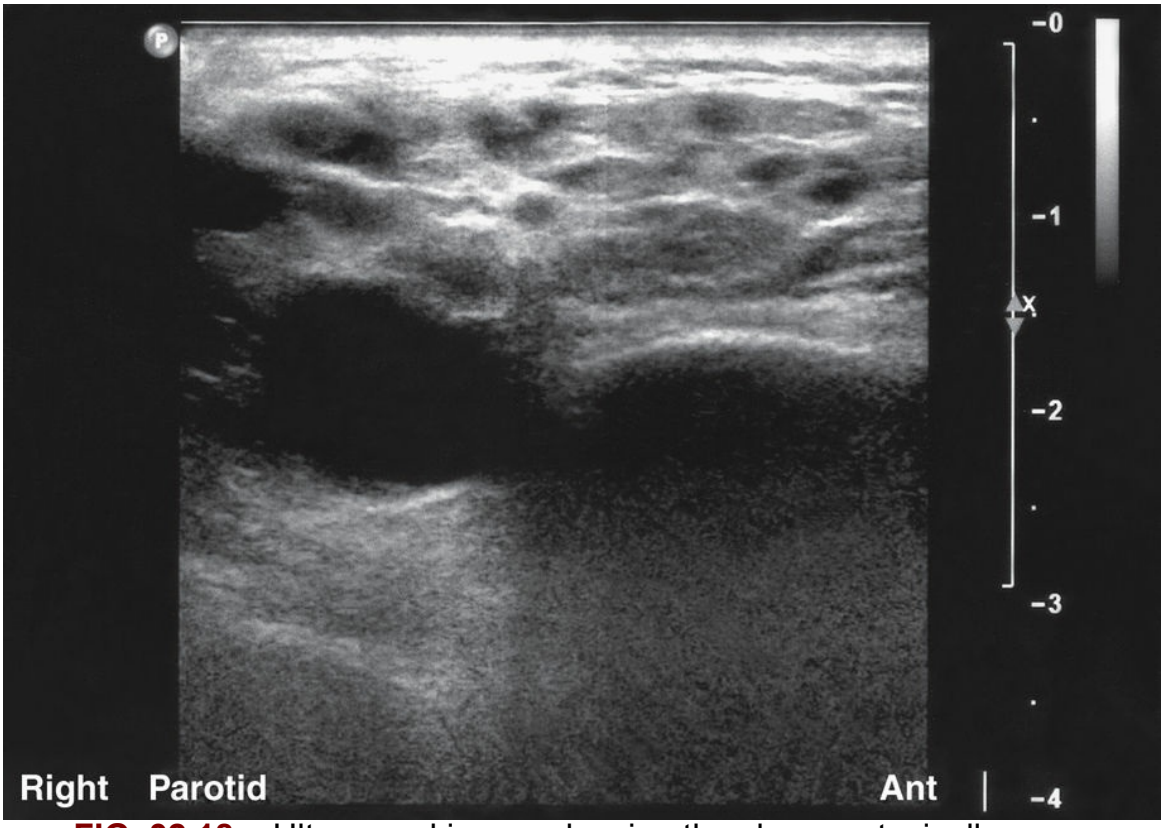


FIG. 32.18 Ultrasound image showing the changes typically seen within the parotid gland in Sjögren's syndrome. The multiple small hypoechoic (dark) areas represent lymphoepithelial infiltration of the gland parenchyma.
Courtesy of of Mrs J.E. Brown.

Magnetic Resonance Imaging (MRI)

Indications

- Discrete swelling or lump both intrinsic and extrinsic to the salivary glands
- Generalized swelling, e.g. Sjögren's syndrome.

Advantages

- Ionizing radiation is not used
- Provides excellent soft tissue detail, readily enables

differentiation between normal and abnormal

- Provides accurate localization of masses (see Fig. 32.19) and may be able to distinguish benign from malignant tumours
- The facial nerve may be identifiable
- Images in all planes are available
- *Co-registration* possible with positron emission tomography (PET) scans
- Magnetic resonance (MR) sialography may be performed (see Fig. 32.20) together with MR spectroscopy
- Water in the ducts and glands can be visualized to create MR sialographs without the use of contrast agents (see Fig. 32.20)
- MR spectroscopy can be performed to differentiate different tissues by their chemical constituents.

