BDJ Clinician's Guides

This series enables clinicians at all stages of their careers to remain well informed and up to date on key topics across all fields of clinical dentistry. Each volume is superbly illustrated and provides concise, highly practical guidance and solutions. The authors are recognised experts in the subjects that they address. The *BDJ Clinician's Guides* are trusted companions, designed to meet the needs of a wide readership. Like the *British Dental Journal* itself, they offer support for undergraduates and newly qualified, while serving as refreshers for more experienced clinicians. In addition they are valued as excellent learning aids for postgraduate students.

The BDJ Clinician's Guides are produced in collaboration with the British Dental Association, the UK's trade union and professional association for dentists.

Suk Y. Ng

Cone Beam CT in Dentistry

An Atlas for Dentists and Medical Radiologists

Springer

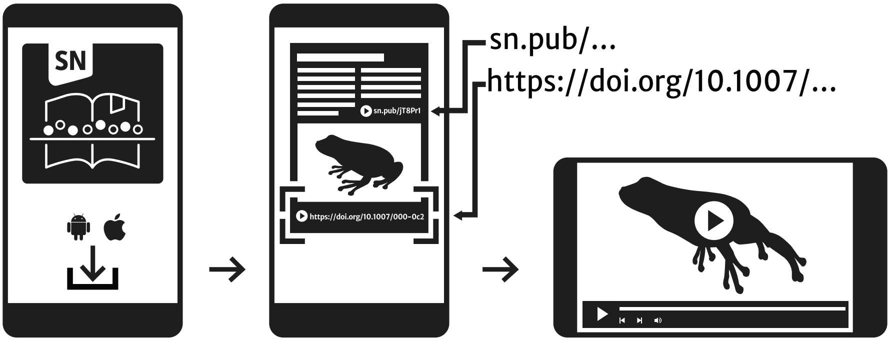
Suk Y. Ng
Dental Radiology
Guy's Hospital and King's College London
London, UK

This work contains media enhancements, which are displayed with a "play" icon. Material in the print book can be viewed on a mobile device by downloading the Springer Nature "More Media" app available in the major app stores. The media enhancements in the online version of the work can be accessed directly by authorized users.

ISSN 2523-3327 ISSN 2523-3335 (electronic)
BDJ Clinician's Guides
ISBN 978-3-031-25479-6 ISBN 978-3-031-25480-2 (eBook)
https://doi.org/10.1007/978-3-031-25480-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Springer Nature More Media App



1. Download

2. Scan Link

3. Enjoy Video

Support: customerservice@springernature.com

Contents

The Three-Dimensional Nature of a Dental CBCT Scan

1

1.1 Introduction

A cone beam computed tomography (CBCT) scan demonstrates anatomical structures within a cylindrical volume. A volume is a three-dimensional entity, but because the images are viewed on a computer screen, the information is seen only in two-dimensional planes. Viewing anatomical structures in two dimensions is common practice and is fundamental to all cross-sectional imaging. Conventionally, there are three anatomical planes: axial, coronal, and sagittal. They are mutually perpendicular to each other (=orthogonal). By viewing a structure in two or all three anatomical planes, the clinician then forms a three-dimensional picture in their mind of the three-dimensional morphology of that structure. Various CBCT software also allow reconstruction of the data volume in other planes, for example, a curved "panoramic" plane. Thus, the viewing and interpretation of CBCT scans requires a deep knowledge of normal anatomy, an understanding of the variable biological effects caused by different types of disease, as well as skilful manipulation of the CBCT volume in conventional and customised viewing planes.

1.2 Viewing Dental X-Ray and CBCT Images

When viewing X-ray images, it is important to have precise ways of describing the location and orientation of anatomical structures. It is equally important to describe the angle from which the structure is viewed. In traditional dental X-ray plain imaging, the radiographs are viewed as if the clinician is standing at the X-ray machine or at the film/receptor position. In cross-sectional imaging, the view is described by naming the plane of the image.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/978-3-031-25480-2_1. The videos can be accessed individually by clicking the DOI link in the accompanying figure caption or by scanning this link with the SN More Media App.

S. Y. Ng, *Cone Beam CT in Dentistry*, BDJ Clinician's Guides,
https://doi.org/10.1007/978-3-031-25480-2_1

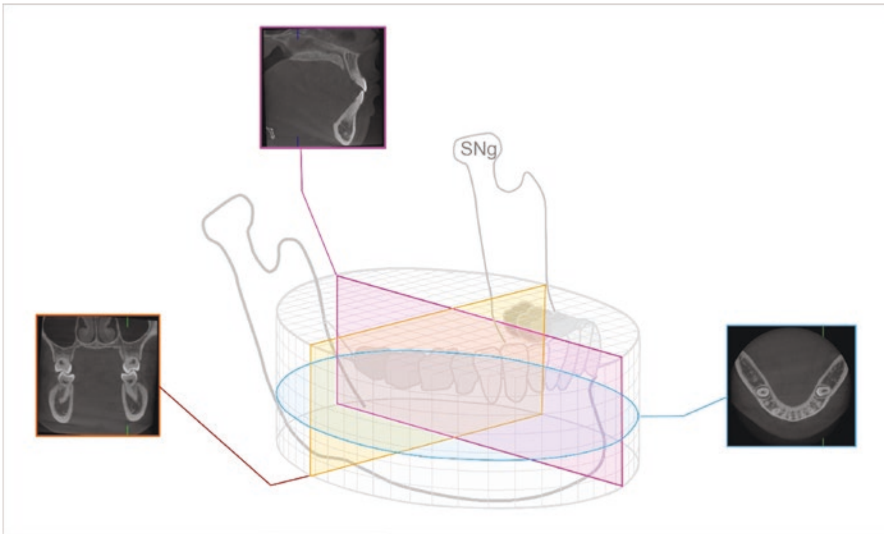


Fig. 1.1 Stylised drawing of a mandible, with CBCT volume superimposed. The three conventional anatomical planes are axial (blue circle), coronal (orange rectangle), and sagittal (pink rectangle)

The conventional anatomical planes of axial, coronal, and sagittal are orthogonal, i.e. at 90° to each other (Fig. 1.1). These three anatomical planes are widely used for cross-sectional imaging in the head, thorax, abdomen, and limbs. In the dento-alveolar regions, due to the curvature of the dental arches, additional planes are often needed, and can be custom-reconstructed by the user. Unsurprisingly, most dentists generally prefer to reconstruct a CBCT image to look similar to the patient's existing dental radiographs.

