3

Endodontic Radiology

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CHAPTER OUTLINE

LEARNING OBJECTIVES

After reading this chapter, the student should be able to:

1. Differentiate between stochastic and deterministic dental x-radiation biorisks and recognize which poses the greatest endodontic patient risk.
2. Understand the basic design of a wall mounted x-ray unit and why it is preferred to hand-held x-ray units.
3. Contrast and compare the differences between the indirect PSP plate sensors, the CCD solid state direct sensors and the CMOS solid state direct sensors used for intraoral endodontic radiography.
4. Understand how shifting horizontal angles of the intraoral x-ray beam can be used to localize the relative buccal vs. lingual/palatal locations of superimposed root canals or jaw pathoses that superimpose teeth.
5. Recognize FOV dimension measurements and how these relate to the coverage needed for most endodontic scan indications.
6. Understand how voxel size affects storage space, uploading, downloading and transmission of CBCT volumes.
7. Differentiate between DICOM file data and proprietary file data and how these interplay with various CBCT viewer software programs.
8. Recognize how beam hardening and scatter artifacts degrade CBCT image quality.
9. Review indications where CBCT imaging provides diagnostic and treatment advantages over the standard endodontic image requirements.

Prologue

Dr. William Herbert Rollins was already an established Harvard-trained physician and dentist when x-rays were discovered in 1895. Dr. Rollins, like his contemporaries, was fascinated by the usefulness of x-ray images. However, he was also one of the first to recognize the poorly understood—but genuine—risks associated with x-ray imaging.

Suffering radiation erythema to his hand in January 1898, and having seen the lethal effects of x-rays in his guinea pig experiments, Rollins attempted to caution his contemporaries of its dangers; however, the enthusiasm for the new x-ray technology was blinding radiographers to its morbid hazards. By the late 1920s, it was clear that there were biorisks associated with x-rays as the ranks of prominent radiographers in the New England area had been thinned. Further demonstrating this risk was the fact that at radiology meetings in the 1920s, roast beef was rarely served because the radiographers wore gloves to hide their scars and, by doing so, could not cut the roast beef with the cutlery provided.[1]

It was not until the post-World War II atomic era, that the scientific community again began to heed the warnings of Rollins from a half century earlier.[1]

Introduction

By virtue of its ability to image beyond the scope of the intraoral examination, radiography is an indispensable part of the diagnostic process in dentistry. Within this scope of oral health care, endodontics makes full use of this most useful of diagnostic techniques.

Imaging in the 21st century no longer relies solely on the use of x-rays for diagnostic imaging. Other imaging modalities from which dental care now benefits include optical scan imaging, magnetic resonance imaging, and on the frontier, ultrasound imaging.[2,3] However, with the advent of digital technology, x-ray imaging remains progressive with constant innovation. These innovations keep x-ray imaging an integral and up-to-date part of the diagnostic process for endodontic care.

The use of sensors in dental imaging has changed dramatically, from the earliest days of photographic emulsion on glass plates, to the development of plastics to support radiographic emulsion (i.e., film). In the 1980s, intraoral digital sensors were introduced by Dr. Frances Mouyen.[4] Endodontics eventually embraced this technology because digital sensors dramatically facilitated the efficiency at which endodontic procedures could be completed.[5]

In the 1960s endodontics became the eighth recognized dental specialty of the American Dental Association. At the same time, extraoral panoramic imaging became the exhilaration of dentistry with its ability to image large areas of the jaws in a single exposure. However, extraoral imaging was not as beneficial to the intricacies of endodontic patient care until the introduction of cone beam computed tomography (CBCT). In the 21st century, CBCT is a digital extraoral imaging modality that has greatly facilitated endodontic care. This chapter outlines the utility of radiographic imaging for endodontic patient care with the continued use of intraoral radiography as well as the progressive advances initiated with extraoral CBCT.

Radiation Biology

Contemporary clinicians must still deal with the reality that there are long-term risks that may be realized from exposure to x-radiation. Endodontic care will typically lead to multiple patient x-ray exposures. The radiation dosage to oral and other tissues has been calculated to be very low and extrapolated to cause minimal (but some) risk.[6,7] Table 3.1 illustrates the effective doses of various dental imaging procedures. This table provides the reader with a measure of the biorisk from intraoral exposures in relation to other dental imaging procedures. A more detailed radiation dosimetry review is available elsewhere.[8,9]

In the early days of x-ray imaging, deterministic biorisks, such as skin burns, scarring, and cataracts, were prominent, and the stochastic risks of malignancy (skin cancers and leukemias, etc.) were also very high. The reality of deterministic risks is negligible today, but the morbidity risk from x-ray–induced malignancies (i.e., stochastic risks) remains.[10,11] Practitioners must also be cognizant of the fact that the probability of getting an x-ray–induced malignant disease increases with increased numbers of exposures. With each exposure from each new endodontic procedure, small but cumulative increases in the probability of suffering an x-ray–induced malignancy exist. However, the endodontist must also remember that the overall patient x-ray biorisk is not merely from endodontic x-ray procedures. Risk will increase and be added to from additional endodontic procedures, such as other dental or medical imaging needs (e.g., dental implants, cardiovascular imaging, brain scanning, gastrointestinal [GI] series, orthopedic imaging, etc.). Therefore the risks remain real, and the need for vigilance to keep radiation exposures as low as reasonably achievable (i.e., ALARA) remains forever present.[12] The value of imaging for any endodontic diagnosis or treatment indication should be determined on an individual basis to assure that the benefit-to-risk assessment supports the use of imaging.[13]

In pediatric patients, the biorisks from the x-radiation are greater than the adult risks for a given radiation dose. This increased risk is due to the pediatric patient's inherently greater radiosensitivity and because children have more remaining years of life during which a radiation-induced malignant neoplasm could develop.[14] Hence, as with any imaging modality, the decision to use any diagnostic x-radiation is an objective-laden thought process where the benefits of the information obtained must outweigh the risks of the x-radiation.

TABLE 3.1 Differential Diagnosis for the Most Common Injuries to the Periodontium

Type of Radiographic Exam	Medain Effective Dose (μSv)	Days of Equivalent Background Radiation
Rectangular Collimation BW PSPP	5	0.6
FMX PSP	40	4
FMX CCD	20	2.5
Round Collimation FMX D-speed	400	48
FMX PSP -	200	24
FMX CCD -	100	12
Panoramic	20	–2.5
Cephalometric	5	0.6
CBCT - large FOV (craniofacial)	120	15
CBCT - medium FOV (full arch; dentoalveolar)	100	12
CBCT -small FOV (~3-5 teeth; <6.0cm. dia.)	50	6

Equipment for 2D Image Capture

Intraoral X-ray Units

Standard Wall-Mounted Units

Dental x-ray units have changed very little over the years since David Coolidge designed the first enclosed x-ray tube and tube head, the Victor CDX, in 1919.[15]

Exposure times have decreased to less than 20% of the exposures from as little as three decades ago. Because of this, the need for large x-ray tube heads housing the larger generators needed to produce kV potentials greater that 70 kV has decreased. The need for high milliamperage (i.e., mA settings greater that 10 mA) is also no longer indicated with the shorter exposure times needed for digital receptors. Most contemporary x-ray tube heads are smaller with kV potentials between 60 and 70 kV and mA in the 6- to 8-mA range. With some exposure times now less than 0.10 seconds, most units have digital microprocessor timers that can reproducibly generate direct current (DC) exposures in the 0.05- to 0.10-second range. These smaller x-ray units produce adequate x-radiation to expose contemporary digital receptors, including American National Standards Institute (ANSI) F speed film, and reduce patient radiation dose with the shorter exposure times

Another option available in dental x-ray units is the recessed x-ray tube. Instead of the x-ray tube placed adjacent to the window within the tube head and the position indicating device (PID), contemporary x-ray tube heads have the x-ray tube recessed further away from the window (Fig. 3.1). The recessed tube produces a longer focal distance (x-ray source-to-object distance), which projects a sharper image outline. With an increased focal distance, the inverse square law dictates that the exposure must be increased. However, even though the exposure needs to be greater to obtain a diagnostic image density, the patient dose is actually decreased, which is an added benefit of the recessed x-ray tube. This benefit is because the increased distance will prevent many of the low-energy x-ray photons in the beam from reaching the patient. Thus the recessed x-ray tube acts as a distance filter, which will decrease the patient dose.

Handheld Units

In the past decade, handheld x-ray units for dental imaging have become very popular in clinical practice.[16,17]

Handheld units were originally designed for the benefit of mobility to provide dental imaging in remote locations where standard equipment is not available or for nonambulatory patients in need of dental services who cannot access standard dental facilities. Because these units are made for portability, they have become more popular in regular office designs and are used as a single unit for multiple standard operatories. Image quality is generally acceptable; however, due to the portability, the maximum kV and mA are less than those possible with standard units. The biggest issue with handheld units is the radiation dose to the operator if used without proper training. However, units have been shown to have adequate shielding to protect the operator if used properly with a backscatter shield.[18-20]

Proper usage includes assuring that backscatter shields are attached to the units so that the operators can keep their bodies within the protective range of the shield (Fig. 3.2).

Because of their convenience and popularity, several handheld units are now commercially available. There is concern that some newer units do not have the same degree of protective operator shielding.[21] This aspect is a critical feature when considering a handheld unit of choice.

Despite their convenience for remote venues, the units lack the power of the wall-mounted units. However, smaller power packs are necessary to keep the unit at an appropriate lighter weight for the handheld use of the typical office staff member. Hence, remote charging and reinserting battery packs become an additional maintenance task. Care must also be taken when lifting and handling the nonergonomic units to avoid shock damage.

Furthermore, there is concern that the features of portability do present challenges for optimal image quality and safety. Consequently, unless clinical facilities demonstrate distinct advantages of handheld units over wall-mounted units where the latter installations are possible, the routine practice of using handheld units over wall-mounted units is not always a recommended guideline.[22]

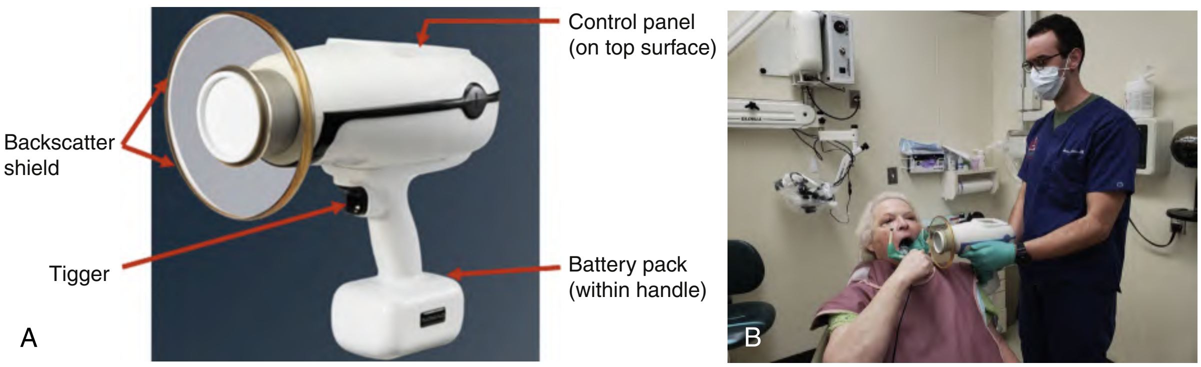
• **Fig. 3.1** X-ray tube head with position dot indicating the position of the focal spot that is inside the x-ray tube head *(red arrow)*. The inset image demonstrates the increased length of the focal distance. This increased length offers sharper image outlines and reduced patient dose.

Intraoral Image Receptors

As described in this chapter's introduction, the types of sensors used in dental imaging have changed dramatically. Digital sensors are the preferred type of sensor for endodontic management. Although it has been shown that the digital image quality has no major advantages over film images,[23-28] digital sensors are by far more practical than film. Digital sensors are advantageous in that there is reduced patient radiation exposure, with increased speed of image acquisition, storage, retrieval, and transmission. An additional advantage of digital sensors over film is that digital sensors forego the arduous chemical film processing, which takes longer and also requires the use of a darkroom. Digital sensors have dramatically facilitated the efficiency at which endodontic procedures can be completed.