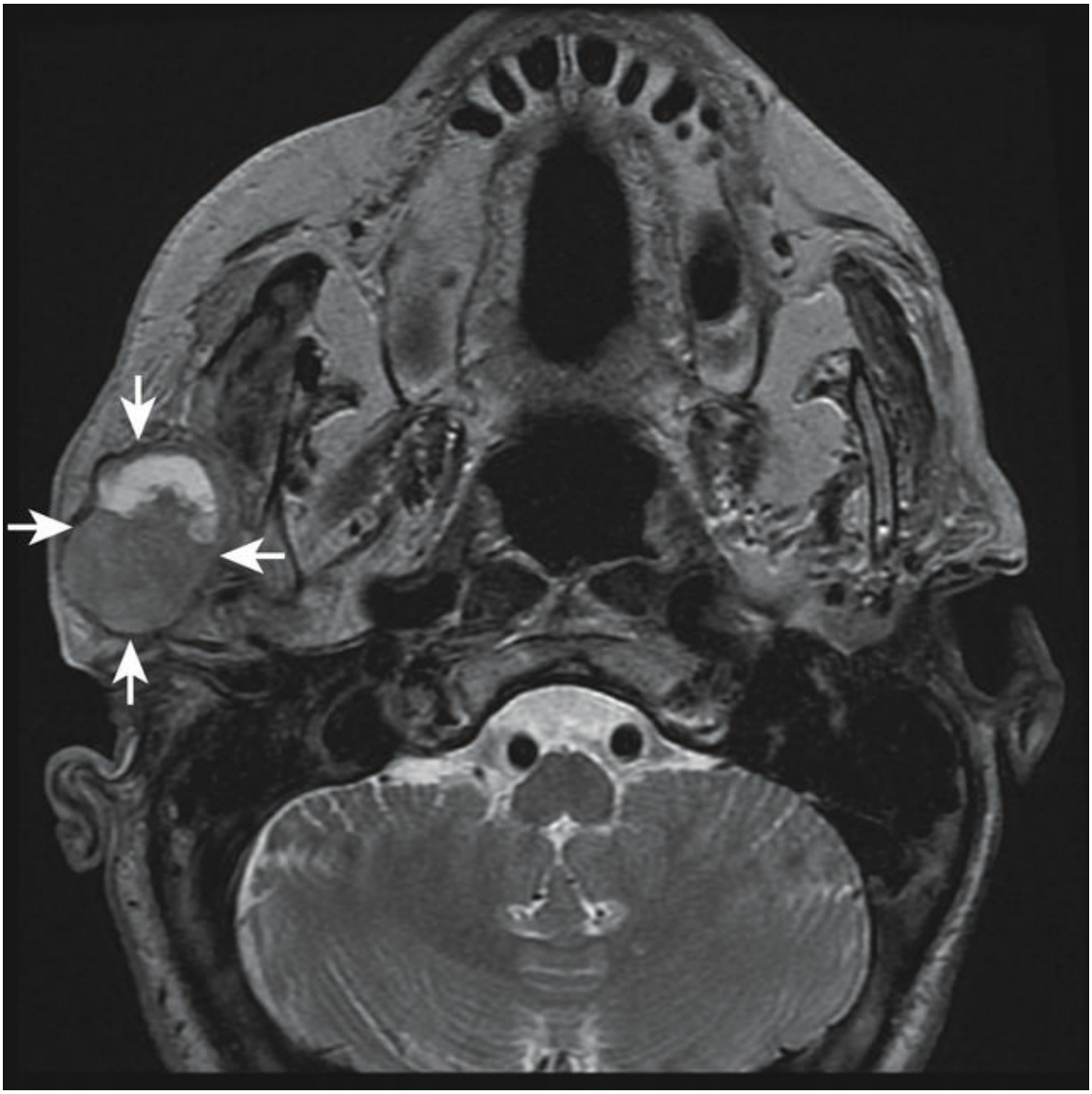


FIG. 32.19 Axial MRI scan, showing a well-circumscribed mass in the right parotid gland (arrowed).
Courtesy of Dr M. Hourihan.

