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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First edition 1992
Second edition 1996
Third edition 2002
Fourth edition 2007
Fifth edition 2013
Sixth edition 2021

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ISBN: 978-0-7020-7688-6

Content Strategists: Alison Taylor/Alexandra Mortimer
Content Development Specialist: Fiona Conn
Senior Project Manager: Karthikeyan Murthy
Design: Renee Duenow
Art Buyer: Muthukumaran Thangaraj
Marketing Manager: Deborah Watkins

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

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.

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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.

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PART I
Introduction

OUTLINE

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).

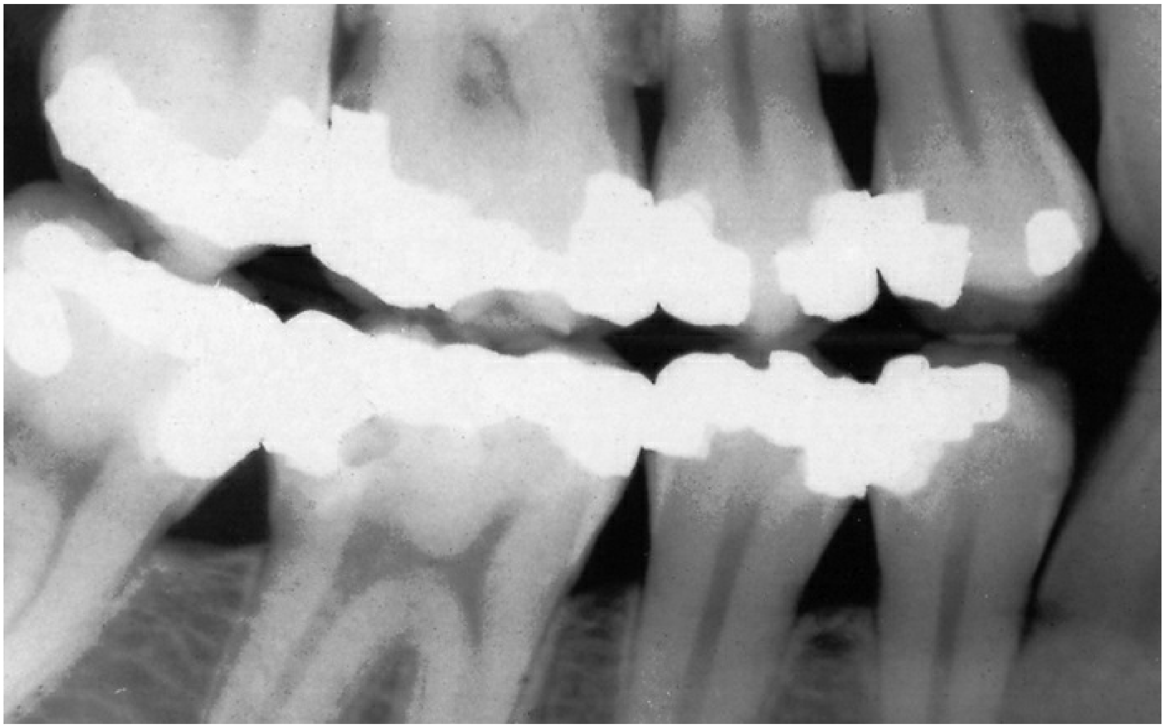

FIG. 1.1 A traditional two-dimensional dental radiograph showing the hard tissues of the teeth, containing metallic amalgam restorations, and the supporting alveolar bone.

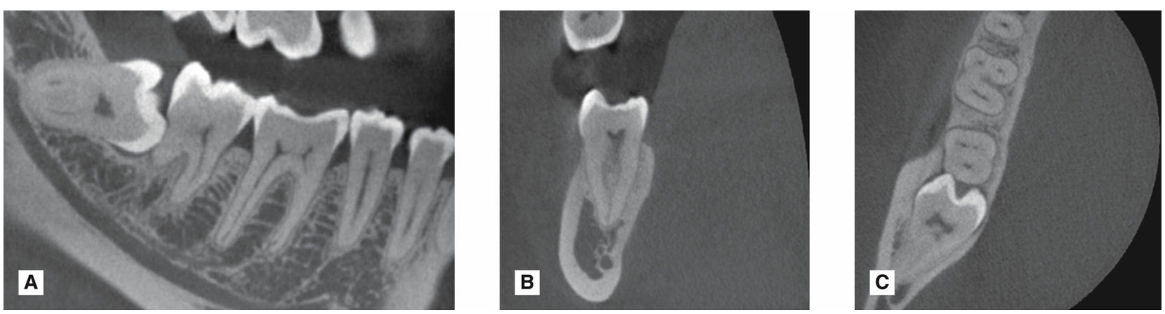

FIG. 1.2 Modern cone beam computed tomography (CBCT) radiographic images in three dimensions of the lower right molar teeth in the **(A)** sagittal, **(B)** coronal and **(C)** axial planes.

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* .

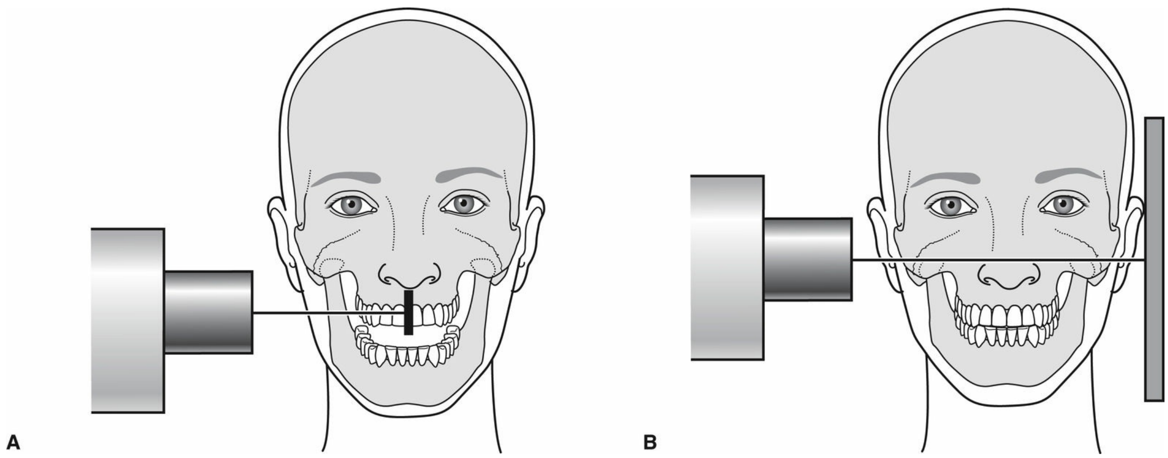

FIG. 1.3 Diagrams showing the basic requirements for two-dimensional radiography – an X-ray generating machine, a patient and an image receptor for **(A)** intraoral imaging and **(B)** extraoral imaging.