Types of Digital Image Receptors

Digital image formats include indirect photostimulable phosphor (PSP) plates and the direct solid-state sensors that may either be



• **Fig. 3.2** **A**, KaVo™ NOMAD Pro 2™ handheld x-ray unit. **B**, Proper operator position for handheld x-ray unit which maximizes operator protection from backscatter radiation. All operator body parts are within the shields protective range. (**A**, Courtesy KaVo, Charlotte, NC. USA; www.kavo.com) the charge-coupled device (CCD) sensor or the complementary metal-oxide semiconductor (CMOS) active pixel sensor. The latter is also abbreviated as CMOS-APS.

Photostimulable Phosphor Plates

The PSPs are considered indirect because, after exposure, the sensor must be removed from the patient's mouth and transferred to a laser scanner so that the stored latent electronic charges of the pixels on the sensor's surface can be scanned with a laser light to generate an electrical signal. The digital process includes assigning a numerical value to the electrical signal strength of each of the pixels. These numerical values are then assigned a gray-scale value to be used by the imaging software for display on a monitor.

Solid-State (Direct) Sensors

The solid-state direct sensors transmit the electronic signal straight from the sensor directly to a computer so the image can be displayed in as little as 3 to 5 seconds or less, depending on the computer processing speed and the server's size and efficiency.

At this time, the CMOS is the predominantly used direct sensor. They are generally less expensive to manufacture and are faster in transmitting the electronic signal for processing and require a simple USB connection to a computer. Despite the improved CCD sensitivity to x-radiation, their slightly greater manufacturing costs and their more cumbersome digital processing sequences have now decreased their commercial availability.

Despite the advantages and increased preference for direct digital sensors, there remain some disadvantages, which delay an industry-wide total conversion to these sensors. Direct digital sensors are thicker (5 to 8 mm)[29] and less comfortable than the thinner and more flexible traditional film or PSPs. Because of this discomfort, not all patients tolerate imaging procedures with direct sensors. Although the direct digital sensors have the approximate height and width of conventional film sensors, the actual active sensor area is smaller, ranging among different manufacturers from 20% to 25% reduction of the image surface area compared with conventional film or PSPs.[29,30]

This problem creates issues with cut-off apices from the compromised vertical dimension and missing apices when the horizontal dimension is compromised, and horizontal angulation is needed to image the multiple root apices of multirooted teeth.

Dental Film

For those clinicians still using dental film, "F"-speed film is the film recommended for endodontic use. However, the slower "D"-speed film is still available, the increased radiation exposure and slightly higher contrast are not of any added benefit for endodontic imaging. Although the active surface areas are larger on film (as previously discussed), this technology is being replaced by direct sensor technology. For clinicians still using dental film, a more detailed discussion of their use and chemical film processing is discussed in other reference sources.[31-33]

Techniques for Intraoral Image Capture

Periapical Imaging

The main image capture techniques for periapical imaging are the paralleling technique and the bisecting angle technique. These techniques are amply described in main radiology textbooks.[33-35] For the paralleling technique, the receptor is ideally positioned parallel to both the long axis and the mesiodistal plane of the tooth being evaluated. The beam is then directed perpendicular to the plane of the receptor. It is necessary to stabilize the receptor in this planned position. When it is not possible to place the receptor parallel to the tooth, the bisecting angle technique may then be applied. With this technique, the receptor is stabilized against the lingual side of crown and the adjacent palatal/lingual mucosa. Because the receptor no longer parallels the long axis of the tooth, it is necessary to project the vertical angle of the x-ray beam perpendicular to the plane that bisects the angle formed by the intersecting planes of the long axis of the tooth and the vertical axis of the receptor. Frequently, clinicians choose to align all these planes freehand, with the use of simple receptor bite blocks or with other simple holding instruments (modified hemostats, Snap-a Ray devices, etc.), but without the aid of beam alignment devices (Fig. 3.3, *A* and *B*). However, for more predictable imaging, receptor stabilizing–beam alignment devices are available for this purpose. These instruments are preferred for best image quality with minimal projection artifact, such as cone cutting, foreshortening, elongation, and so on (Fig. 3.3, *C*).

When working length images or master cone images are needed, the rubber dam clamp does make it more cumbersome to position the receptor. Again, the use of the receptor stabilizing–beam alignment devices best facilitate obtaining the most favorable images. Specially adapted instruments are made with appropriate bite block modifications to accommodate the rubber clamp and endodontic files positioned in the canals (Fig. 3.3, *D*).

Due to the variability of human nature, it is not always possible to get patient cooperation to tolerate the placement of the instruments necessary for beam alignment. This difficulty is especially true for the "working" radiographs taken during an endodontic treatment with the rubber dam in place. Sometimes, it may require cooperation by the patient if they hold the sensor in position. In these scenarios, trying the *modified paralleling* technique is recommended.[36] Essentially, the sensor is not parallel to the tooth, but the central beam is oriented at right angles to the receptor surface. In endodontic working radiographs, a further modification is made by varying the horizontal beam angle.

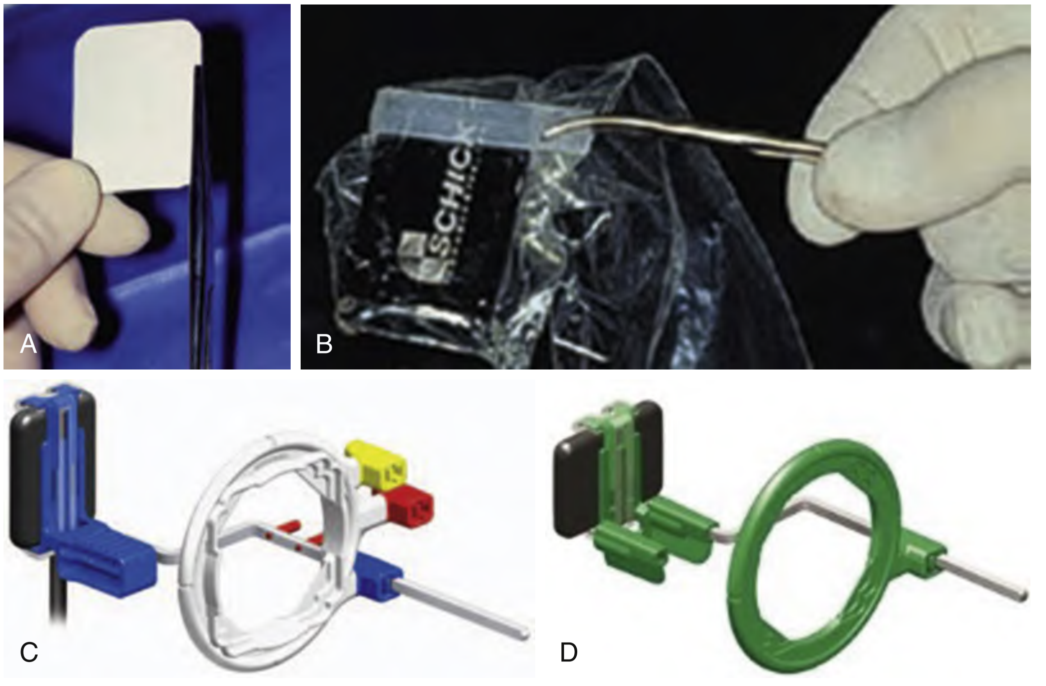
Tube Shift

Modification of the horizontal angle of the x-ray beam becomes a necessary modification to separate structures that superimpose one another on the 2D image. Principles of relative movement of structures and sensor orientation are applied to the differentiation of object position, as demonstrated in Figs. 3.4 and 3.5.[37-39]

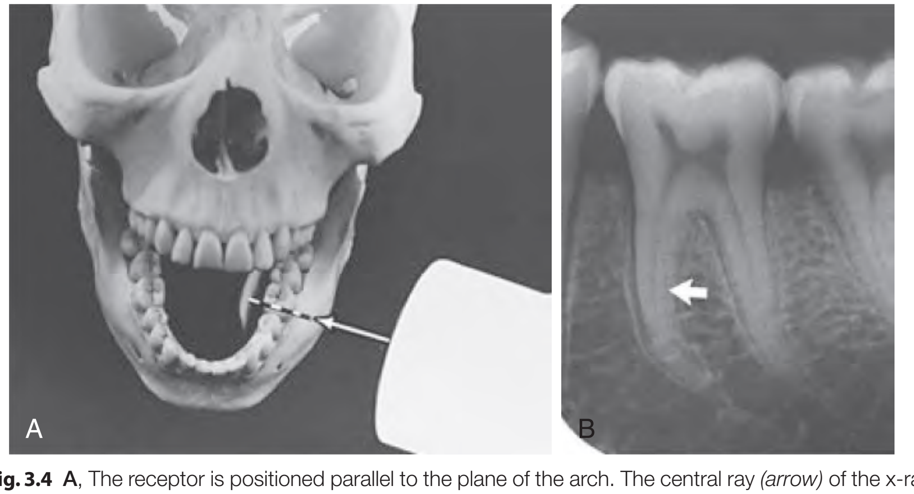
These principles of tube shift have been adapted to object localization of structures in the nonvisible buccolingual dimension of 2D radiography. One of the most useful techniques in endodontics is the SLOB Rule.[38] SLOB is an acronym—**S**ame **L**ingual **O**pposite **B**uccal, as first described by Richards.[38]

When two objects and the sensor are in a fixed position buccal and lingual from each other, and the radiation source is moved in a horizontal or vertical direction, the images of the two objects move apart in opposite directions (Fig. 3.6).

One way to visualize this effect is to close one eye and hold two fingers directly in front of the open eye so that one finger is superimposed on the other. By moving the head one way and then the other, the position of the fingers relative to each other shifts. The same effect is produced with two superimposed roots (the fingers) and the way in which they move relative to the radiation



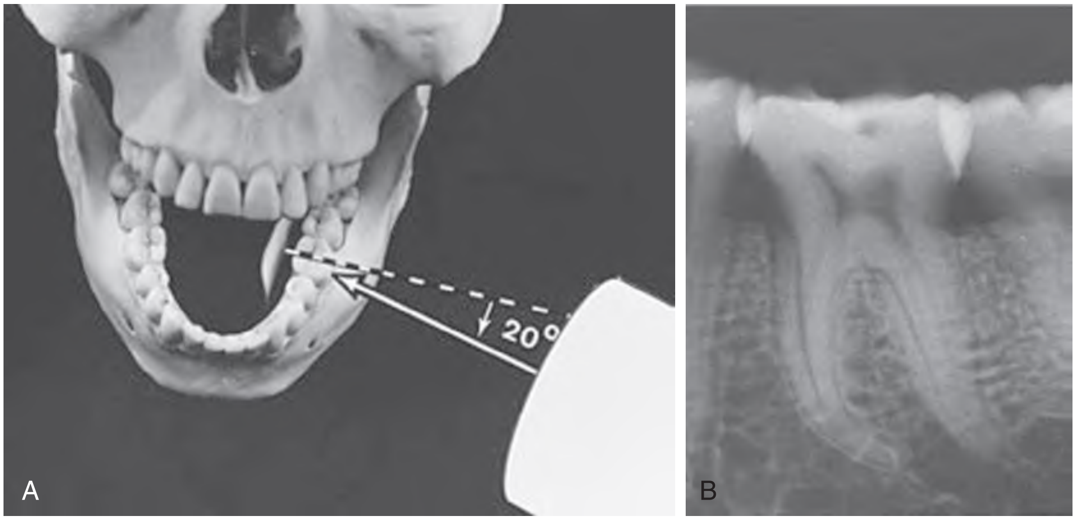
• **Fig. 3.3** Receptor Stabilizing Devices for Intraoral Imaging. **A**, A hemostat is used for grasping film or a PSP plate and does help orient the x-ray beam. **B**, A hemostat holds a plastic holder for a solid-state digital sensor. **C**, The Rinn XCP-DS ORA receptor stabilizing-beam alignment device is used for standard periapical projections. **D,** The XCP-DS FIT Universal Sensor Holder and beam alignment device for working endodontic radiographs. This sensor holder stretches to fit all types of receptors including solid state sensors. (**C**, Courtesy Dentsply Sirona, York, PA; **D**, Courtesy Dentsply Sirona, York, PA)