Disadvantages

- Provides no information on salivary gland function
- Limited information on surrounding hard tissues
- May not distinguish benign lesions with high water content from cysts.

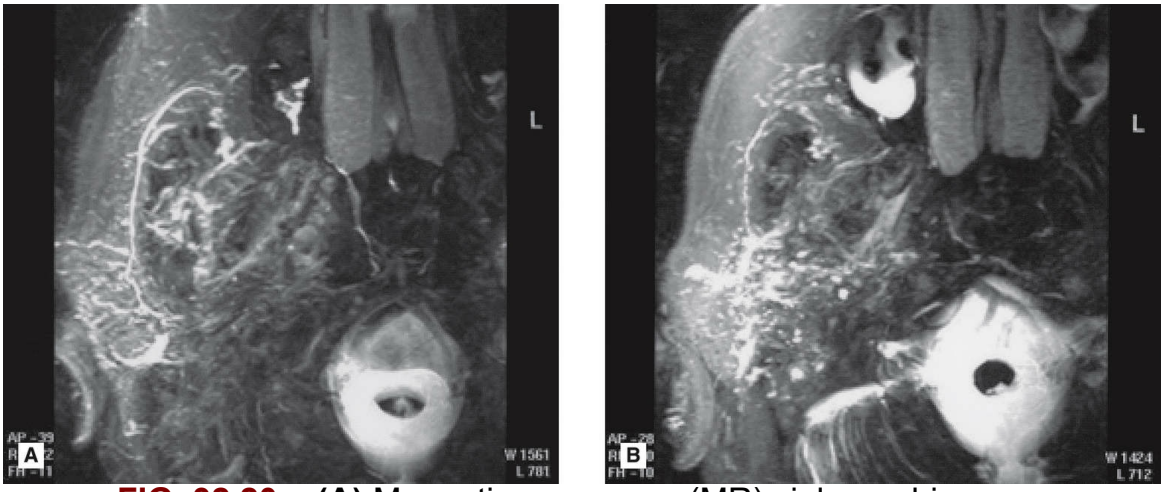


FIG. 32.20 **(A)** Magnetic resonance (MR) sialographic image showing a normal parotid gland and **(B)** MR sialographic image of a patient with Sjögren's syndrome.
Courtesy of Dr V. Rushton.

Radioisotope Imaging

Indications

- Dry mouth as a result of salivary gland diseases such as Sjögren's syndrome
- To assess salivary gland function
- Positron emission tomography (PET) for salivary gland tumours.

Advantages

- Provides an indication of salivary gland function (see Fig. 32.21)
- Allows bilateral comparison and images all four major salivary glands at the same time
- Computer analysis of results is possible
- Can be performed in cases of acute infection
- *Co-registration* of PET scans with CT scans or MRI scans (see Chapter 18).

Disadvantages

- Provides no indication of salivary gland anatomy or ductal architecture
- Relatively high radiation dose to the whole body
- The final images are not disease specific.