1.2.1 Conventional Anatomical Planes

1.2.1.1 Axial

The axial plane is a plane at 90° to the long axis of the human body. An axial plane separates the body into an upper half and a lower half. In the head, the axial plane is parallel to the Frankfort plane, and almost parallel to the occlusal plane.

1.2.1.2 Coronal

The coronal plane is named after the coronal suture in the skull and is at 90° to the axial plane. A coronal plane separates the body into front and back halves.

1.2.1.3 Sagittal

The sagittal plane is at 90° to the axial and coronal planes. It divides the body into right and left halves.

A CBCT scan is shown in Fig. 1.2, in which one slice from each of the three anatomical planes is shown, together with a volume-rendered image in colour (also

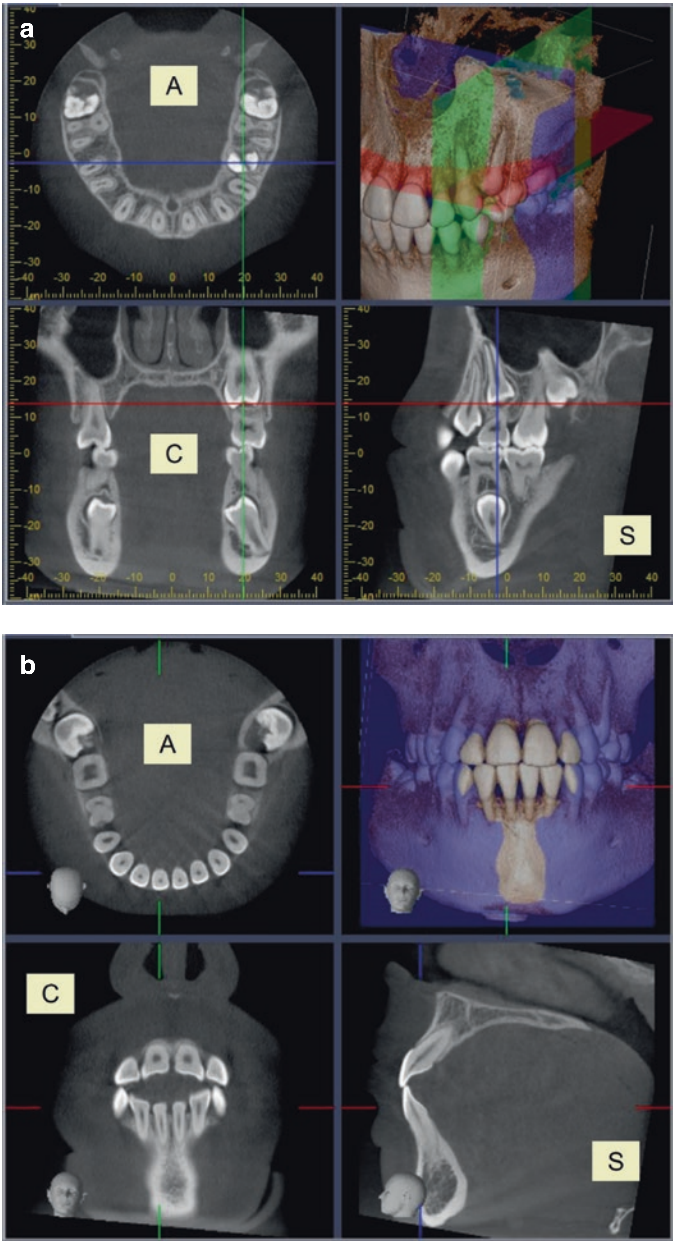


Fig. 1.2 (**a, b**) The dento-alveolar region shown in axial (A), coronal (C), and sagittal (S) planes. The red orientation line shows the location of this particular axial slice in the other two planes. The blue line shows the location of the coronal slice, and the green line shows the location of the sagittal slice. In (**a**), the ruler is displayed on the left and bottom of each image window. In (**b**), the head orientation icon is shown in the bottom left corner of each image window. The volume-rendered image can be either coupled (**b**) or uncoupled (**a**) from the orthogonal slices. The orientation lines can be long (**a**) or short (**b**) in this particular viewing software

known as colour-rendered). This combination is a very common way of viewing CBCT scans. Within the viewing software, an observer is meant to use a computer mouse to manipulate the orientation lines in order to scroll through all the image slices in all three planes. The orientation lines are essential to show the exact location of a particular slice with reference to the other two planes.

1.2.2 Conventional Dental Radiographs

Intraoral radiographs of individual teeth are taken with the X-ray film, or digital receptor plate, inside the patient's mouth. The radiographic image is an instantaneous, single-shot, permanent, record of the shadows cast by all the objects or anatomical structures in the path of the X-ray beam. Objects in a straight line have their shadows all superimposed on each other. The clinical purpose of a **periapical radiograph** is to show the whole crown and root of one tooth and the immediately adjacent teeth, as well as 3 mm or more of bone beyond the apex of the root.

The purpose of a **bitewing radiograph** is to show the crowns of upper and lower posterior teeth on one side; typically two bitewings (right and left) are taken in order to assess dental caries at the contact points of posterior teeth.

Panoramic radiograph (or dental panoramic tomogram) (sometimes called DPT, OPG, or OPT) is an extra-oral radiograph. Technically, the imaging modality is narrow beam rotational tomography. Being a tomographic technique, only a thin slice of the patient's jaws is "in focus"; and areas outside of the "focal corridor" will appear blurred. The thick tomographic slice is curved, shaped like a horse-shoe in the horizontal plane, to match the shape of the dental arches. In the vertical plane, the focal corridor is a vertical extension of the horse-shoe. The thickness of the panoramic slice is about 1 cm in the incisor region, increasing to about 3 cm in the molar region. A full panoramic radiograph shows all the patient's teeth as well as the supporting bone structures in the maxilla and mandible. Structures such as the cervical spine also appear, but they are outside of the focal corridor and thus appear as out-of-focus "ghost shadows". Most modern panoramic machines allow "field limitation" technique in order to restrict the radiation exposure to one half or even smaller section of the jaws.