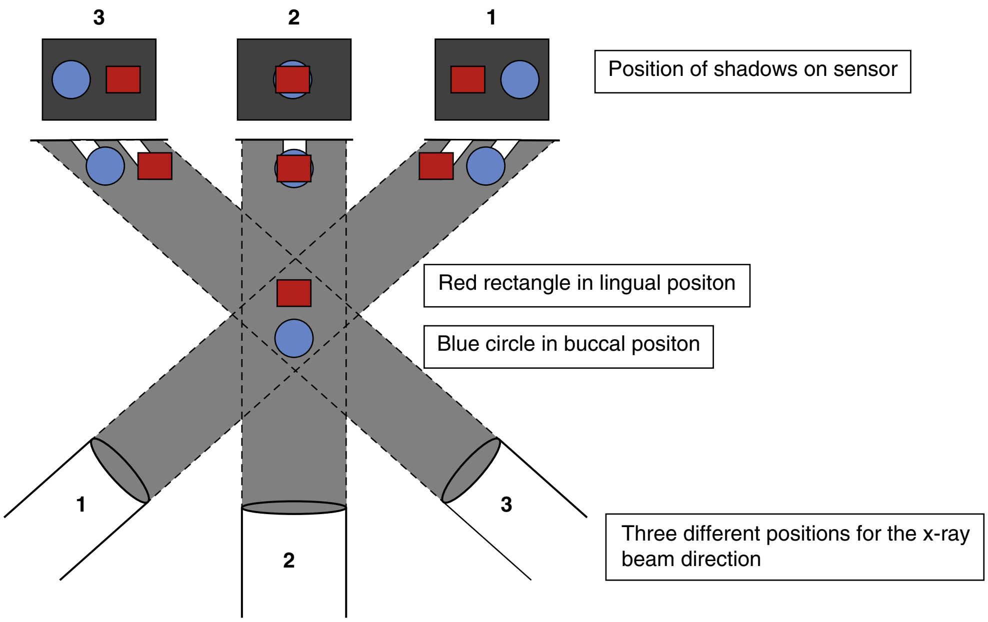
• **Fig. 3.4** **A**, The receptor is positioned parallel to the plane of the arch. The central ray *(arrow)* of the x-ray beam is directed toward the receptor at right angles. This is the basic beam–receptor relationship used for horizontal or vertical angulations. **B**, There is a clear outline of the first molar but limited information about superimposed structures (canals that lie in the buccolingual plane). The *arrow* points to a periodontal ligament space adjacent to a superimposed root bulge, not to a second canal. (From Walton RE: Endodontic radiographic techniques, *Dent Radiogr Photogr* 46(3):51–59, 1973.)

source (the eye) and the central beam (the line of sight). When the cone-shift technique is used, it is critical to know in which direction the shift was made and to determine what is buccal and what is lingual. Otherwise, serious errors may occur. Fig. 3.7 demonstrates how the horizontal angle is shifted to accomplish these localization techniques.

This horizontal tube-shifting technique can be used to separate superimposed root canals and superimposed roots or to separate roots of teeth from adjacent superimposing anatomy, such as the mental foramen in the mandible or the zygomatic process of the maxilla in the maxillary arch. Examples of this tube shift are demonstrated in Fig. 3.11, *A–F*, of the next section.



• **Fig. 3.5** **A,** The horizontal angulation of the cone is 20-degrees mesial from the parallel, right-angle position (mesial projection). **B,** The resultant radiograph demonstrates the morphologic features of the root or canal in the third dimension. For example, two canals are now visible in the distal root of the first molar. (From Walton RE: Endodontic radiographic techniques, *Dent Radiogr Photogr* 46(3):51–59, 1973.)

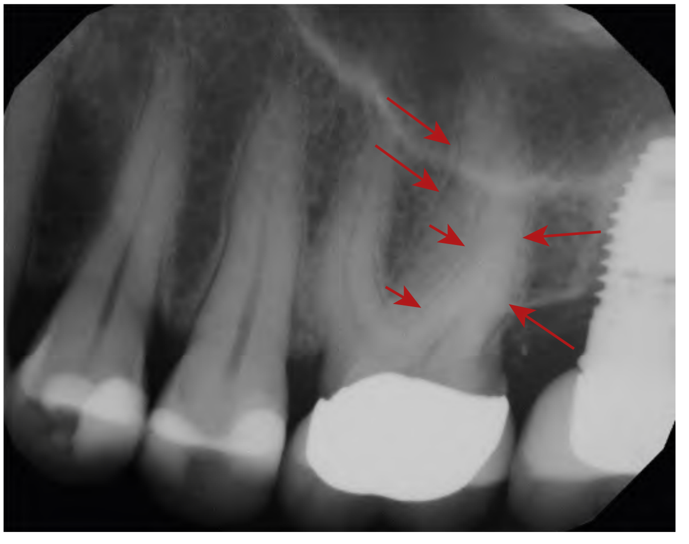


• **Fig. 3.6** This schematic demonstrates the projected images of the blue circle (buccal) that is closest to the x-ray source and the red rectangle that is further from the x-ray source and closest to the receptor (lingual). In Position 2 of the x-ray beam, the objects superimpose on the Sensor 2 projected image. When the object superimposes on this single 2D image, it is not possible to tell which of the objects is positioned in the buccal or lingual position. When the beam is projected from Position 1 (i.e., left of Position 2), the objects are separated on the projected Sensor 1 image. The resulting image on Sensor 1 shows the red rectangle lingual object moved in the same left direction as the beam and the blue circle buccal object moved in the opposite direction of the beam to the right; hence, the acronym SLOB—**S**ame **L**ingual **O**pposite **B**uccal. When the beam is projected from Position 3 (i.e., right of Position 2), the objects are separated on the projected Sensor 3 image. The resulting image on Sensor 3 shows the red rectangle lingual object moved in the same right direction as the beam and the blue circle buccal object moved in the opposite direction of the beam to the left, hence the SLOB rule applies again. (Modified from: Abramovitch K. Imagery Chapter 5. In *Impacted teeth*, Alling III CC, Helfrick JF and Alling RD. WB Saunders, Philadelphia, 1993, pp. 110–116.[39])

• **Fig. 3.7** Horizontal angulation is determined by looking down from the top of the patient's head. **A,** The position is set by aligning the horizontal plane of the position indicating device (PID) indicated by the arrow, parallel to the long axis of the hemostat handle. Mesial **(B)** and distal **(C)** horizontal angulations are then varied accordingly. (From Walton RE and Fouad AF, 2014.)

Study Questions

1. The major biorisk from x-rays used for endodontic imaging is:
   a. Deterministic
   b. Traumatic
   c. Cyclic
   d. Stochastic
2. A disadvantage of digital solid-state sensors for periapical imaging is the:
   a. Smaller area for image capture
   b. Projection of double images
   c. Greater propensity for dimensional distortion
   d. Inferior diagnostic sensitivity to dental film
3. In comparison with handheld x-ray units, wall-mounted x-ray units:
   a. Are more durable
   b. Have greater portability
   c. Produce less image distortion
   d. Process digital images more quickly
4. Handheld x-ray units:
   a. Improve image resolution
   b. Increase biorisk to the radiographer
   c. Require shorter exposure times
   d. Are used only with digital sensors
5. Tube shifting is a
   a. CBCT technique that improves image resolution
   b. A method of directing the rotational path in a CBCT scanner
   c. Beam alignment method that minimizes root canal length distortion
   d. Technique used to localize the buccal and lingual position of objects



• **Fig. 3.8** This standard periapical projection shows the root surface outlines with the periodontal ligament space and the adjacent lamina dura around the roots of the premolars and first molar. Even with the superimposition of the palatal and distobuccal roots, the root surface outlines *(short, thick arrows)* and the periodontal ligament space *(longer, thick arrows) and* adjacent lamina dura *(long, thin arrows)* still project, and the clinician must visualize these structures to evaluate periapical health.

Endodontic Imaging Needs

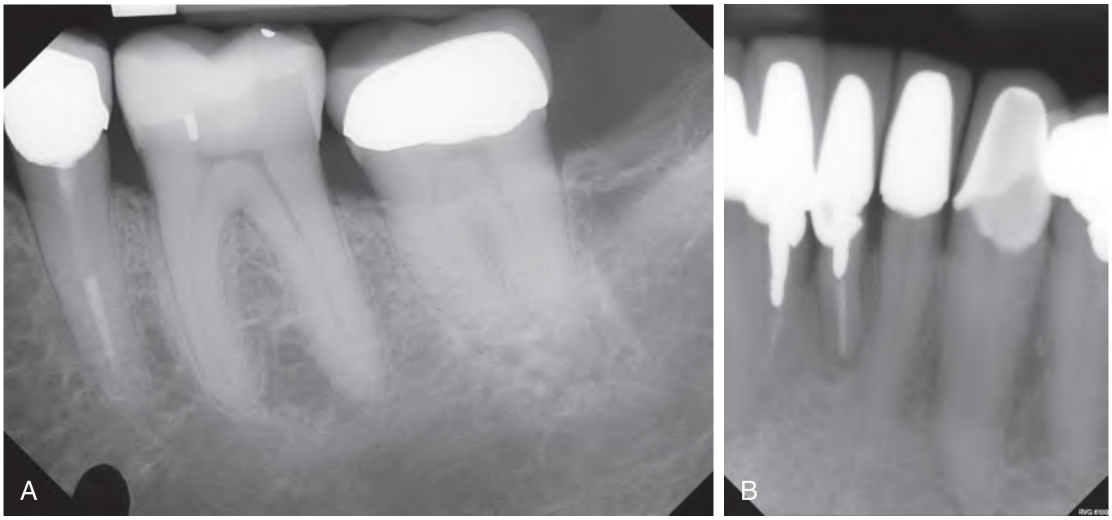
There are numerous indications in endodontic patient management where imaging plays a vital role in decision making and treatment rendering. These indications range from diagnosing a treatment indication, to rendering the treatment, and then to follow-up of the treatment. These situations are outlined later in this section (Video 3.1).

Disease Diagnosis

Before diagnosing any disease process, the clinician must be able to distinguish the normal anatomic range of structures in the dentoalveolar complex and its supporting structures. This range would include the root and pulp anatomy of any affected dentition and their relationship to adjacent structures, whether maxillary molar roots adjacent the zygomatic process and maxillary sinus in the maxilla or the apices of mandibular premolars adjacent the mental foramen. Pulp chambers are identified within the dental crown, and the root canals will extend from the pulp chamber to its specific root apex. The periodontal ligament (PDL) space is differentiated from the pulp chamber as it follows the outline of roots and has a consistent narrow width (<1.0 mm) around the roots. It also will have a peripheral thin radiopaque lamina dura adjacent to it (Fig. 3.8).

Identifying Pathosis

The recognition of disease requires an understanding of the pulpal, periodontal, or periapical changes that may arise in



• **Fig. 3.9** **A,** Physiologic apical periodontal ligament (PDL) outlines are present on the mesial and distal roots of tooth #19. Note the position of the retentive pin adjacent the mesial pulp horn which was the cause of the patient's odontalgia. **B**, Note the altered apical PDL and external resorption on #24 that is occurring in the absence of symptoms. These changes and the periodontal bone loss compromise this tooth's prognosis.

the presence of disease and how these changes can affect the identification of the normal anatomic outlines. Similarly, an understanding of systemic or local hard tissue pathologic processes that affect the jaws is also necessary to recognize these processes as they present. The more astute clinicians recognize these changes in their earliest stages of tissue alteration. It is also important to remember that pathologic processes in their earliest stages are often symptomatic before the development of prominent radiographic signs or clinical signs or symptoms (Fig. 3.9).

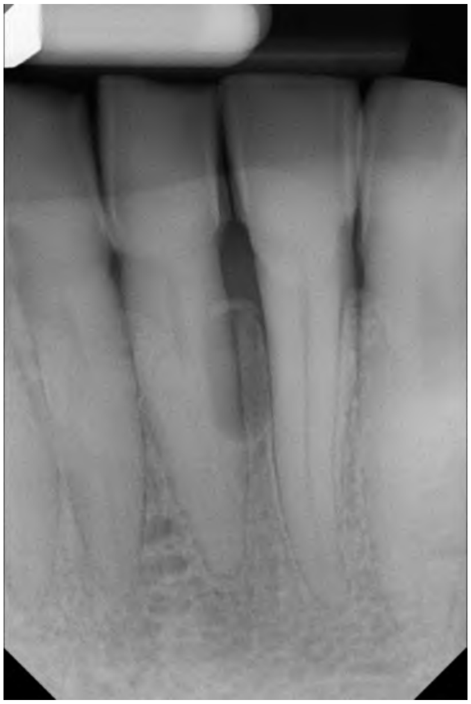
The presence and nature of lesions that may arise on routine or follow-up radiographs must be evaluated on any images taken during the course of treatment or follow-up. These lesions may be periapical, periodontal, or nonendodontic. It is important to repeat that such lesions frequently present with no overt signs or symptoms and may be detectable only radiographically (Fig. 3.10). A more detailed discussion of pathologic changes is given in Chapters 1 and 4.