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.

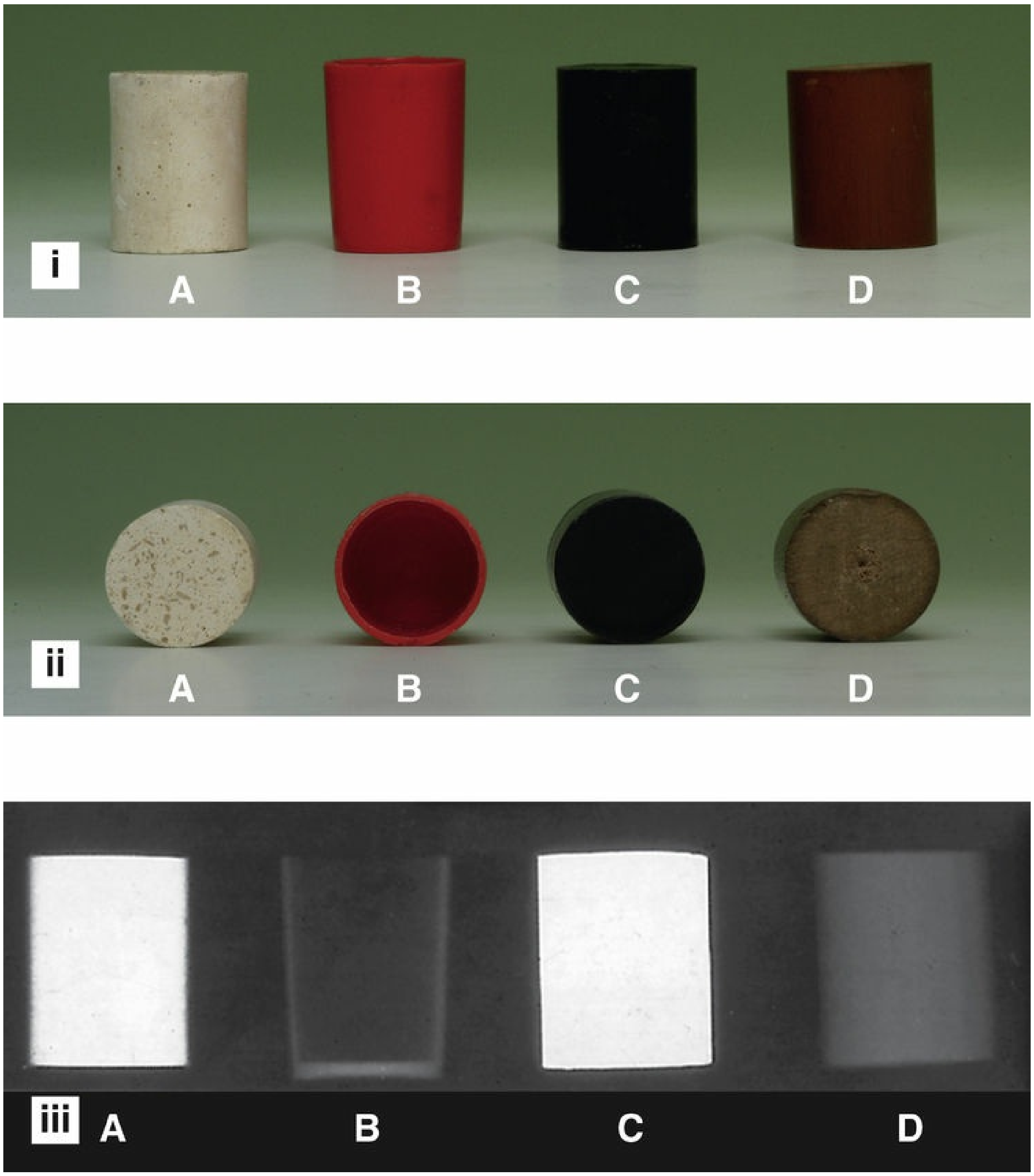

FIG. 1.4 **(i)** Front view and **(ii)** plan view of various cylinders of similar shape but made of different materials: **(A)** plaster of Paris, **(B)** hollow plastic, **(C)** metal, and **(D)** wood. **(iii)** Radiographs of the cylinders show how objects of the same shape, but of different materials,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