In terms of viewing and orientating conventional dental radiographs, it would be easiest to start with the full panoramic tomogram (Fig. 1.3a). The upper teeth are located in the maxilla, the lower teeth are in the mandible. The patient's midline is in the middle of the radiograph. The patient's right is on the observer's left, and the patient's left is on the observer's right.

The right and left sectional panoramic radiographs (Fig. 1.3b, c) are orientated in a similar way to a full panoramic. Note that some panoramic machines have only one orientation marker "L", whilst other have two markers "R" and "L". The location of an "L" marker is always in the bottom right corner of the image. This can potentially cause confusion when it appears in a right sectional panoramic radiograph (Fig. 1.3b).

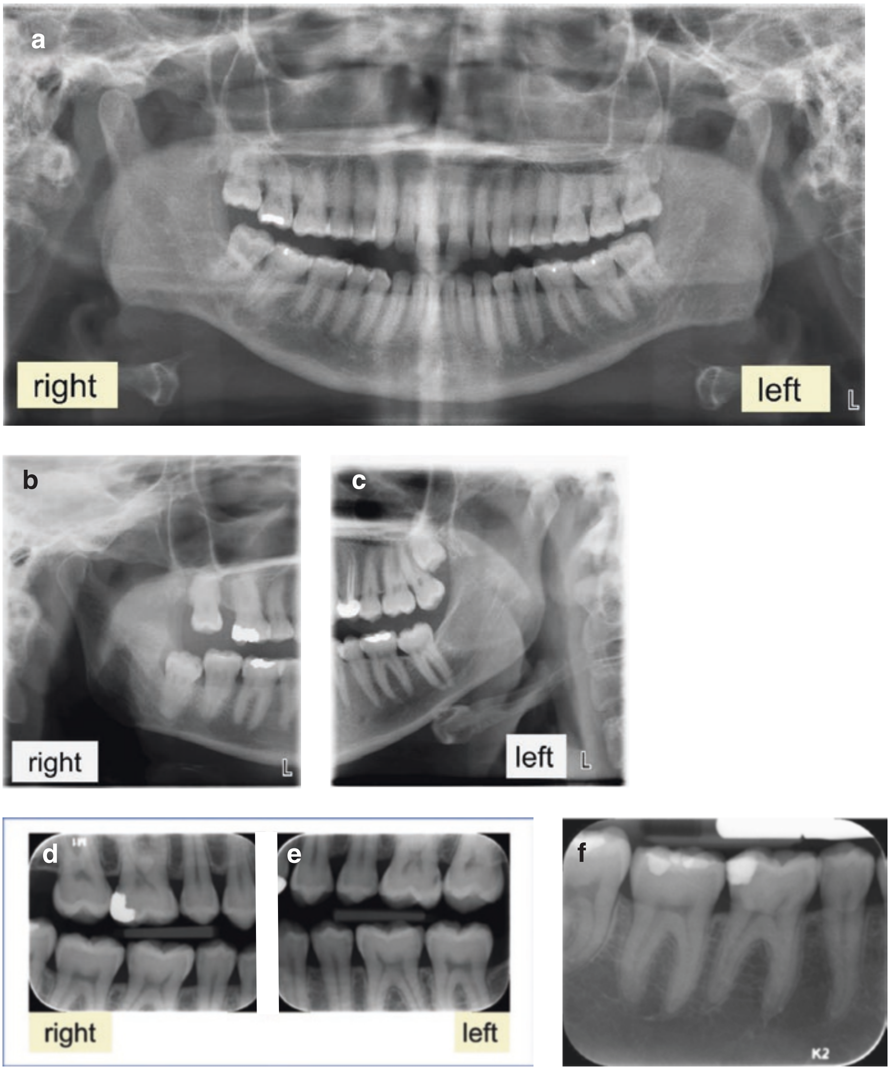


Fig. 1.3 Right and left orientation in conventional dental radiography:
(**a**) full dental panoramic tomogram, patient D807
(**b**) right sectional panoramic tomogram, patient D809
(**c**) left sectional panoramic tomogram, patient D810
(**d**) right bitewing, patient D808
(**e**) left bitewing, patient D808
(**f**) periapical radiograph of lower right molars (LR8765), patient D808

The viewing and orientation of intraoral dental radiographs requires a knowledge of dental anatomy. If X-ray film were used, then a physical raised dot in one corner of the film helps to identify which is the “front” and “back” of the film (dot should be raised facing towards the observer). If a digital image receptor were used, then an identification letter or number in one corner of the image should help with orientation (the letter or number should be the right way round, not back-to-front). For bitewings (Fig. 1.3d, e), it is useful to remember that the occlusal plane (where upper and lower teeth bite together) gently curves upwards towards the posterior (or distal) aspect, and lower molars have two roots whilst upper molars have three roots. For periapical radiographs (Fig. 1.3f), the shape of crowns, the number of roots, the adjacent structures such as antral floor or inferior dental (ID) canal will help to identify the teeth and thus the orientation of the radiographs.

1.2.3 Right and Left in Coronal Plane

When viewing coronal CBCT images, the patient’s right is on the viewer’s left, and the patient’s left is on the viewer’s right (Fig. 1.4). It is as if the viewer were looking at the patient whilst both are standing facing each other. This is fairly intuitive and is the accepted convention.