Moving Superimposed Structures

Radiopaque anatomic structures often overlay and obscure roots and apices. Using special cone angulations, these radiopaque structures can be "moved" to give a clear image of the apex. The zygomatic process of the maxilla is one such structure[40] (Fig. 3.11, *A* and *B*). The mental foramen on the buccal surface of the mandibular basal bone can be positioned on radiographs to superimpose in the vicinity of the mandibular second premolar apex. In these instances, it can simulate apical periodontitis. Again, a horizontal shift of the beam angulation can separate the two structures for a better evaluation of the premolar apices (Fig. 3.11, *C* and *D*).

Locating Roots and Canals

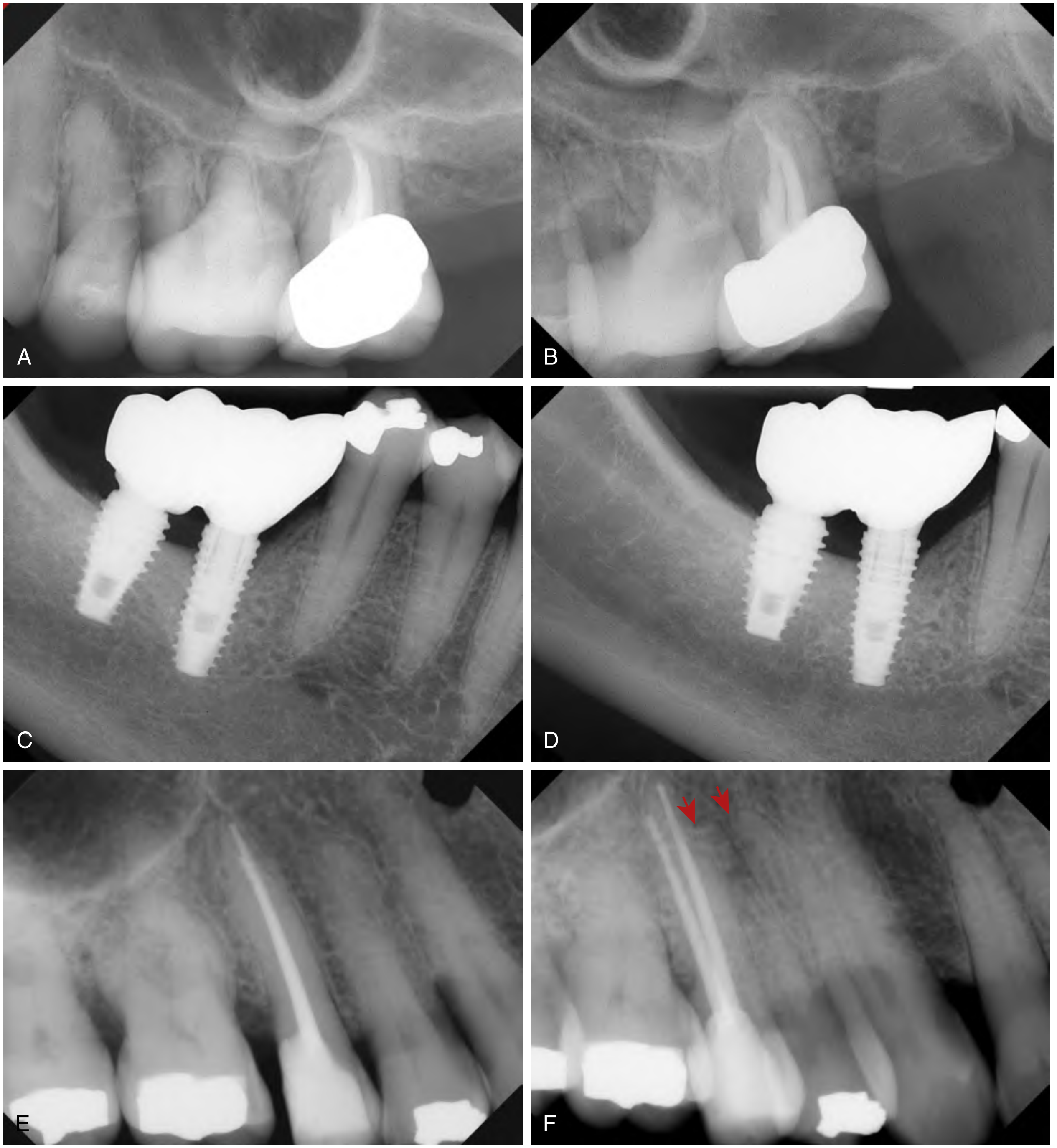
Canal location is obviously essential to success. Standard and horizontal beam-shifting techniques allow the practitioner to determine the position of canals either not located on a standard periapical image or possibly even missed during access (Fig. 3.11, *E* and *F*).



• **Fig. 3.10** This 60-year-old female patient presented with asymptomatic gingival swelling. There were no signs of pulpal disease on any of her radiographs. A lateral periodontal cyst is present in the #23/#24 interradicular bone.

Evaluating Treatment Progress

During endodontic treatment, "working" radiographs are needed usually with a dental rubber dam and clamp in place. These images are needed at various stages during the treatment phase. These include the (1) initial assessment of working length; (2) determining the working length; (3) fitting the master cone; and (4) evaluating the obturation made while the dental dam is in place



• **Fig. 3.11** **A**, The #14 palatal root apex is difficult to evaluate. **B**, By changing the horizontal angle by 20 degrees to the distal, the buccally positioned zygomatic process moves mesial (opposite the direction of the tube shift), and the palatal root can be evaluated better when isolated from the zygomatic process. **C**, Radiolucent area over the apex could be mistaken for pathosis. **D**, Pulp testing (vital response) and a more distal horizontal and increased vertical angulation show the radiolucency to be the buccal positioned mental foramen. With this distal angulation, the #29–#30 interproximal contact opens and the mental foramen moved more mesial and inferior to the #29 apex. **E** and **F**, The first premolar root outlines are not clear. By shifting the horizontal angle by 20 degrees to the distal, the outlines of the palatal and buccal roots are identified. The buccal root has moved mesially (opposite the direction of the tube shift), and the palatal root has moved distally (the same direction as the tube shift). Arrows point to the palatal and buccal apices. (Courtesy Dr. Jason Fowler, Loma Linda, CA.)

(intermediary fill radiograph), which creates problems in film placement and cone positioning. These radiographs are exposed during the treatment phase and the special tube-shifting technique applications discussed earlier in this chapter may then be necessary to accomplish diagnostic images.

Initial Assessment of Working Lengths

The distance from a reference point to the radiographic apex is determined precisely. This determination establishes the distance from the apex at which the canal is to be prepared and obturated[41] (Fig. 3.12).

Determining Working Length

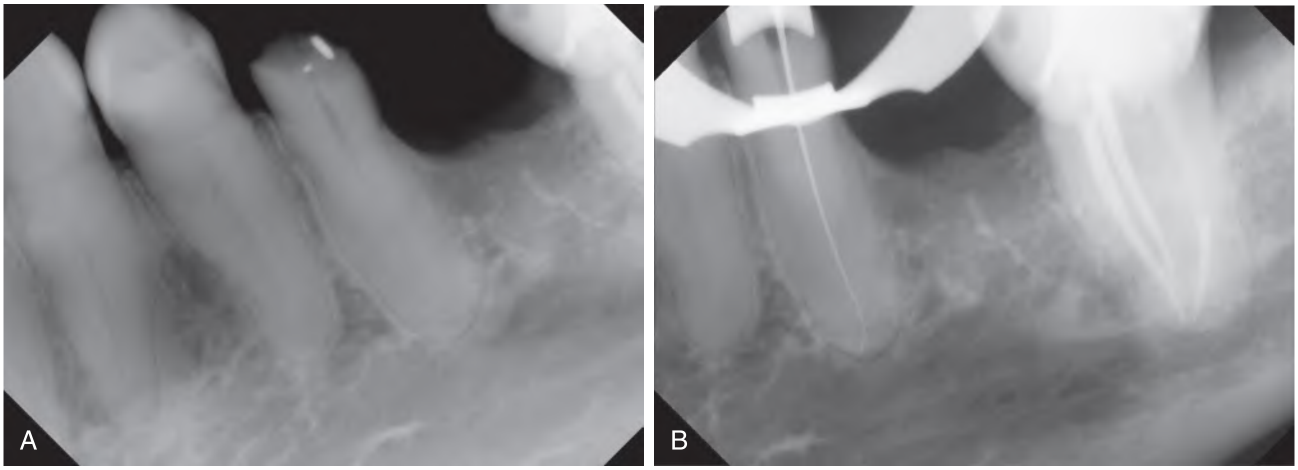
In general, establishment of working length should require only a single exposure. If a root contains or may contain two superimposed canals, either a mesial or distal angle projection is absolutely necessary; the straight facial view is not particularly helpful.[42] Additional working length radiographs may be required later for confirmation of working lengths to detect the presence or lengths of newly discovered canals or for reexposure if an apex has been cut off in the first radiograph. The length from the apex, density, taper, and outline of the root canal's shape are constantly evaluated with these images.

Master Cone

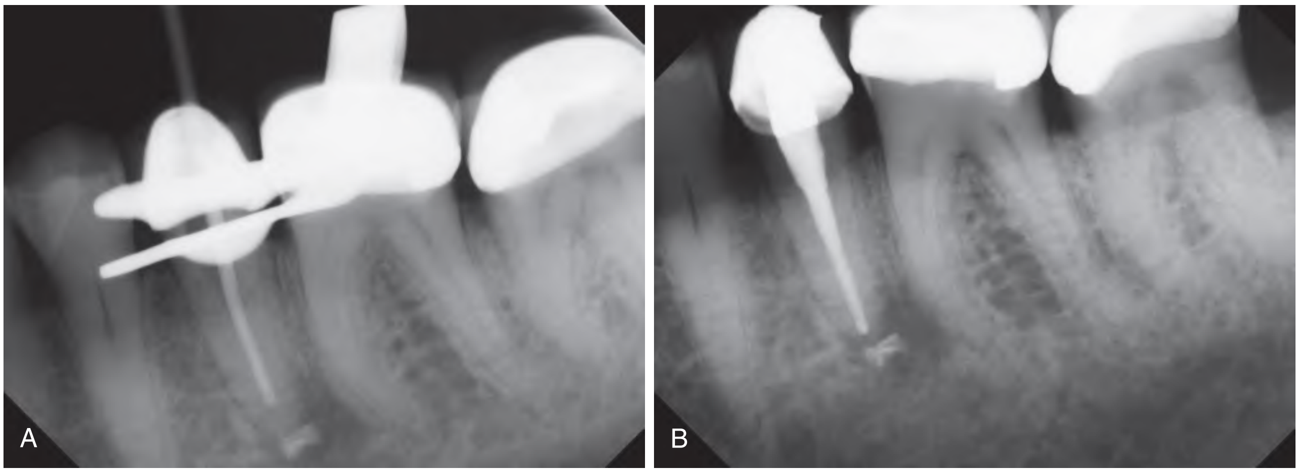
The same principles used with working length films apply. With proper technique, only one radiograph is necessary to evaluate the length of the master gutta-percha cone. The master cones should extend to, or very close to, the corrected working length (Fig. 3.13, *A*) Procedures for the fitting of master cones are discussed in Chapter 15.