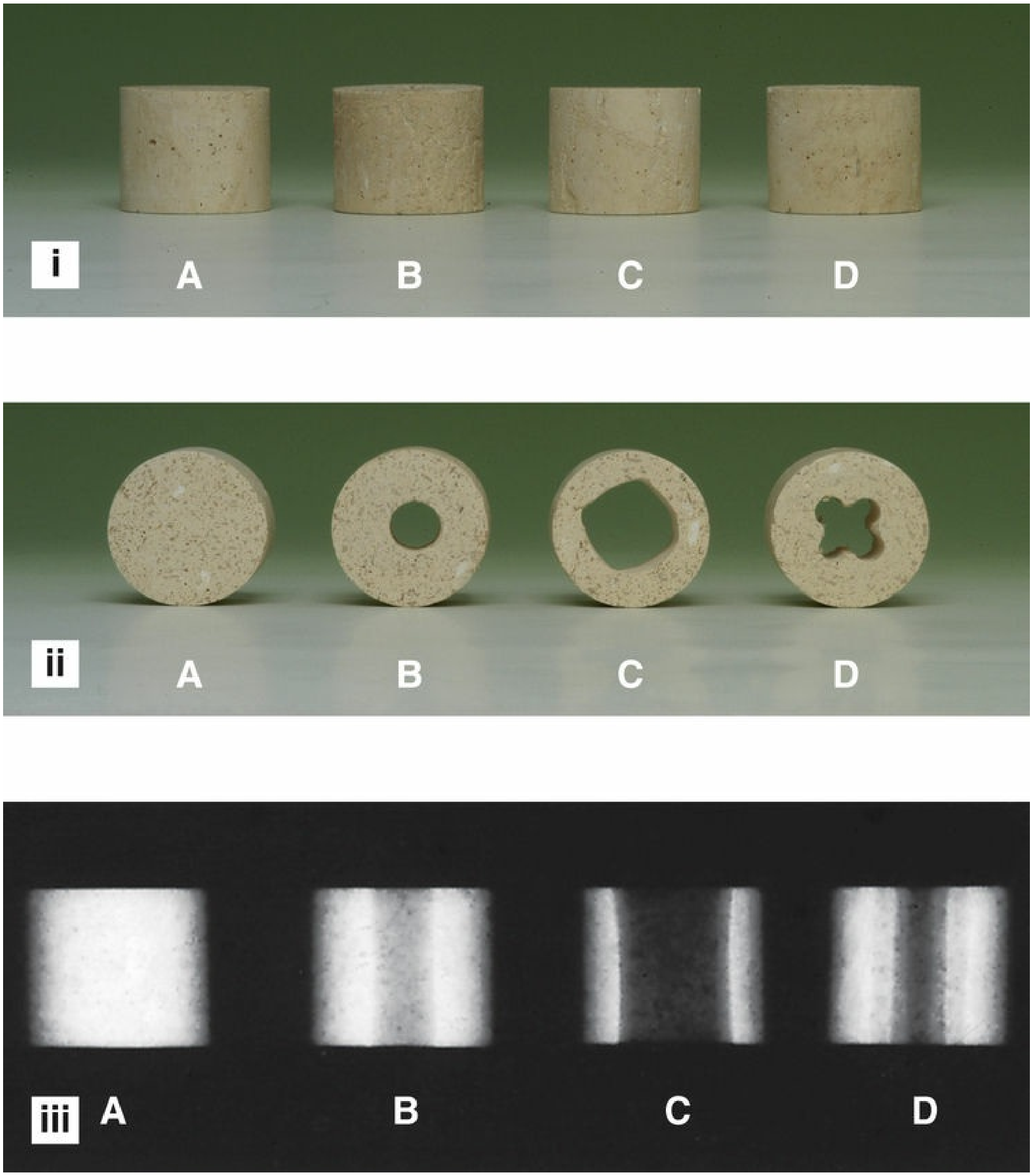

FIG. 1.5 **(i)** Front view of four apparently similar cylinders made from plaster of Paris. **(ii)** The plan view shows the cylinders have varying internal designs and thicknesses. **(iii)** Radiographs of the apparently similar cylinders show how objects of similar shape and material, but of different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

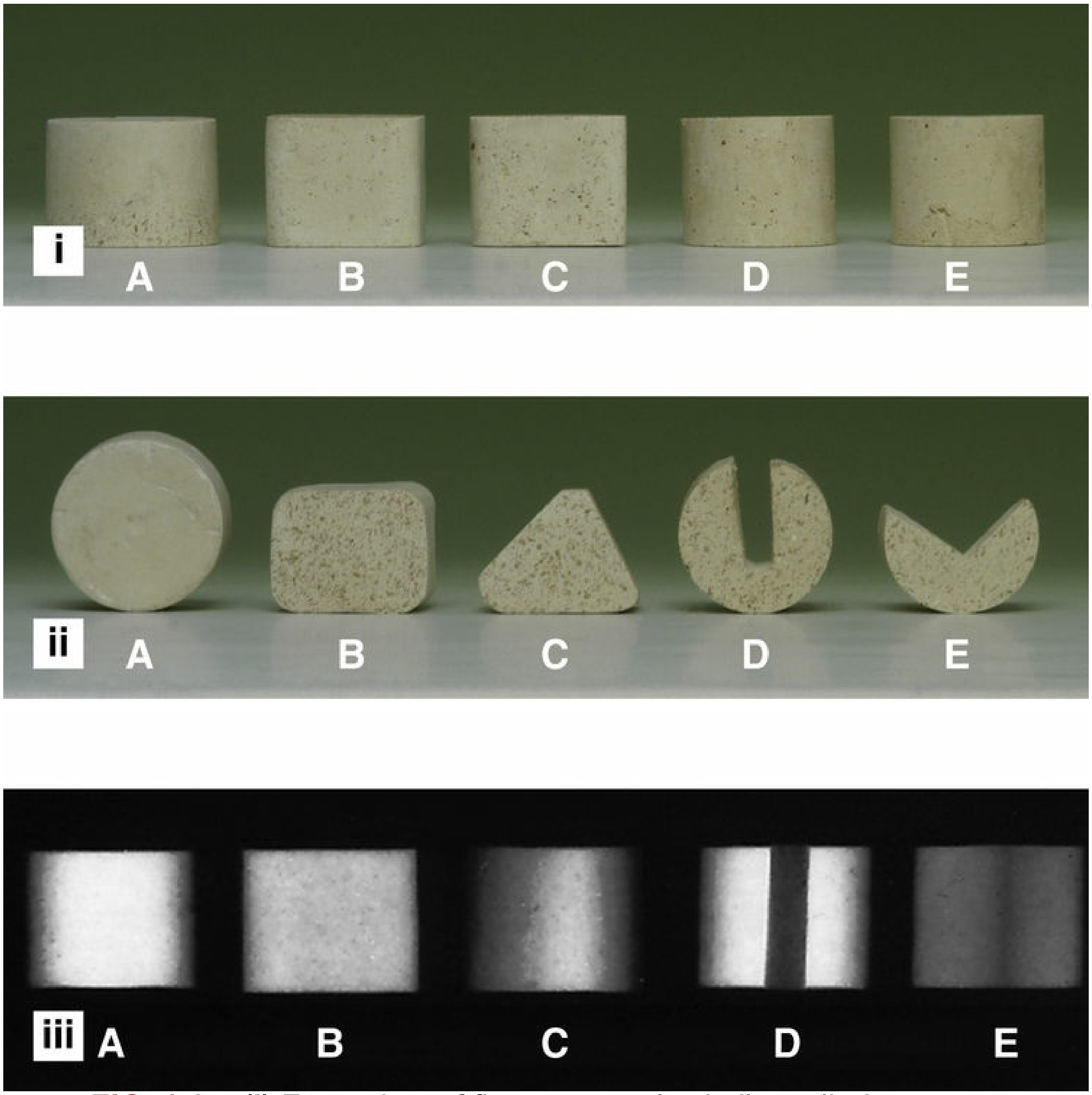

FIG. 1.6 **(i)** Front view of five apparently similar cylinders made from plaster of Paris. **(ii)** A plan view shows the objects are in fact different shapes. **(iii)** Radiographs show how objects of different shape, but made of the same material, produce different radiographic images.

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.