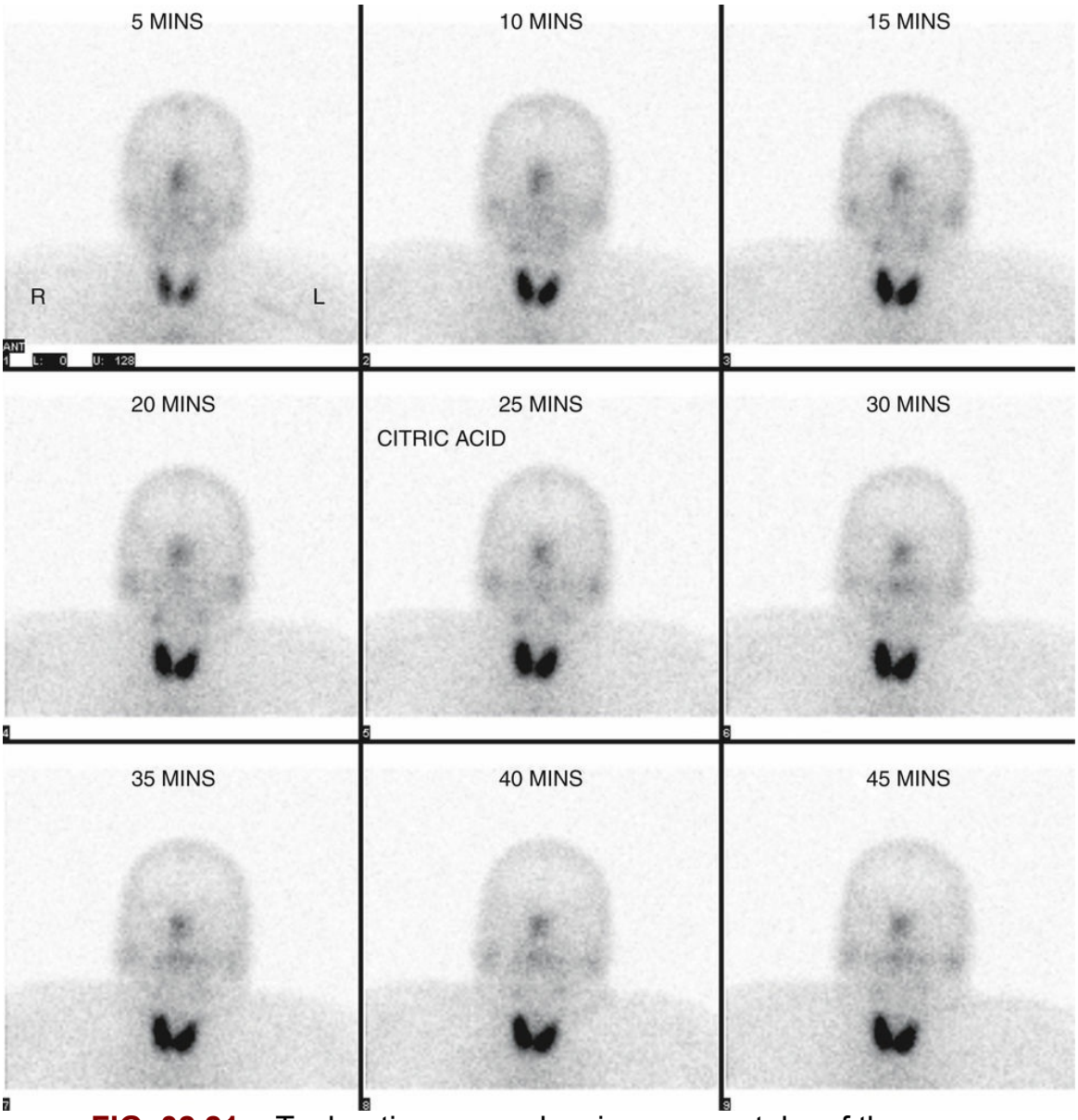


FIG. 32.21 Technetium scan showing poor uptake of the technetium in all the salivary glands in comparison to the thyroid gland in keeping with Sjögren's syndrome.
Courtesy of Dr J. Rees.

Computed Tomography (CT)

Indication

- Discrete swellings both intrinsic and extrinsic to the salivary

glands.

Advantages

- Provides accurate localization of masses, especially in the deep lobe of the parotid (see Fig. 32.22)
- The nature of the lesion can often be determined
- Images can be enhanced by using contrast media, either in the ductal system (CT sialography) or more commonly intravenously
- *Co-registration* possible with PET scans.

Disadvantages

- Provides no indication of salivary gland function
- Risks associated with intravenous contrast media if used (see Chapter 18)
- Fine duct detail is not well-imaged
- High radiation dose
- May be difficult to distinguish tumours in the submandibular gland from normal gland tissue (owing to similar density).