Evaluating the Obturation (Intermediary Fill and Final Radiographs)

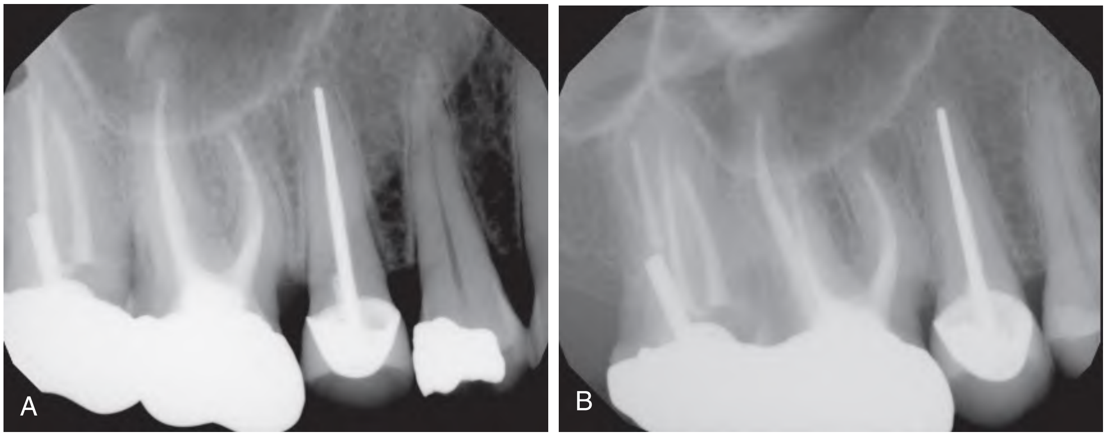
After canal obturation, postoperative radiographs provide considerable information on the general quality of obturation in terms of the overall density and presence of voids and quality of fill to the level of the apical foramen, which are determined from these radiographs (Fig. 3.13, *B*).



• **Fig. 3.12** **A,** An initial assessment of working length. Note the tip of the endodontic file and its distance relationship with the radiographic apex. **B** and **C**, The preliminary radiograph and then the working length assessment with the tip of the endodontic file at the radiographic apex. This particular tooth and the adjacent premolar have hypercementosis on the root. There is no contraindication to nonsurgical root canal therapy (NSRCT) in roots with this condition.



• **Fig. 3.13** Fitting of the master cone **(A)** and final obturation **(B)** evaluations



• **Fig. 3.14** **A**, On the 2-year posttreatment follow-up, healing is noted at the three apices of the first molar. **B,** The 6-year follow-up demonstrates a periapical lesion on the mesial buccal (MB) root. The patient did report mild, transient symptoms. The premolar and second molar continue to show no signs of recurrent disease in this 6-year time interval.

Follow-up of Treatment Outcomes

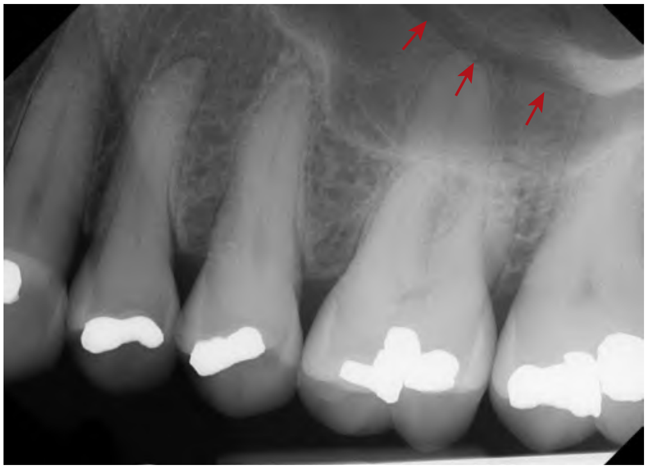
Ultimate success of treatment is verified at specified intervals of months or years after treatment. Generally, the first follow-up is done at 6 months, and then annually for 2 to 4 years until the final disposition of the treatment is determined. Because failure of endodontic treatment can occur before the development of signs or symptoms, follow-up radiographs are essential to evaluate the periapical status[43] (Fig. 3.14).

The same exposure and projection principles used for diagnostic and treatment-evaluation radiographs remain applicable to any of the follow-up or recall radiographs. Exposure factors typically follow the x-ray unit and sensor manufacturer's recommendations. However, these factors can always be tweaked, pending the preference of the clinician, so that the image quality is acceptable and that the exposure parameters do not exceed the recommended dose limits set by the state or any other regulatory agencies.

Pretreatment lesions should be healing or should have healed. In a successfully treated case, reestablishment of the PDL, lamina dura, and trabecular bone is expected to reestablish apical health (Fig. 3.14, *A*). However, if the treatment is deemed to be questionable (missed canals, inadequate fill, root fracture, etc.) or if there is disease recurrence (Fig. 3.14, *B*), additional angled radiographs may become necessary.

Determining Root and Pulpal Anatomy

Determining the anatomy involves not only identifying and counting the roots and canals, but also identifying unusual adjacent anatomy (Fig. 3.15) or anomalous tooth anatomy, such as dens invaginatus and a C-shaped configuration,[44] and determining curvatures, canal relationships, and canal location.[45,46]



• **Fig. 3.15** The curvilinear radiolucent structure adjacent the molar roots and within the superimposing the sinus lumen *(red arrows)*, is the anomalous presence of the posterior superior alveolar canal that courses its way anteriorly in the lateral wall of the maxillary sinus. The presence of this structure on periapical radiographs is dependent on numerous factors in the patient's anatomy and the projection angle of the x-ray beam. If seen unilaterally, it should not be misinterpreted as pathologic.

Cone Beam Computed Tomography

Equipment and Principles for 3D Image Capture

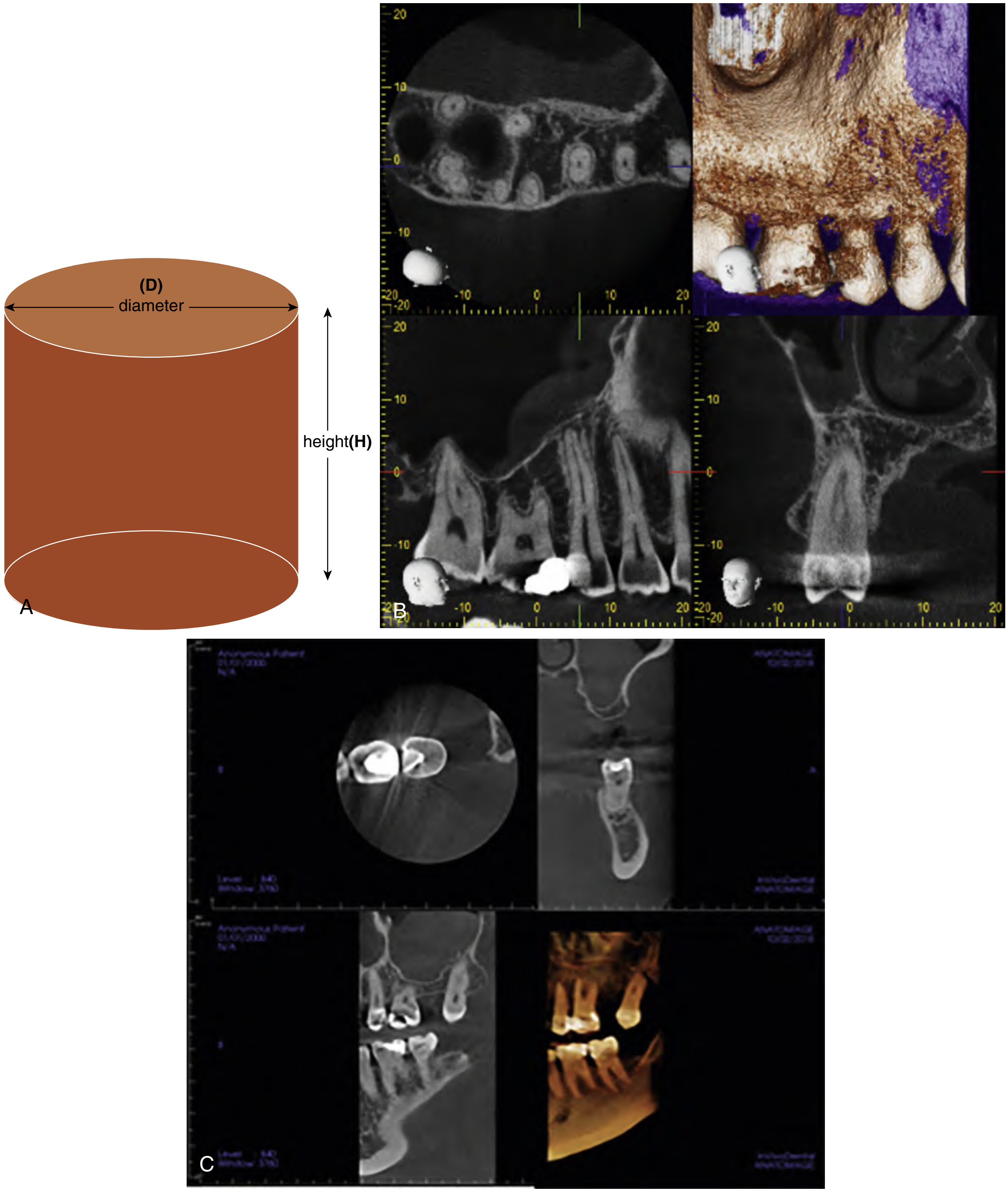
CBCT was introduced two decades ago as a new dental technology for the 21st century[47,48] that has certainly had a dramatic and highly positive effect on endodontic care. The dental marketplace is very competitive, with new units and complementary software programs continuously being developed for CBCT applications in endodontic, other specialty, and general dentistry patient care. Except for the size of the receptor opposite the x-ray tube, CBCT units look similar to panoramic x-ray machines (Fig. 3.16).

• **Fig. 3.16** An example of a cone beam computed tomography (CBCT) unit with small field of views (FOVs) more typically used for endodontic evaluations. Note the flat panel detector *(red arrow)* on the left side of the gantry opposite the x-ray tube head. Veraview X800. (Courtesy J. Morita USA, Inc., Irvine, CA.)

Field of View

The size of the scanned object volume is called the field of view (FOV). The FOV for CBCT units with a flat panel detector is a cylindrical shape. The CBCT scanning controls are programmed to scan FOVs within the limits of the size of the flat panel as determined by the manufacturer. The dimensions of a flat panel detector's FOV are expressed by the height of the cylinder (H) and the diameter of the base (D) (Fig. 3.17, *A*).

The FOV is a very flexible option in contemporary scanners. The range of commercially available FOVs for flat panel detectors can be



• **Fig. 3.17** **A**, Cylindrical shape of the field of view (FOV) for cone beam computed tomography (CBCT) units with flat panel detectors. **B**, 40 mm × 40 mm FOV multiplanar image reconstruction. **C,** 40 mm × 80 mm FOV multiplanar image reconstruction.

from 30 mm (D) × 30 mm (H) to 240 mm (D) × 165 mm (H). For endodontic purposes, the smaller FOV options are typically used. These smaller FOVs are dependent on the size of the detector units but typically range from 40 mm × 40 mm (three to five teeth in one jaw arch) to 40 mm × 80 mm (which will include similar numbers of maxillary and mandibular teeth (Fig. 3.17, *B* and *C*). Although these larger FOVs are available, they are more expensive and not really indicated for the smaller field sizes needed for endodontic purposes. Smaller FOV units which image three to five teeth in a jaw (maxilla or mandible) are therefore the preferred FOV for endodontic evaluations. The area covered in these smaller volumes is adequate for a thorough 3D periapical evaluation of the selected teeth, alveolar bone, and the limited amount of maxillary or mandibular basal bone. Flat panel detectors are the most used detector for CBCT units.

Voxel Size and Bit Depth

Voxel size and bit depth are two components of CBCT imaging not germane to standard intraoral imaging. Voxels are the cubic-shaped elements that store the 3D object density information in the volumetric data. The smaller the voxel size at which the object is scanned, the higher the resolution of the object. Due to the indications for endodontic CBCT imaging (early-stage apical periodontitis, vertical root fractures [VRF], complex root anatomy, etc.), smaller voxel sizes are preferred. Voxel sizes for endodontic reasons are typically in the range of 0.075 mm^3 (75 µm) to 0.125 mm^3 (125 µm). Most other CBCT applications do not require this degree of resolution. For these other indications (implants, large pathologic lesions, etc.), voxel sizes are in the range of 0.20 mm^3 (200 um) to 0.40 mm^3 (400 µm). Although voxel sizes less than 0.075 mm^3 (75 µm) are possible, there is an increase in image graininess that offsets the benefit of the increased resolution.

Because smaller voxel sizes provide more density information of the object, the radiation exposure needs to be higher to generate adequate x-ray photons for the greater number of smaller voxels in the volumetric data. Intuitively, more x-ray photons in the radiation beam are needed to provide the signal to the greater number of smaller voxels that compose the volumetric data of the object. The scan time will be longer, and the frame rate of basis image capture will be higher. This increase in the frame rate causes an increase in the radiation dose for small FOV scans. Consequently, although the radiation dose for endodontic CBCT scans is lower due to the smaller FOV, this dose-lowering is offset by the greater radiation dose needed when the smaller voxel sizes are employed. This paradox with respect to voxel size explains the large dose range for small FOV scans (Table 3.1). It also explains the dose overlap of small FOV scans with the intermediate and large FOV scans. Large FOV scans have a larger dose due to the larger body part being scanned. The option of large FOV scans with small voxels sizes are not typically a setting on CBCT units. The higher frame rate, processing time, RAM, and storage memory are beyond the capacity of larger commercially available CBCT units.