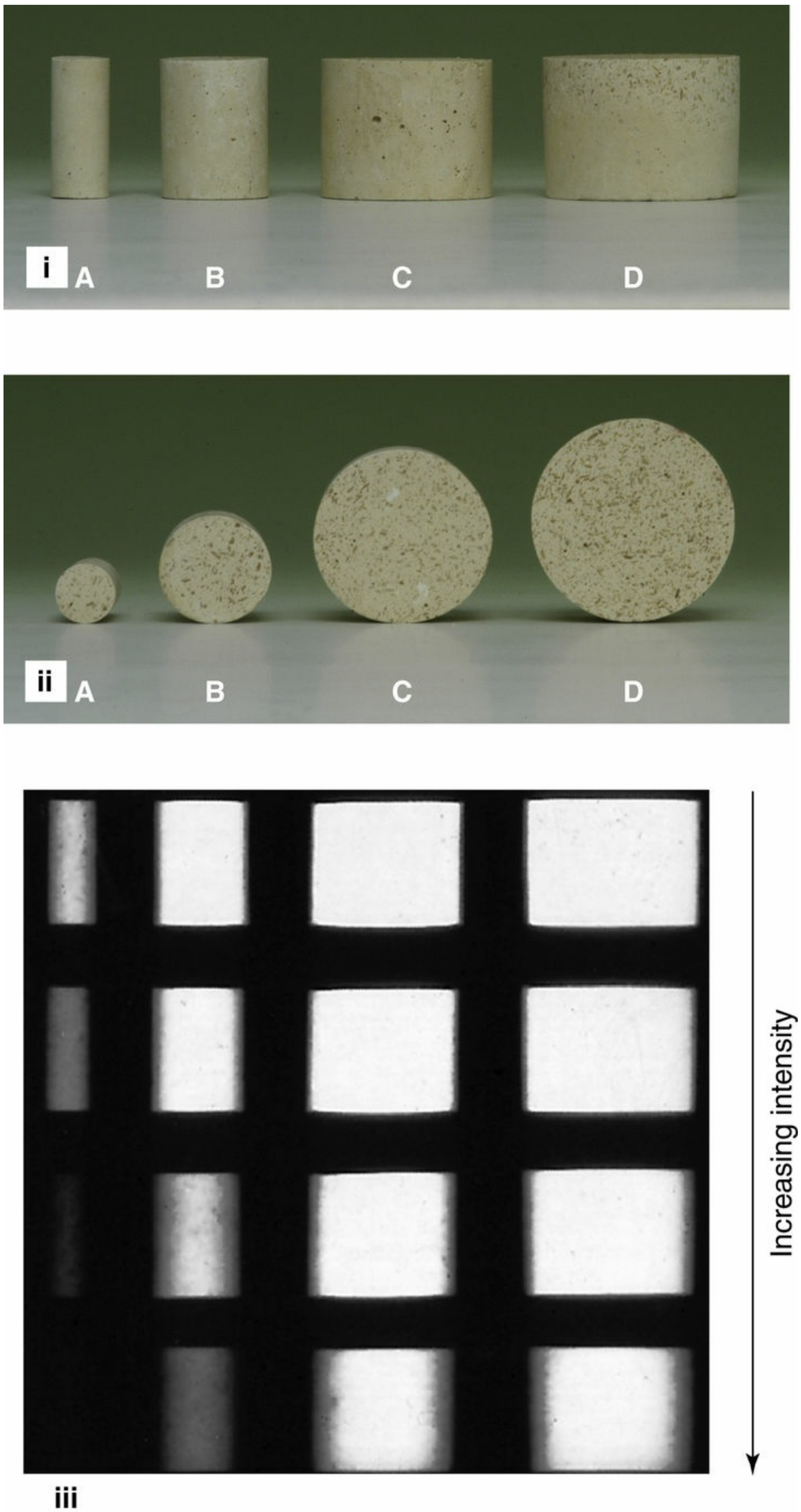
i
A
B
C
D
ii
A
B
C
D
Increasing intensity
iii

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.

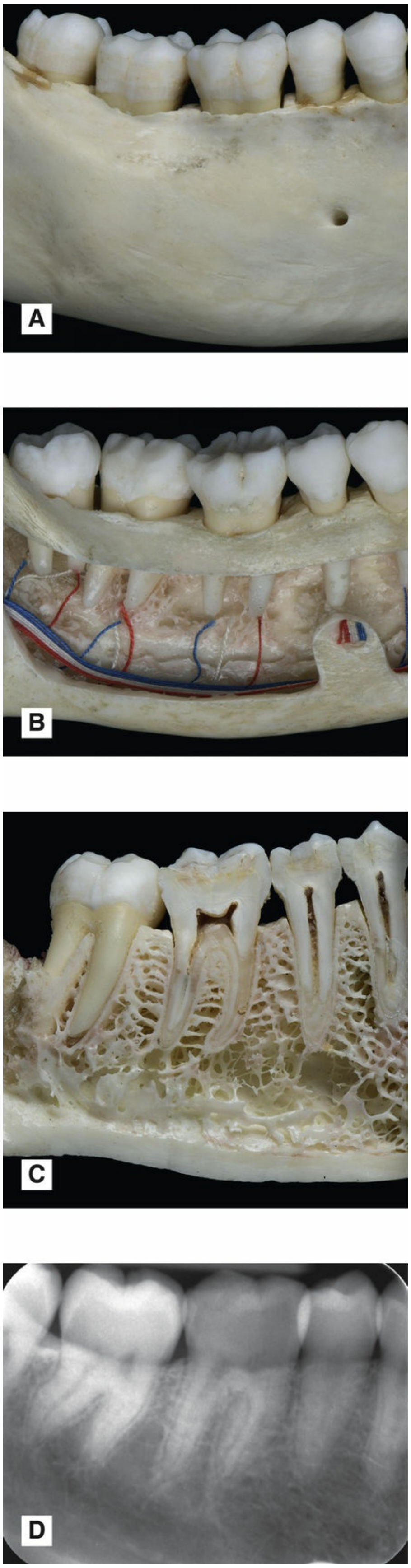
A
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FIG. 1.8 Photographs showing the three-dimensional anatomy of the premolar/molar region of a dried mandible. **(A)** The external bone, **(B)** the teeth embedded in the bone and **(C)** a sagittal section showing the various internal bone structures.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