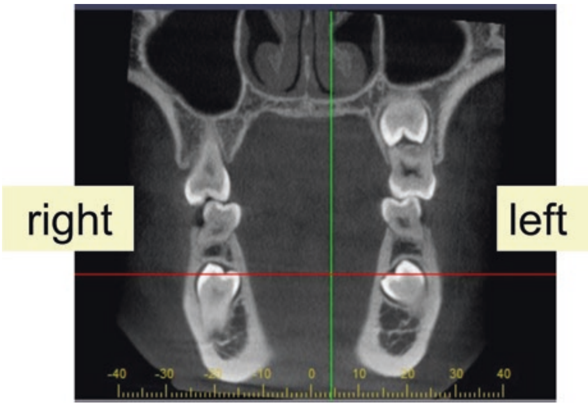


Fig. 1.4 Right and left sides of the patient when viewing in the coronal plane

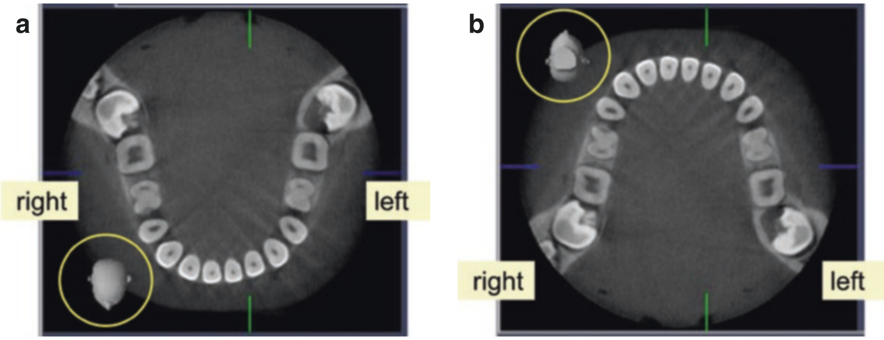


Fig. 1.5 (**a, b**) Right and left when in axial plane. Right and left sides of the patient when viewing an axial image in the (**a**) nose-down position and (**b**) nose-up position. Note that this particular software shows the head orientation icon (yellow circle), which is an additional aid for the observer

1.2.4 Right and Left in Axial Plane

When viewing axial images, the right-left convention is the same as for coronal images. However, some CBCT software shows the axial plane in the "nose-down" (Fig. 1.5a) and others in the "nose-up" position (Fig. 1.5b) .

1.2.5 Sagittal Default

In the sagittal plane, left and right sides are not easily distinguished (Fig. 1.6a, b). There is no convention to dictate whether the image should be viewed as if looking at the patient from the left side or from the right side. Many software allow the sagittal plane to "default to the left". This means that, regardless of whether a sagittal image is from the left or the right side, it is shown as if it were the left side. This is a practice that has been carried over from medical CT. Unfortunately, this is very confusing for dentists. Dentists prefer the orientation of sagittal images to be comparable to the conventional dental intraoral radiographs and dental panoramic tomogram (Fig. 1.3a–f).

It will be a long time before a convention will emerge with regard to the display of sagittal images. In the meantime, clinicians must carefully observe the orientation lines and correlate with the coronal and axials planes in order to determine the right-left nature of a sagittal image.

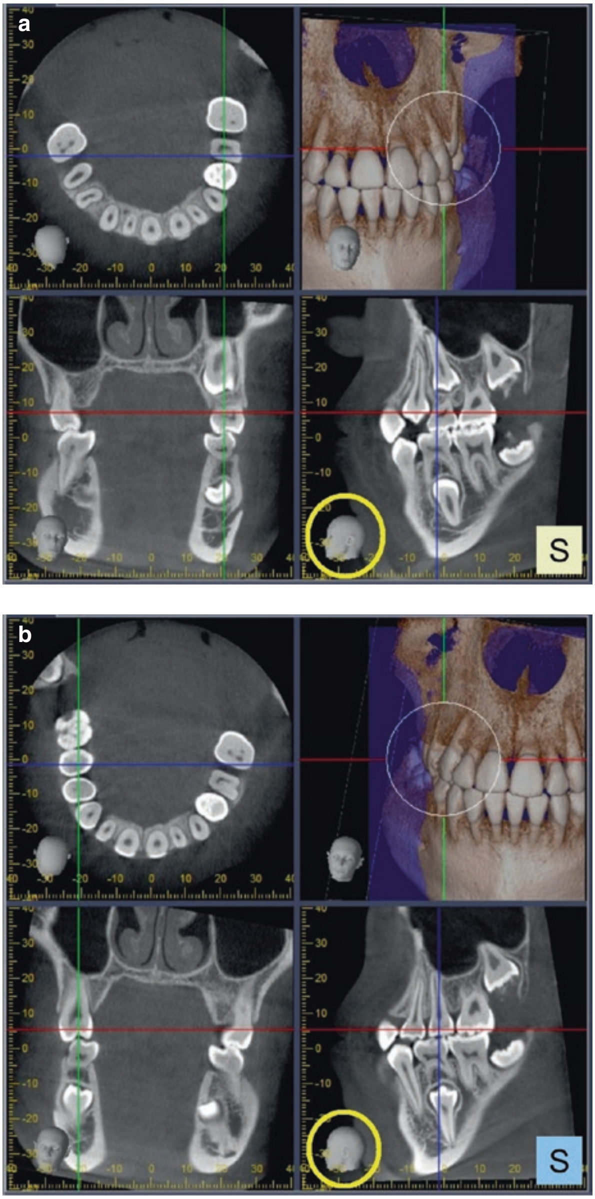


Fig. 1.6 (**a**) Sagittal slice, of left side. These images have been manipulated (by rotating the axial image counter-clockwise) to show the most number of posterior teeth on the **left** side in the sagittal slice (S). The sagittal orientation line (green line) is on the left side. The upper teeth present in the sagittal plane are UL34E567 (with UL57 being unerupted). The lower teeth seen in the sagittal plane are LL4E567 (LL57 are unerupted). The orientation head icon (yellow circle) shows that the sagittal plane is being viewed from the left side of the patient.
(**b**) Sagittal slice, of right side. These images have been manipulated (by rotating the axial image clockwise) to show the **right**-side posterior teeth in the sagittal slice. The upper teeth that are shown are UR34567, whilst the lowers are LL4E567. At first sight, these images look very similar to those in Fig. 1.6a. But careful inspection will reveal that the sagittal image has defaulted to the *left*, as can be deduced by observing the green orientation line, and also the orientation head icon (yellow circle)

1.2.6 Horizontal and Vertical Flip

Occasionally, it is necessary to flip an image in order to view it in an orientation that matches a different scan, to allow direct comparison. Sometimes it is desirable to flip a sagittal image in order to avoid right-left confusion. Flipping an image can cause unintended and potentially serious consequences. Therefore, users must be careful!