Another property of the image detector is the bit depth. The bit depth is an exponential binary property expressing the total number of gray shades the detector is able to discriminate. A 16-bit detector (i.e., 2^{16}) can display 65,536 shades of gray. The range of bit depth of commercial CBCT units is between 12 and 16 bits (4096 and 65,536 shades of gray), indicating the wide range of contrast discrimination capability. Although the detector is capable of this degree of gray scale discrimination, limiting features to the contrast resolution include the lower bit depth of the imaging software and the monitor display, and the eye perception of the viewing clinician. Even though bit depth is important for contrast resolution, the American College of Radiology has concluded that there is no added benefit to diagnostic interpretations by the use of higher than 8-bit depth in the viewing computer's operating system.[49]

Volumetric Data and Projection Data

During a CBCT scan, image capture software, usually proprietary to each machine manufacturer, will capture multiple "basis" images at the various angles in the scan rotation. The number of basis images per scan ranges from 300 to 600 images. The complete set of basis images is called the *projection data*, which is then used by the software to construct a 3D volumetric data set. This processed data is then accessed by image reconstruction software programs to "construct" the primary multiplane images or multiplanar reconstructions (MPR) for display, as previously seen in Fig. 3.17, *B* and *C*. The MPRs are often derived from the proprietary software that comes with the particular CBCT scanner. However, because of the versatility of independent "third-party" imaging software to also construct multiple kinds of secondary reconstructions (panoramic, temporomandibular joint, implant planning, etc.), clinicians may prefer to view the scan data in these other software programs. Third-party imaging software is software not associated with the capture and proprietary software of the CBCT scanner. Currently, a variety of third-party software programs are commercially available for image reconstruction of CBCT volumetric data sets. Some examples are listed in Table 3.2.

Image File Format

If third-party software is being used, the file format of the volume set must be converted from the proprietary file format or file language to a more universal or common digital file format. This common digital file format must conform to the Digital Imaging and Communications in Medicine (DICOM) standard (National

TABLE 3.2 Third-party software available for imaging DICOM CBCT data sets

Software	Manufacturer
NobelClinician	Nobel Biocare USA, LLC Yorba Linda, CA
CareStream 3D	CareStream Dental Rochester, NY
Dolphin 3D	Dolphin Imaging Chatsworth, CA
InVivoDental	Anatomage Inc. San Jose, CA
OnDemand3D	Cybermed Inc. Irvine, CA
OsiriX	Pixmeo SARL Berne, Switzerland
Xelis™ Dental	Infinitt NA, Phillipsburg, NJ

Electrical Manufacturers Association [NEMA] Standard PS3 2018, i.e., the current DICOM standardized file format.)[50] This format is the International Organization for Standardization (ISO) referenced standardized digital file format for medical images and related information (i.e., ISO 12052.) To facilitate access to health care, multiple imaging modalities used in medicine and dentistry (x-ray, visible light, ultrasound, etc.), all must be compliant with ISO 12052.

Scatter and Beam Hardening Artifacts

During image reconstruction of a data set, dense metal structures in the FOV often cause scatter and beam hardening artifacts on the image reconstructions. Gutta-percha and silver point endodontic filling materials, cement overfills, metal posts, silver amalgam, dental implants, and metal alloys used in coronal restorations all create artifacts that present either as light or dark scatter lines (streaking), or as a dark periphery adjacent to metallic borders (beam hardening). The streaks often superimpose regular anatomy and significantly degrade image quality. The main types of beam hardening are the dark streaks or the dark bands that present adjacent radiopaque restorations in the image reconstructions. The latter often simulates disease, such as recurrent caries or fractures in endodontically treated teeth (Fig. 3.18, *A* and *B*). In other instances, beam hardening can also give the illusion of extra root canals, which, if not properly interpreted, can lead to inappropriate endodontic treatment (Fig. 3.18, *C*–*E*).

These artifacts are prominent problems for dental applications with CBCT as root canal treatment (RCT) fillings and coronal metallic restorations are often within the FOV of most dental and endodontic patient CBCT scans. The metallic restorations then cause the resultant beam hardening and streak artifacts, which then compromise the image quality. To repeat, the examples in Fig. 3.18 illustrate how harmful these artifacts are at degrading image quality and making image assessments very difficult.

Software correction algorithms that minimize these metallic artifacts have been reported.[51,52] However, they have not been demonstrated to be any more beneficial than noncorrected software programs when evaluating peri-implant and periodontal disease[53] or root fractures.[54] Differences in root fill materials also have no effect on minimizing the effects of these artifacts.[55] Consequently, there are no immediate methods to correct or minimize these prominent artifacts. The best way to avoid streaking and beam hardening is to try to keep the FOV as small as possible in an attempt to minimize the number of metals within the scan's FOV.

Indications and Special Applications

The American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR) wrote a joint position paper in 2011.[56] They made several evidence-based guidelines for CBCT use in endodontic patient care. This joint position paper was subsequently updated in 2015,[57] and the key recommendations from this latest publication are outlined in the remainder of this chapter.

1. 2D Imaging remains the initial imaging procedure of choice

Endodontic diagnosis depends on evaluation of the patient's chief complaint, the medical and dental history, and the clinical and radiographic examination. According to these AAE/AAOMR recommendations, 2D intraoral imaging remains the imaging procedure of choice for these initial evaluations and most endodontic imaging needs (Recommendation 1).

Only if the 2D evaluation leaves the diagnosis or the treatment in question does CBCT with its advanced capabilities become indicated. These situations will arise as 2D radiographs have inherent limitations due to the manner in which anatomic structures in three dimensions are compressed onto a 2D image. Interpreting 2D images continues to be a somewhat subjective process. Goldman et al.[58] showed that the agreement between six examiners was only 47% when evaluating healing of periapical lesions using 2D periapical radiographs. In a follow-up study, Goldman et al.[59] also reported that when examiners evaluated the same images at two different times, they had only 19% to 80% agreement with their previous interpretations. Agreement among six observers for detecting periradicular radiolucencies with 2D digital images was less than 25%; whereas the agreement for five of six observers was approximately 50%.[60] Several studies have shown where CBCT overcomes many of the 2D imaging limitations.[61-67]

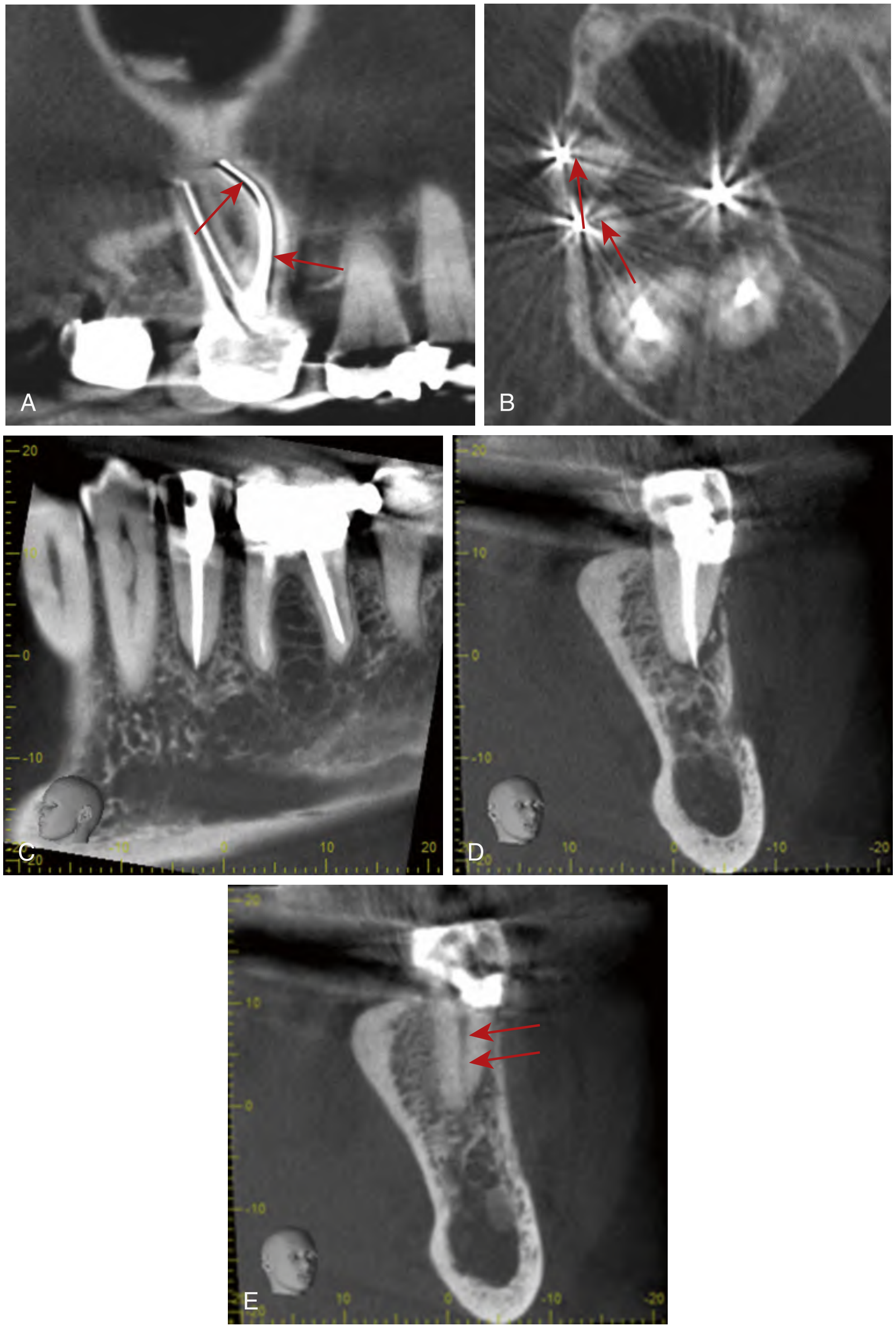
2. Limited FOV CBCT is indicated for cases with contradictory or nonspecific clinical signs and symptoms associated with endodontically untreated or previously treated teeth

This indication is the main premise of AAE/AAOMR Recommendation 2. CBCT imaging has the ability to detect periapical pathology before it is apparent on 2D radiographs[68] (Fig. 3.19). This capability was validated in clinical studies in which the sensitivity of detecting apical periodontitis on intraoral radiographs versus CBCT images was 20% and 48%, respectively.[69] Ex vivo studies in which simulated periapical lesions were created showed a similarly greater CBCT sensitivity than did intraoral radiography.[70,71]