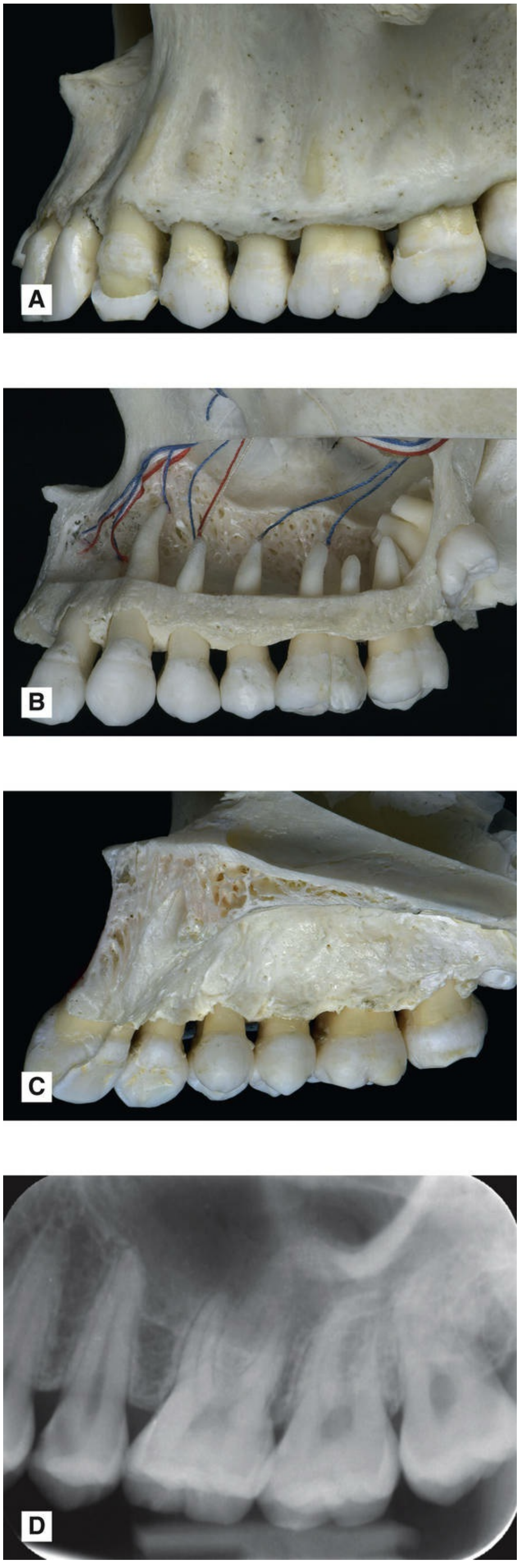
A
B
C
D

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.

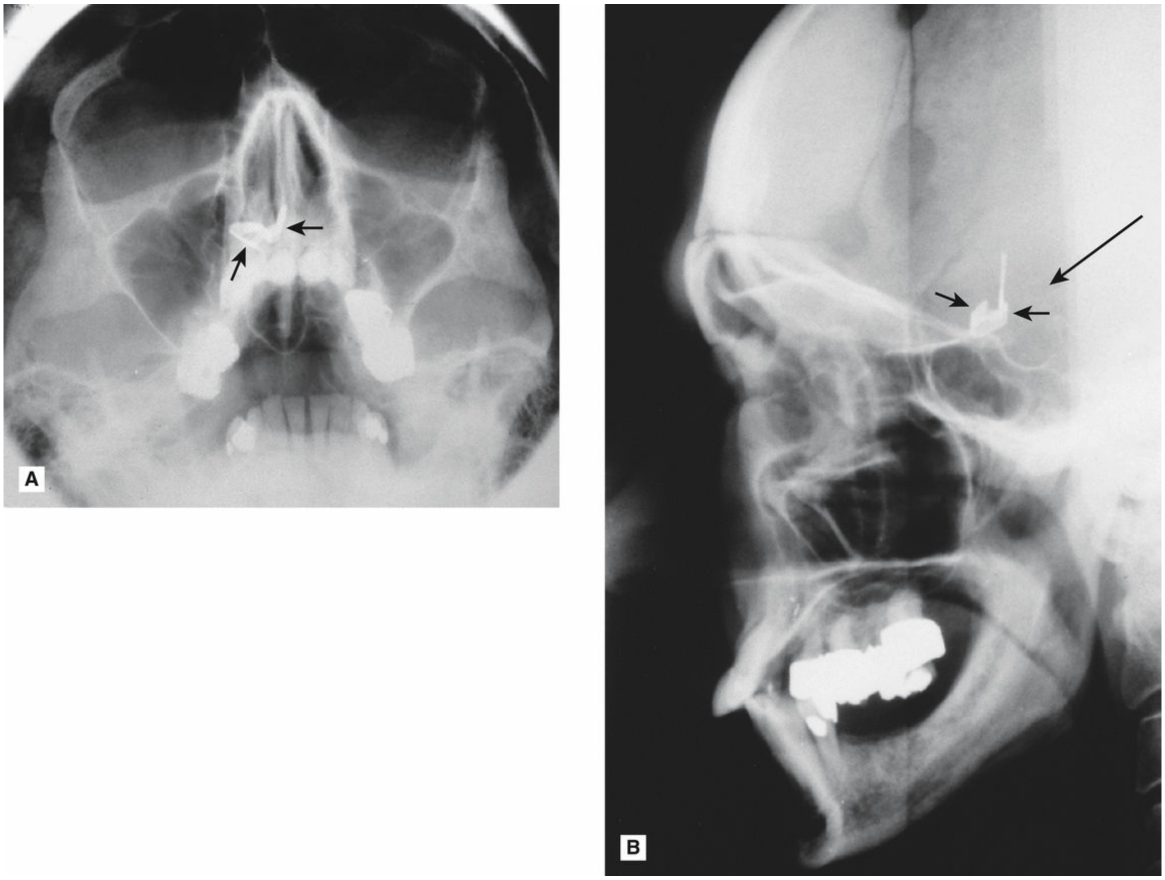

FIG. 1.12 The limitations of traditional two-dimensional skull radiographs illustrated using **(A)** An *occipitomental* (from the front) and **(B)** a *lateral skull* (from the side). A radiopaque (white) object (arrowed) is evident on both images. On the occipitomental view, it can be seen apparently 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).