Flipping can be done in a horizontal or a vertical direction, as explained using an analogy (Fig. 1.7) and some CBCT images (Figs. 1.8 and 1.9).

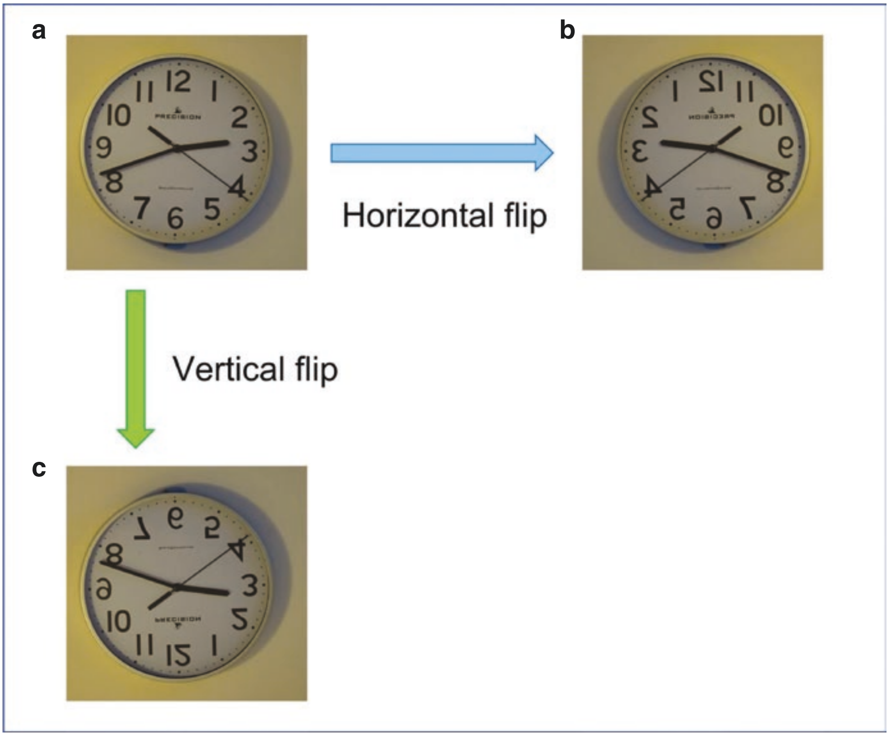


Fig. 1.7 Clock face. In this analogy, an image of a clock face is shown in three ways:
(**a**) normal,
(**b**) horizontally flipped, and
(**c**) vertically flipped.
By looking at the clock numbers, the direction of the flip is apparent to the reader. However, if the numbers were not present, then the hour, minute, and second hands would still show a time reading, a reading which would still appear believable

2.6.4.2 Upper Second Premolar

See Fig. 2.14.

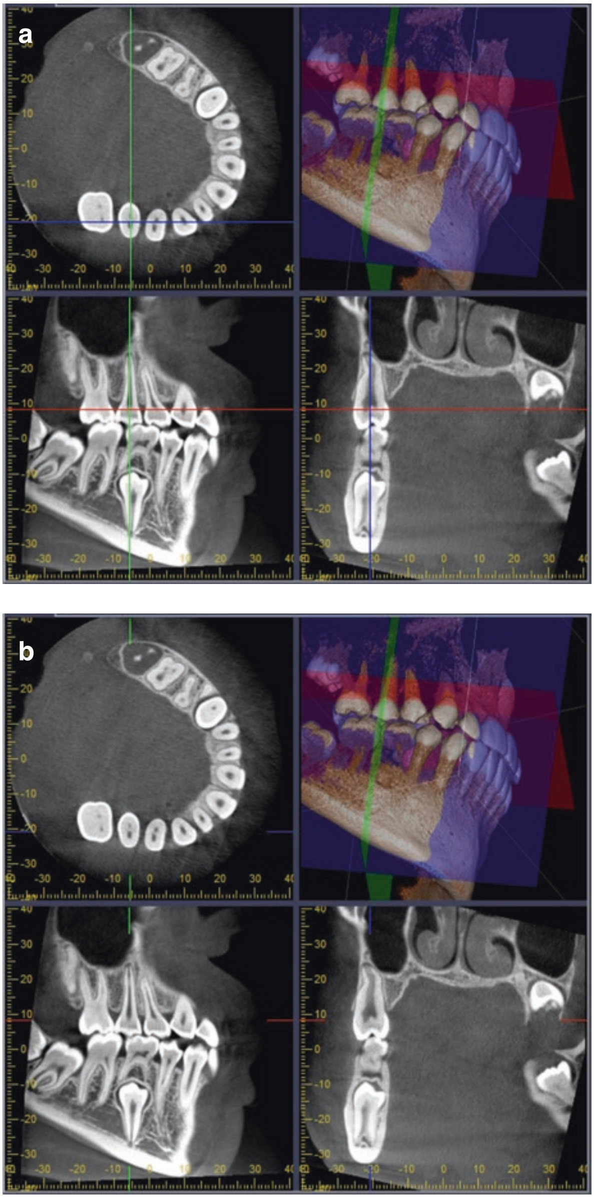


Fig. 2.14 (**a**) (with long orientation lines) Orthogonal cross-sections of upper right second premolar (UR5). The second premolar usually has similar shape and size to the first premolar, but the palatal cusp is more equal in size to the buccal cusp. In the coronal (oblique coronal) image here, the root apex of UR5 has a distinct bend. The root shape may have been influenced by adjacent structures, such as the maxillary sinus, during root development. The root canal is still open at the apex, thus root development has not yet reached its natural end-point. (**b**) (with short orientation lines) Orthogonal cross-sections of upper right second premolar (UR5)

2.8.3 Upper Left First Premolar (UL4)

See Fig. 2.23.