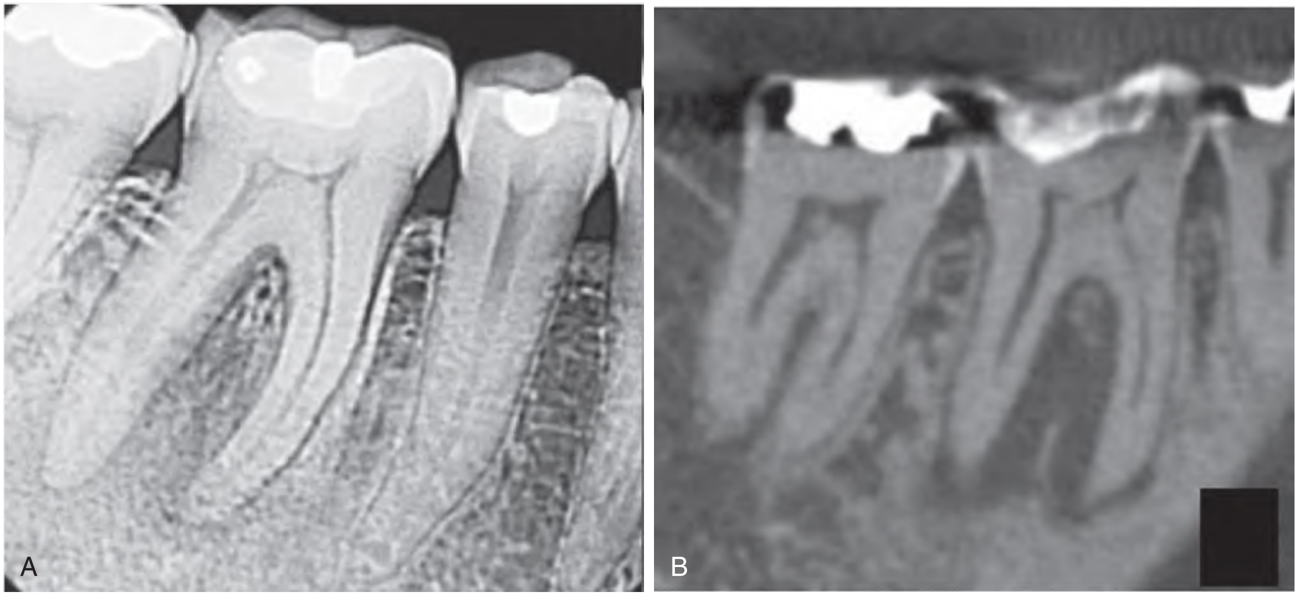
The inability to determine the etiology of persistent dentoalveolar pain can be attributed to the limitations in both clinical vitality testing and intraoral radiography. Atypical odontalgia (AO) is a persistent dentoalveolar pain without the evidence of periapical bone destruction.[72] The diagnostic yield of CBCT compared with intraoral radiographs was 17% greater in definitively diagnosing apical periodontitis from suspected AO.[73]

3. Limited FOV CBCT should be considered the imaging modality of choice for initial treatment of teeth with the potential for extra canals and suspected complex morphology

The efficacy of CBCT as a modality to accurately explore tooth anatomy and identify the prevalence of extra or atypical canals is the premise of Recommendation 3. The greater sensitivity at identifying a second mesiobuccal canal (MB2) in maxillary molars with CBCT in comparison with the gold standard (clinical and histologic sectioning) has been well documented.[74,75] Fig. 3.20 demonstrates a recurrent case of apical periodontitis in a maxillary first molar initially diagnosed and treated with periapical imaging. The recall radiograph with the persistent disease is seen in Fig. 3.20, *A*. Fig. 3.20, *B*–*D* demonstrates the MB2 canal in the multiplanar reconstructions. The MB2 was not seen when tooth #14 was diagnosed and treated with periapical radiographic imaging. The final postoperative periapical radiograph Fig. 3.20, *E* shows the obturated MB1 and MB2 canals.



• **Fig. 3.18** Beam Hardening Artifact and Streaking Adjacent the #5 Root Canal Treatment (RCT). **A**, Parasagittal reconstruction with beam hardening artifact adjacent the #3 MB RCT. **B**, Radiolucent and radiopaque streak artifact radiates from the #3 MB and #3 DB root fills. Note how the former often simulate fracture lines *(arrows)*. **C**, Parasagittal reconstruction evaluating the persistent pain on #20. **D**, Cross-section of #20 oriented through the root canal filling. Note the fill overextension and the ~2.0 mm widening of the apico-buccal periodontal ligament (PDL) that is not apparent on 2D imaging. **E**, Cross-section of #20 oriented between the root canal filling and the distal proximal surface. Note the beam hardening artifact of the RCT filling that simulates a second unfilled canal.



• **Fig. 3.19** This patient presented with pain to percussion and no response to cold testing on #30. Periodontal probing depths were within normal limits. Root canal therapy was indicated based on the cone beam computed tomography (CBCT) radiographic findings and the clinical tests. **A,** Periapical radiograph of tooth #30. **B,** 2D parasagittal CBCT reconstruction. The periapical radiolucency is better delineated demonstrating involvement of the furcation and both the mesial and distal root periapices.

CBCT showed higher mean values of specificity and sensitivity in comparison with intraoral radiographic assessments in the detection of the MB2 canal.[76]

4. Limited FOV CBCT should be used for the detection of VRF
A thorough dental history, pain symptoms, clinical signs of swelling, a sinus tract, and/or an isolated deep periodontal pocket are suggestive of a VRF. Radiographically, a combination of a periapical and a lateral root radiolucency "halo" (or J-shaped) appearance is also suggestive of VRF. Any combination of these clinical and radiographic findings may be present to establish a presumptive diagnosis of VRF.[77] The following five CBCT findings were found to be consistent in confirmed cases of VRF[78]:

1. Loss of bone in the midroot area with intact bone coronal and apical to the defect
2. Absence of the entire buccal plate of bone in MBR
3. Radiolucency around a root where a post terminates
4. Space existing between the buccal/or lingual plate of bone and fractured root surface
5. Visualization of the VRF on the CBCT multiplanar views.

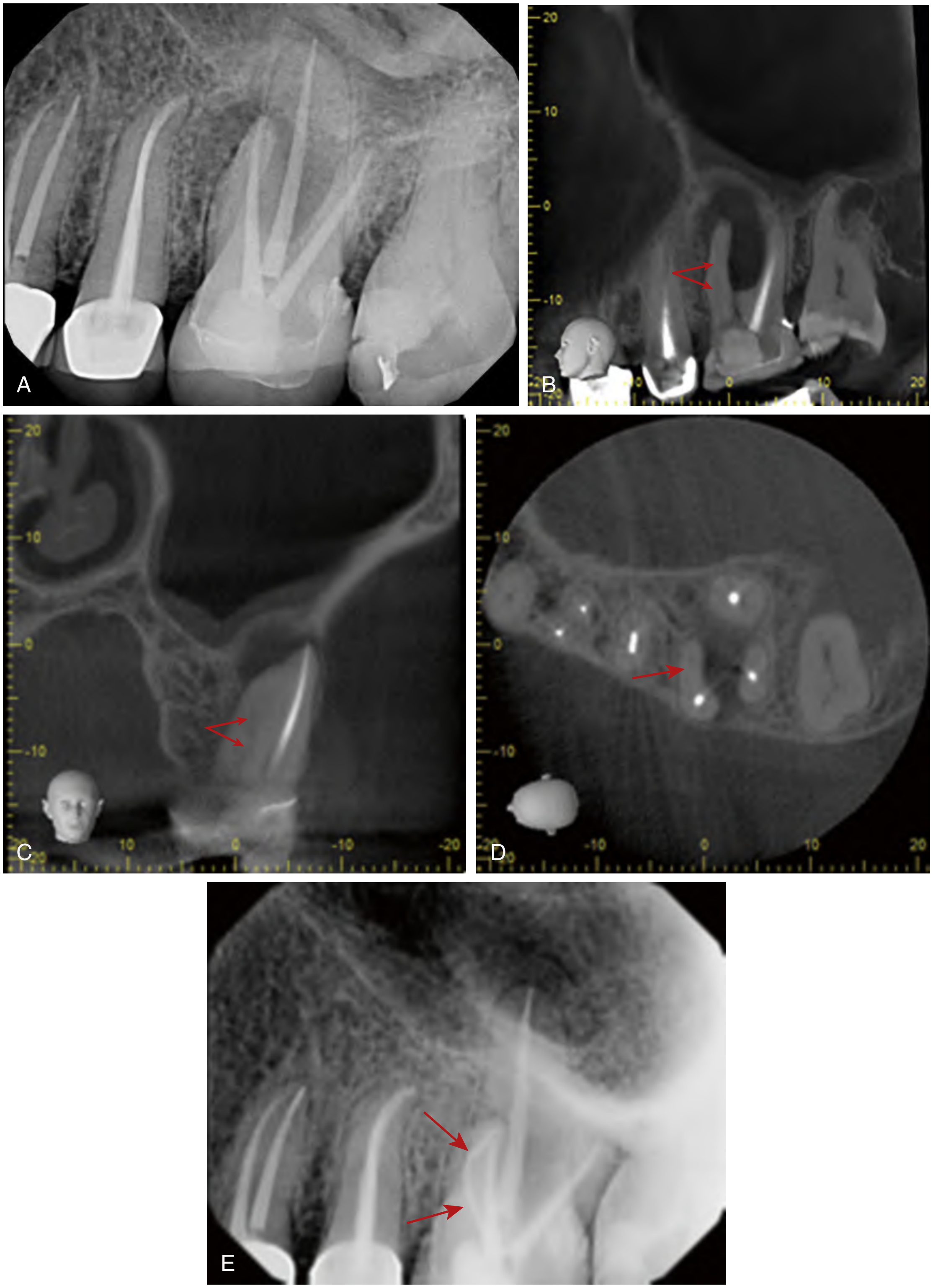
Fig. 3.21 shows an example of the sensitivity of CBCT in detecting a VRF. The application of a dye during surgical exploration is still the gold standard for VRF diagnosis.[79]

Several studies have demonstrated the validity of using CBCT to detect VRFs when 2D imaging is inconclusive (Recommendation 6). In a study comparing the sensitivity and specificity of CBCT with those of 2D radiography in detecting VRF, the sensitivity and specificity were 79.4% and 92.5%, respectively, for CBCT and 37.1% and 95%, respectively, for 2D imaging.[80] This same study reported that the specificity of CBCT was reduced in the presence of root canal filling material.[80] Higher sensitivity and specificity were observed in a clinical study in which the definitive diagnosis of VRF was confirmed at the time of surgery to validate CBCT findings, with sensitivity being 88% and specificity 75%.[81] In vivo and laboratory studies[82-83] evaluating CBCT in the detection of VRF agreed that sensitivity, specificity, and accuracy of CBCT were generally higher and reproducible. The detection of fractures was significantly higher for all CBCT systems compared with that of intraoral radiographs.

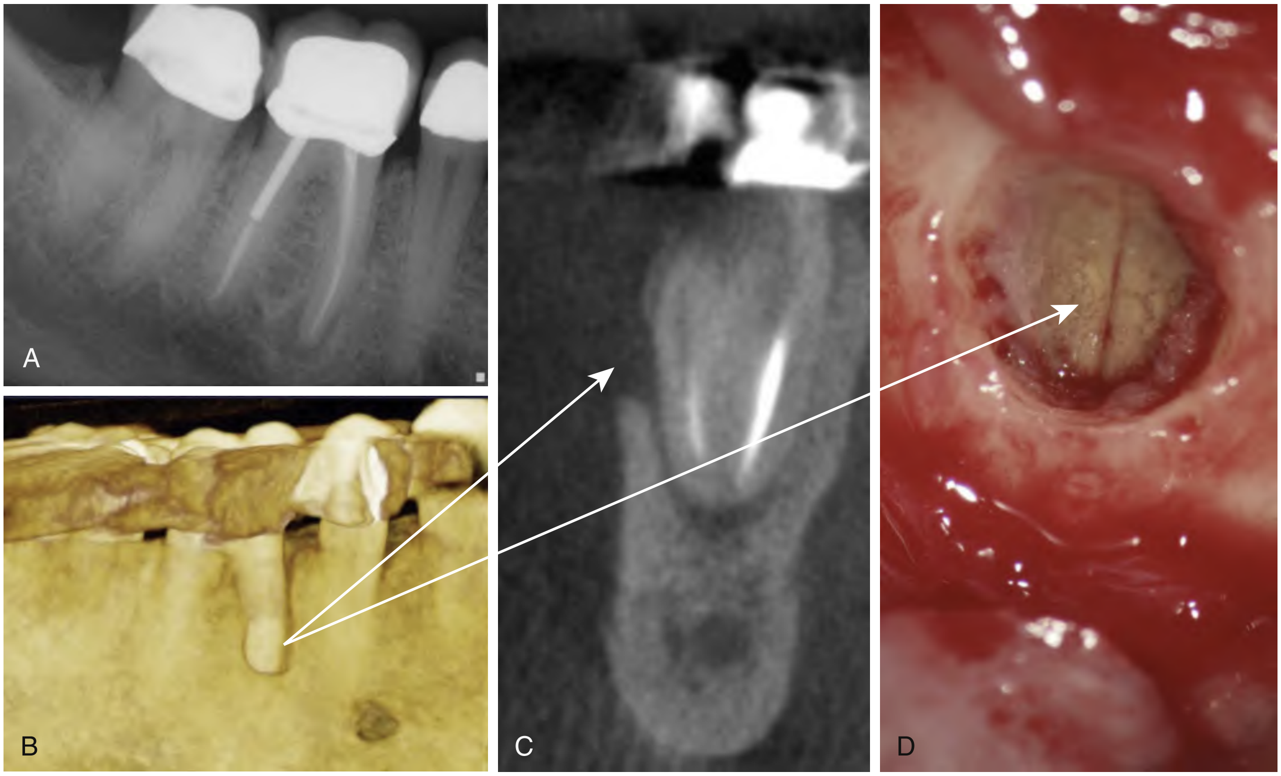
However, any radiographic assessment of fracture must be interpreted with caution because the detection of VRF is dependent on the size of the fracture and the spatial resolution (voxel size) of the CBCT.[84] Consequently, this affects the sensitivity in not being able to detect a fracture that may actually be present (false negative finding). The beam hardening and streaking artifacts discussed previously also make it difficult to discern these VRF, either by obscuring or by simulating fracture lines. The former may also contribute to a false negative finding. The latter would affect the specificity and lead to a false positive finding if in fact a fracture was not present. These VRF diagnostic dilemmas come to light more often in teeth with posts because these teeth have more potential for root fracture and the metallic posts and metallic coronal restorations contribute to the streaking artifact, which would then affect both the sensitivity and the specificity of VRF diagnosis.