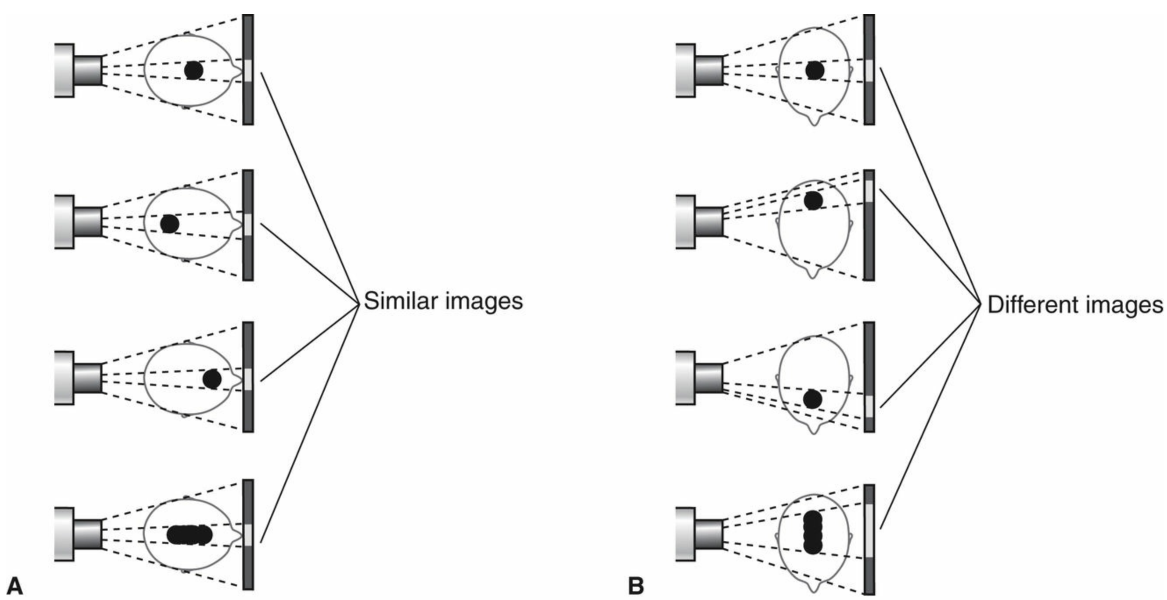

FIG. 1.13 Diagrams illustrating the limitations of a two-dimensional image. **(A)** Posteroanterior views of a head containing a variable mass. The mass appears as a similar-sized opaque image on the radiograph, providing no differentiating information on its position or shape. **(B)** The side view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

illustrated in **(A)** .

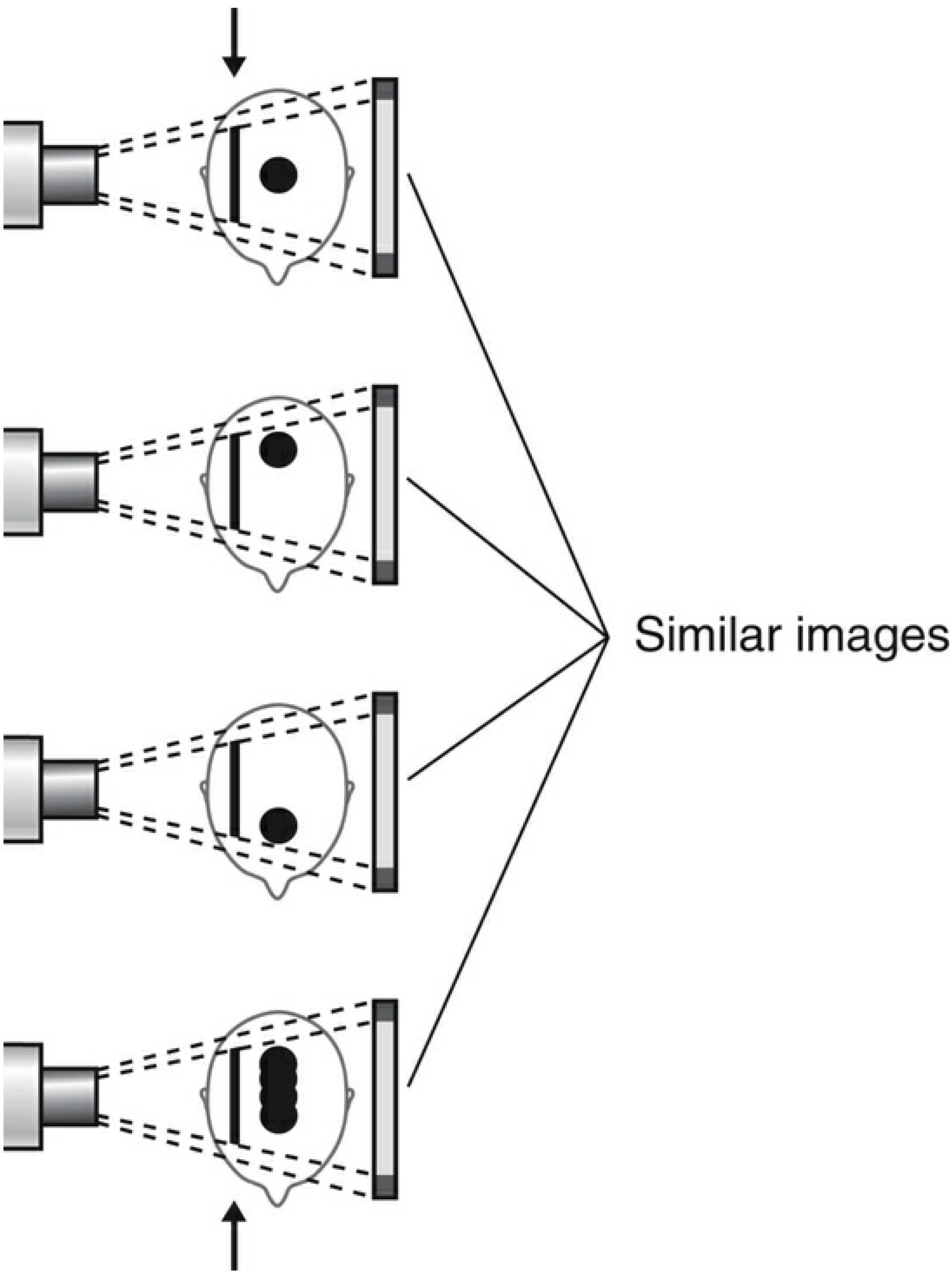

FIG. 1.14 Diagram illustrating the problems of

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 .