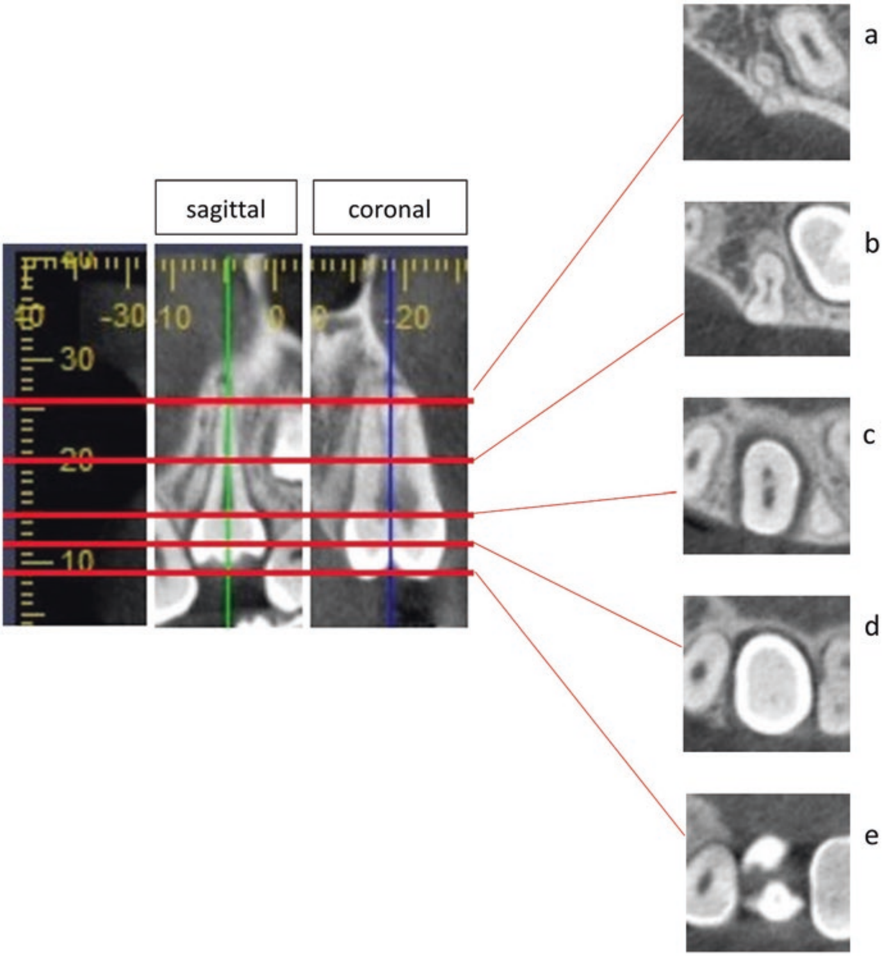


Fig. 2.23 (scale in millimetres) With sagittal and coronal sections for reference, an upper left first premolar (UL4) is shown in transverse section at (starting from most superior):
(**a**) near root apices
(**b**) mid third of root
(**c**) junction of crown/root
(**d**) widest part of crown
(**e**) through the cusp tips.
This tooth is not yet erupted, so the cusp tips are pristine and unworn. The single root bifurcates in the apical third region to form two apices. The root is oval in shape in the coronal third, but gradually changes to a “bow-tie” shape in the mid-third as it bifurcates

3.11 Skull Base, Bilateral

3.11.1 Orientation Lines for Composite Pictures from Scan D819

In the next four pairs of composite pictures from scan D819, the locations of the axial, coronal, and sagittal slices are shown in Fig. 3.49a, b, c, superimposed on the colour-rendered images of the face and facial skeleton. Readers should refer to the coordinate numbers on the rulers to see the exact locations.

See Fig. 3.49.