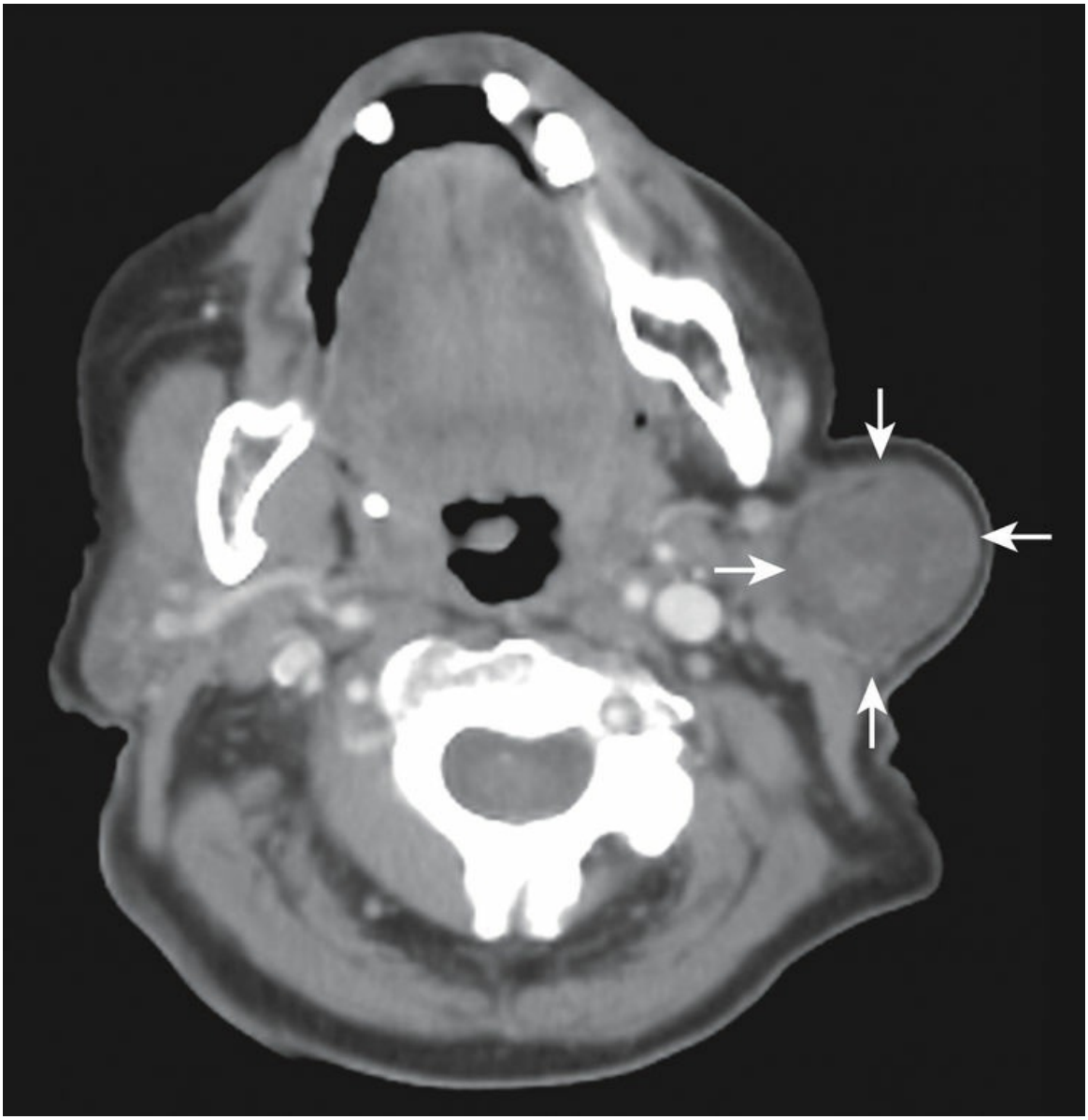


FIG. 32.22 Axial CT scan showing a clearly identifiable benign parotid tumour (arrowed).
Courtesy of Dr M. Hourihan.

To access the self assessment questions for this chapter please go to http://evolve.elsevier.com/Whaites/essentials/

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