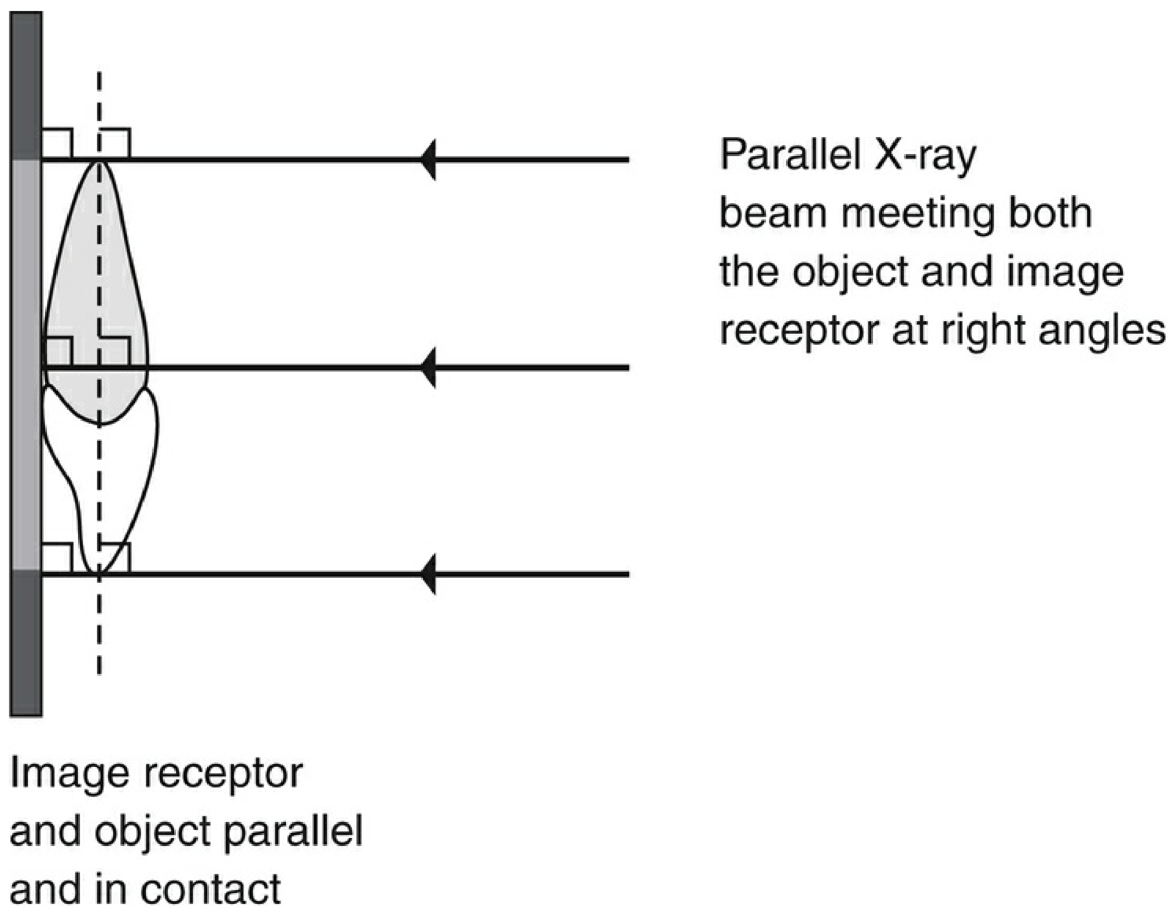

FIG. 1.15 Diagram illustrating the ideal geometrical relationship between the object, image receptor and X-ray beam.

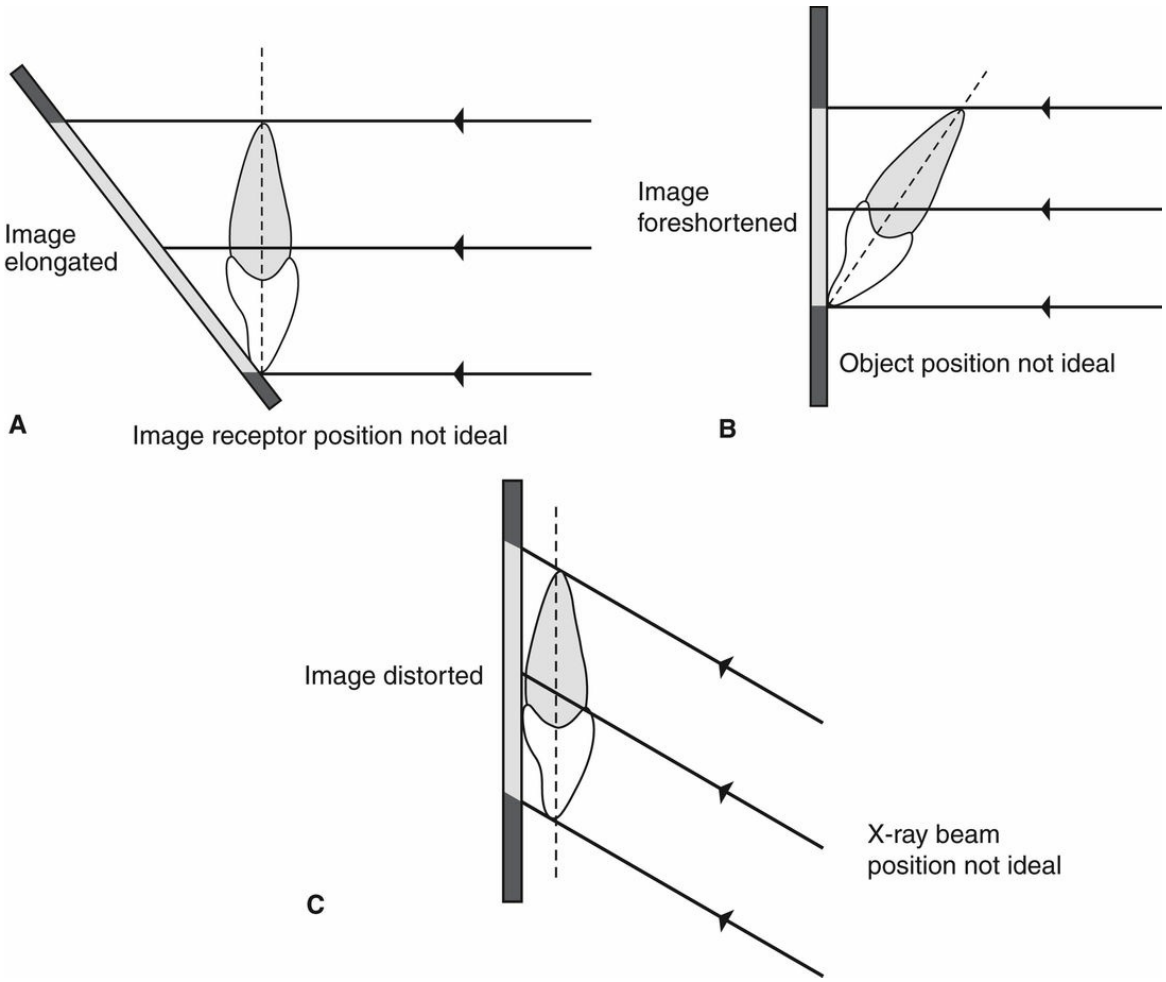

FIG. 1.16 Diagrams showing the effect on the final image of varying the position of **(A)** the image receptor, **(B)** the object and **(C)** the X-ray beam.

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 .