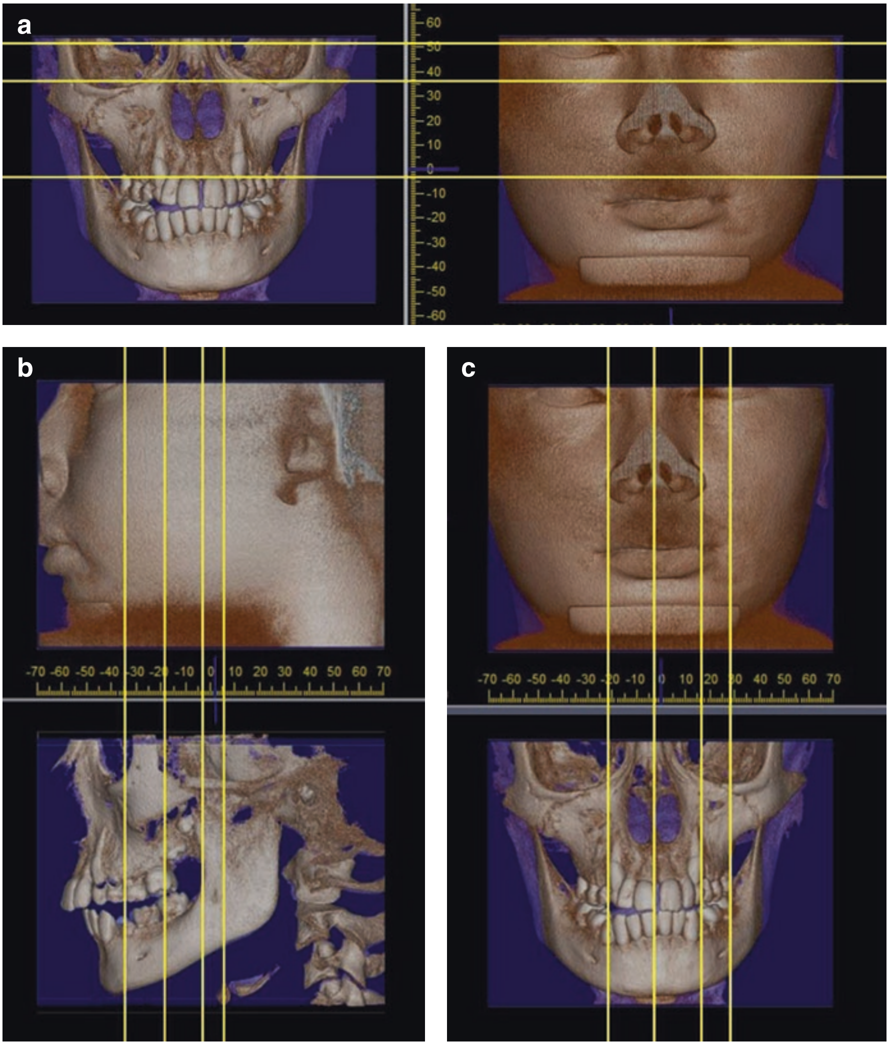


Fig. 3.49 (**a**) D819. Axial slices at coordinate locations of +50, +36, and −03. The line for +35 has not been drawn in: it is too close to +36.
(**b**) D819. Coronal slices at coordinate locations of −35, −18, −03, and +05.
(**c**) D819. Sagittal slices at coordinate locations of −21, −04, +17, and +29

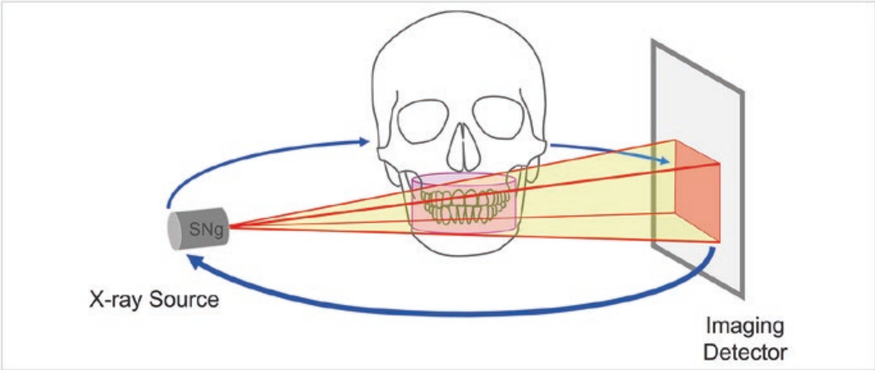


Fig. 7.33 CBCT image acquisition. The X-ray beam (yellow) revolves in a single 360° revolution around the patient's head. The X-ray beam is cone shaped when it leaves the X-ray tube but is then collimated according to the size of the required field. Thus, the final beam shape is pyramidal (red lines). Because the beam revolves around the patient, the overall shape of the acquired volume is cylindrical (pink)—circular in the horizontal plane, and rectangular in the vertical plane

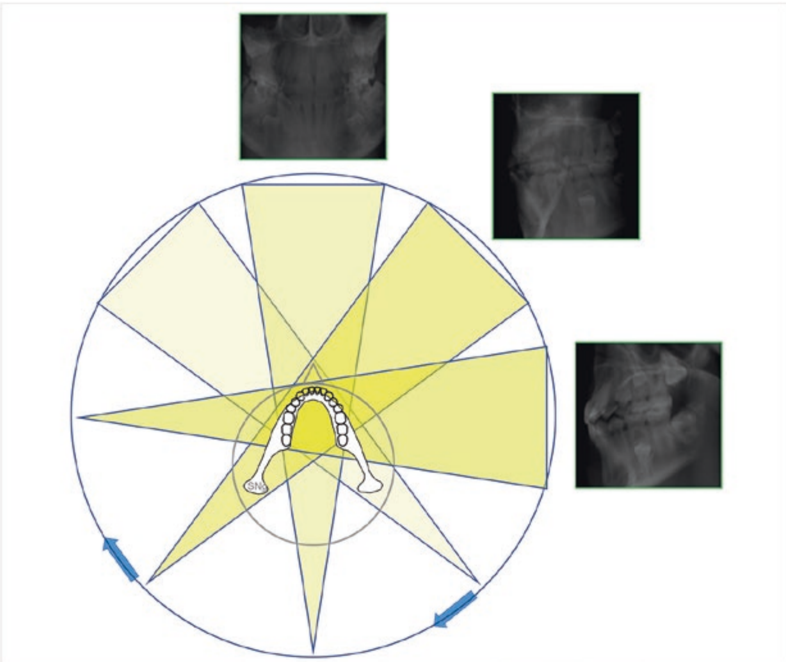


Fig. 7.34 Basis images. During a CBCT scan, at each position of the X-ray beam, a basis image is taken of the patient's jaws. Each basis image looks like a very dark skull radiograph. There can be between 100 and 600 basis images, depending on the machine settings. In this grossly simplified schematic, only four positions and three basis images are shown

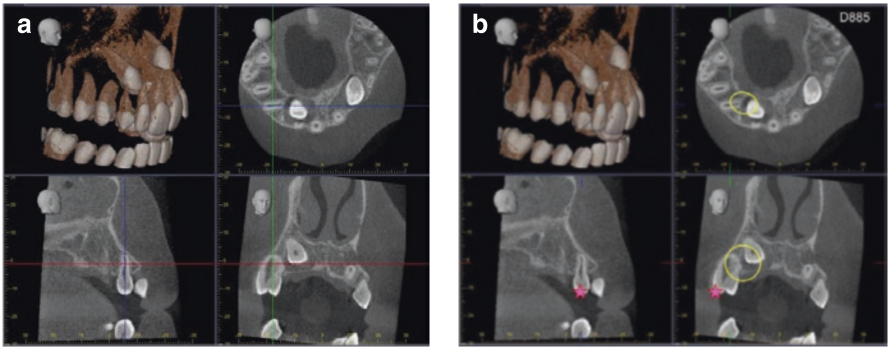


Fig. 8.49 (**a, b**) Case D885. Right first premolar. UR43. The three planes have been manipulated to best show the UR4 (pink star) at its maximum length and also its relationship to the UR3. There is no hard tissue contact between these two teeth (yellow circles). However, the UR4 does show stunted root formation so its development is most likely to have been affected by the presence of UR3 and its dental follicle

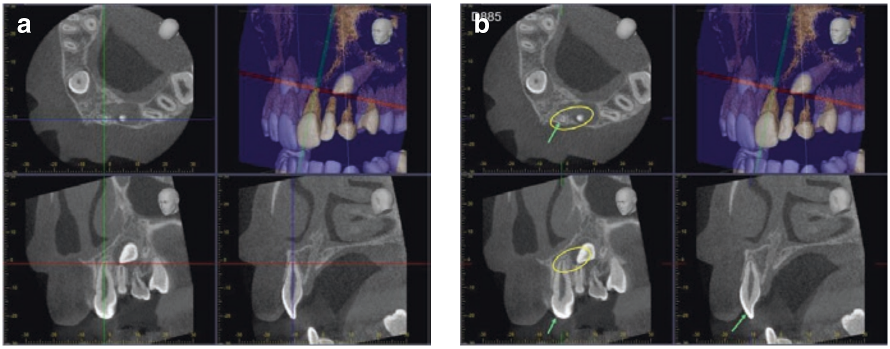


Fig. 8.50 (**a, b**) Case D885. Left central incisor. UL13. The root apex of UL1 is clearly separated (yellow circles) from the crown tip of UL3. This is shown in the three planes as well as the volume-rendered image. Although UL1 root is relatively short, it does not show any signs of resorption. Green arrows point to UL1

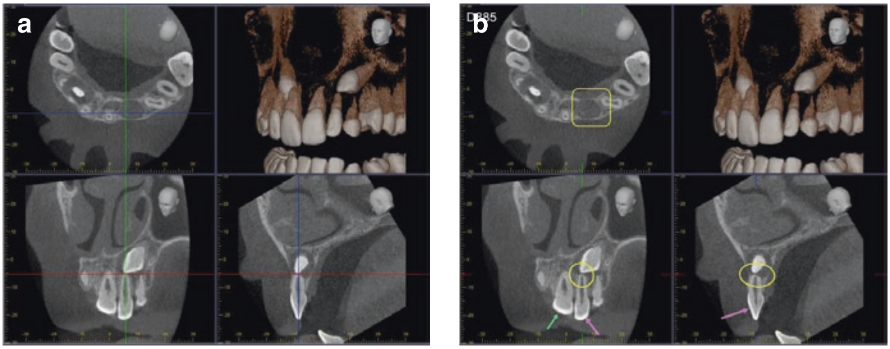


Fig. 8.51 (**a, b**) Case D885. Left lateral incisor. UL23. The UL2 (pink arrows) is showing a short root, blunting of the root apex, and wide-open apical foramen. These are signs of root resorption. The dental follicle of the UR3 (yellow circles, yellow square) is in contact with the UL2 root. Green arrow points to UL1

When teeth are lost, the bone crestal arch tends to resorb more on the buccal side than the palatal or lingual side. This means the bone arch becomes smaller and smaller. And yet the occlusal arch (to be reconstructed) is required to be the same as the previous natural teeth. These mismatched arches are a challenge for the implant specialist and prosthodontist.

8.5.4 Imaging Stent and Fiducial Markers

To maximise the treatment planning aspects of the CBCT scan, the patient should be wearing an imaging stent during the scan. The stent can be a modified copy denture or a custom-made vacuum-formed acrylic appliance. Some examples are shown in Fig. 8.55.

The stent must contain radiopaque **markers** or **fiducials** to help define the sites of interest, especially if there are two or more potential implant sites. The radiographic markers may be small objects inserted into the stent, or a thin application of

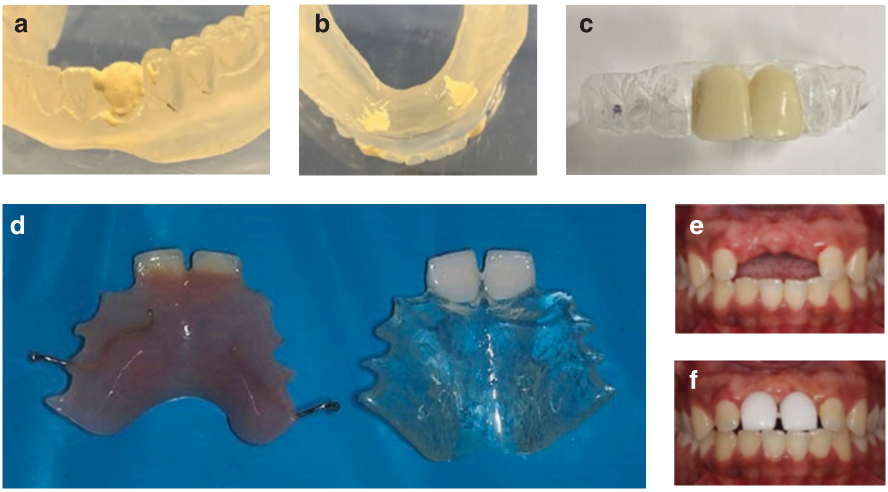


Fig. 8.55 (**a–f**) Examples of imaging stents and fiducial markers, from 3 different patient cases.

In (**a**), an existing lower full denture has been reproduced in one solid acrylic block. A layer of radiopaque paint has been applied to the denture tooth at location of LL3, to act as a marker for this location. On the fitting surface of this copy denture, some radiopaque paint has been applied to the positions of LR3 and LL3 (**b**).

In (**c**), the patient did not have an existing denture. Thus an imaging stent was custom made by making a vacuum-formed acrylic shell (transparent) and then filling in the edentulous space with radiopaque acrylic to resemble two denture teeth (upper central incisors).

In (**d**), an upper partial denture (pink acrylic) has been copied in clear acrylic together with two radiopaque denture teeth (fitting surface is facing away from the camera). In e and f, the patient is shown without and with the imaging stent from (**d**)