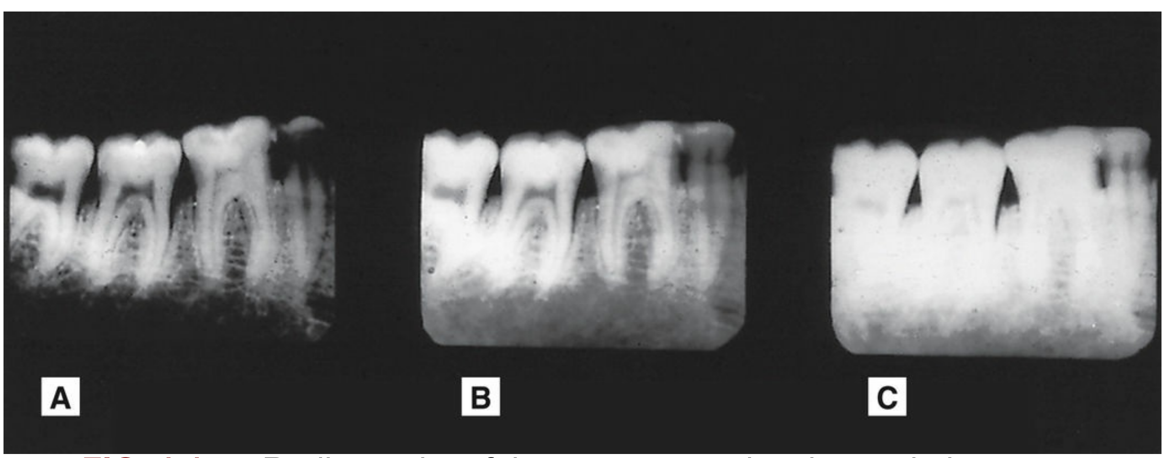

FIG. 1.17 Radiographs of the same area showing variation in contrast – the visual difference in the black, white and grey shadows owing to the penetration of the X-ray beam. **(A)**

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

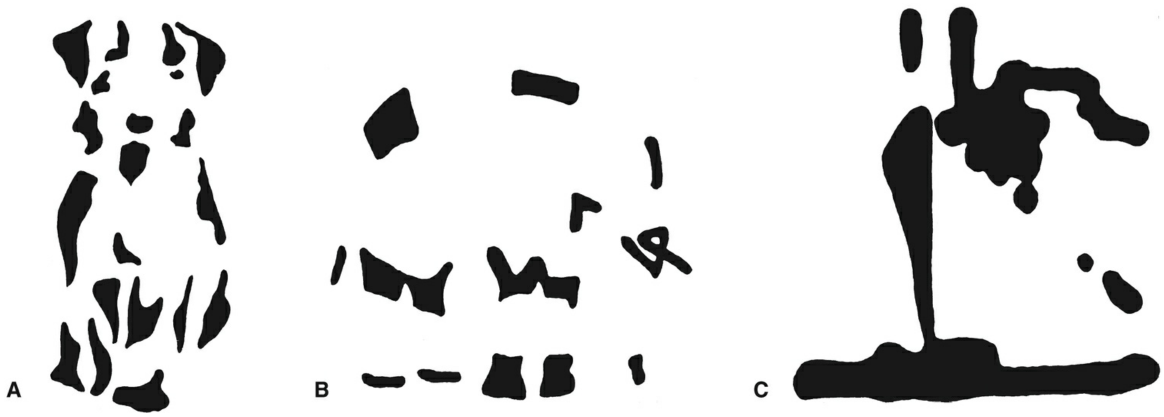

FIG. 1.18 The problem of partial images requiring the observer to fill in the missing gaps. Look at the three non-clinical pictures and what do you perceive? The objects shown are **(A)** a dog, **(B)** an elephant and **(C)** a steam ship. We all see the same partial images, but we do not necessarily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

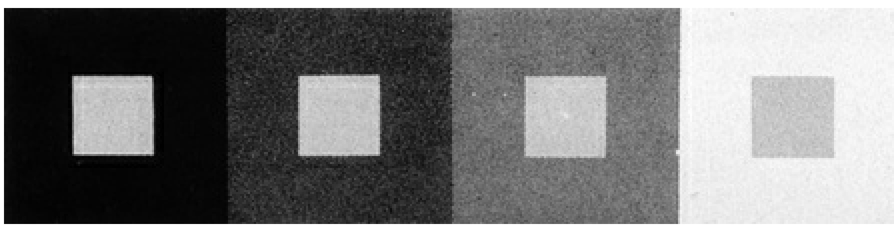

FIG. 1.19 The effect of contrast. The four small inner squares are in reality all the same grey colour, but they appear to be different because of the effect of contrast. *Figure from: Cornsweet TN 1970 Visual Perception. Harcourt Brace and Company, with permission .*

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.

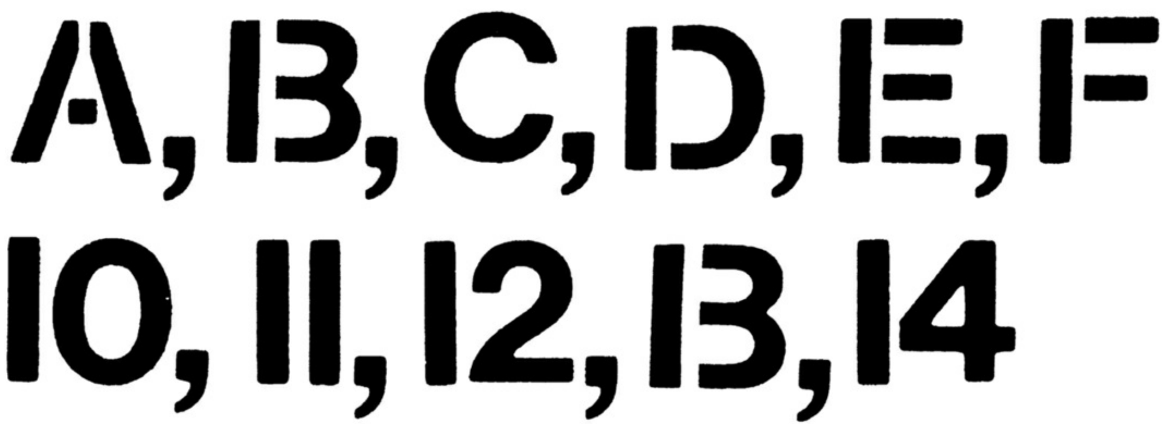

FIG. 1.20 The effect of context. If asked to read the two lines shown here most, if not all, observers would read the letters A, B, C, D, E, F and then the numbers 10, 11, 12, 13, 14. Closer examination shows the letter B and the number 13 to be identical. They are perceived as B and 13 because of the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

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

PART II
Radiation Physics, Equipment and Radiation Protection

OUTLINE