5. Utilization of Limited FOV CBCT in non-surgical retreatment, surgical treatment planning, assessment of endodontic treatment complications or retreatment of treatment complications:
Accurate diagnostic data leads to better treatment decisions and potentially more predictable outcomes.[85] The use of CBCT has been recommended for treatment planning of endodontic surgery (Recommendation 7).[86-88]

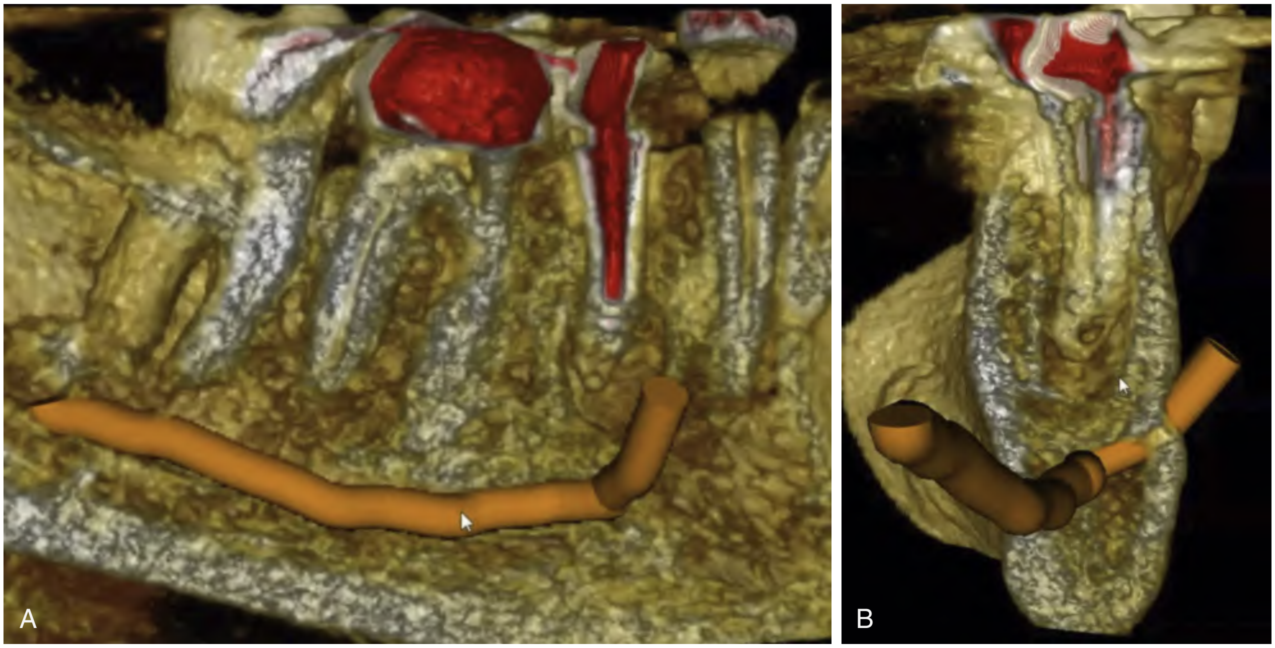
CBCT was a more accurate imaging modality for the diagnosis and subsequent treatment planning of endodontic pathology compared with the diagnosis and treatment decisions using only periapical radiographs. An accurate diagnosis was reached in 36.6% to 40% of the cases when using periapical radiographs in comparison with 76.6% to 83.3% of the cases when using CBCT.[89] This high level of misdiagnosis is potentially clinically relevant, especially in cases of invasive cervical root resorption and VRF, when a lack of



• **Fig. 3.20** **A**, A follow up 2D periapical image on #14 demonstrates recurrent apical periodontitis. **B–D**, The sagittal, coronal, and axial cone beam computed tomography (CBCT) reconstructions further document the recurrent #14 apical periodontitis and the unfilled palatal canal in the mesiobuccal root (MB2). **E**, The 2D periapical image of the retreatment demonstrates the filled MB2 canal (see *arrows*). (**A,** Courtesy Dr. Janelle Silvers, Redlands, CA; **E,** Courtesy Dr. Janelle Silvers, Redlands, CA.)



• **Fig. 3.21** **A**, Periapical radiograph of tooth #30; **B**, 3D reconstruction demonstrating midroot buccal plate fenestration of the mesial root. **C**, 2D coronal reconstruction demonstrating the midroot buccal fenestration *(arrow)*. **D**, Surgical curettage and degranulation of the defect demonstrating the mesial root's vertical fracture *(arrow)*.



• **Fig. 3.22** **A**, 3D rendering demonstrating the relation of the inferior alveolar nerve (IAN) to the periapical defect at the #29 periapical lesion. **B**, A cropped 3D coronal rendering demonstrating the mental foramen and the IAN in relation to the base of the periapical defect *(arrow)*. Note the apical root resorption.

early detection could lead to unsuccessful treatment and tooth loss. The previous study also demonstrated that the treatment plan may be directly influenced by information gained from CBCT studies as the examiners altered their treatment plan after viewing the CBCT scan in 56.6% to 66.7% of the cases overall (Recommendation 8). This high number indicates that CBCT had a significant influence on the examiners' treatment plan.

6. Use of limited FOV CBCT to localize root apex/apices and to evaluate the proximity to adjacent anatomic structures

CBCT visualization of periapical disease proximity to vital structures and anatomic landmarks is superior to that of periapical images. Therefore it is recommended for surgical treatment planning where such proximity is suspected (Recommendation 9). Figs. 3.22 and 3.23 exemplify the use of CBCT

• **Fig. 3.23** **A**, Periapical radiograph of tooth #30. This tooth was referred for periapical surgery after nonsurgical retreatment was unsuccessful. An untreated third distal canal was identified and treated, and the mesial canals were blocked. **B**, Cone beam computed tomography (CBCT) coronal reconstruction of #30 mesial root demonstrating the communication of the periapical defect with the inferior alveolar canal. **C**, Surgical view of the mesial root apex after curettage and degranulation of the defect. The inferior alveolar nerve was uncovered immediately inferior to the base of the defect *(white arrow)*. **D**, Axial and coronal views of tooth #30 at the 24-month recall demonstrating complete remodeling of the defect and restoration of the surgically defect in the buccal cortical plate.

• **Fig. 3.24** This patient was referred for evaluation and treatment of an internal resorptive defect on #21. **A**, Parasagittal view of tooth #21 demonstrating the external/internal resorptive defect. **B**, Cross-sectional view of tooth #21 also demonstrating the external/internal resorptive defect. **C**, 3D reconstruction of the resorptive defect. In addition to the resorptive defects, images **(B)** and **(C)** demonstrate a buccal root perforation *(white arrow)*. This cone beam computed tomography (CBCT) finding rendered tooth #21 nonrestorable, and this changed the endodontic treatment plan.

imaging in surgical treatment planning of cases with proximity to vital structures.

7. Use of CBCT in endodontic diagnosis and detection of resorptive defects

Diagnosis and detection of root resorption is often challenging owing to the quiescent onset nature and varying clinical presentation. Because CBCT is a better imaging option than periapical imaging for resorptive defects,[90,91] it is the AAE/AAOMR Recommendation 12. There is now a 3D classification for external cervical resorption (ECR) that takes into account lesion height, degree of circumferential spread, and proximity to the root canal.[92] This novel and clinically relevant classification that relies on CBCT better facilitates the objective description of ECR progression or resolution. It is also expected to facilitate effective communication of ECR between colleagues. Fig. 3.24 shows an example where CBCT imaging facilitated the diagnosis and treatment planning of inflammatory resorptive defects.

8. Use of CBCT in endodontic diagnosis and detection of traumatic dental injuries (TDI)

Radiographic assessment is important to identify the location, type, and severity of TDI. In the 2012 International Association of Dental Traumatology guidelines,[93] a series of periapical radiographs from different angulations and an occlusal film are recommended for evaluation of TDI. However, 2D imaging has limitations in the evaluation of TDI due to projection geometry, magnification, superimposition of anatomic structures, distortion, and projection errors. The use of CBCT for TDI is now a recommendation of the AAE/AAOMR (Recommendation 11), particularly traumatic or horizontal root fractures (HRFs) and lateral luxations, for monitoring of healing and or any related complications.

In the diagnosis of HRF using 2D imaging, the fracture line will be detected only if the x-ray beam passes directly through it. The 2D nature limits the accuracy in the diagnosis of the location, severity, and extent of HRF. The risk of misdiagnosis of the location and extent of the fracture by using only 2D intraoral radiography could lead to improper treatment and an unfavorable outcome. Because of the limitations of intraoral radiography, CBCT was suggested as the preferred imaging modality for diagnosis of HRF.[94]

CBCT overcomes several of the limitations of 2D imaging by providing a considerable amount of 3D information about the nature and extent of the HRF. The significant difference in the nature of HRF when assessed with 2D radiographs compared with CBCT has been reported.[95] Fig. 3.25 demonstrates a case where CBCT imaging is advantageous in the diagnosis, prognosis, treatment planning, and treatment follow-up of an HRF case.

• **Fig. 3.25** A 15-year-old patient with a history of trauma to the anterior maxilla was referred for consultation of teeth #8 and #9. Tooth #8 had a grade I mobility and tooth #9 had a grade II+ mobility. **A**, Periapical radiograph of teeth #8 and #9 demonstrated midroot horizontal root fractures in both teeth. Periodontal probing depths were within normal limits. The marginal and attached gingiva demonstrated normal color and architecture. **B** and **C** are the sagittal views of teeth #8 and 9, respectively. Note the oblique nature of the root fractures and bone fill between the coronal and apical segments in **(C)**. Because the patient was asymptomatic and cone beam computed tomography (CBCT) revealed no periradicular pathosis, a palatal splint was suggested to address the mobility, but no endodontic intervention was recommended at the time.

Study Questions

6. In CBCT scanning, generally the smaller the voxel size, the __________ the image resolution.
   a. darker
   b. higher
   c. lower
   d. worse
7. "Beam hardening" effects seen on CBCT reconstructions
   a. Occur when the mA settings are high
   b. Compromise diagnostic image quality
   c. Improve the outlines of endodontic treated canals
   d. Occur less with restorative materials in the FOV
8. The AAE/AAOMR joint position paper on the CBCT applications for endodontic patient care is highly valued because:
   a. Many endodontists follow the recommendations.
   b. The recommendations are evidence based.
   c. The use of CBCT images can shorten the duration of RCT treatment.
   d. CBCT images are the most definitive for posttreatment follow up evaluations.
9. The imaging procedure of choice for most endodontic evaluations is:
   a. Limited CBCT FOV with a large voxel size
   b. Periapical intraoral imaging
   c. Any size CBCT FOV with high resolution
   d. The procedure favored by the treating endodontist
10. Consistent CBCT findings for a VRF include all of the following EXCEPT:
    a. Loss of bone at the mid root level with intact bone apical and coronal to the defect
    b. Apical radiolucency around a root with a restorative post
    c. Absence of cortical bone in the 3D multiplanes
    d. Actual visualization of the VRF in the CBCT multiplanes
11. CBCT is a preferred imaging modality for evaluating
    a. HRF
    b. Carious dental lesions approaching the pulp
    c. Posttreatment recalls of more than 5 years
    d. All maxillary first molars in need of endodontic treatment

ANSWERS

Answer Box 3

1 d. Stochastic
2 a. Smaller area for image capture
3 a. Are more durable
4 b. Increase biorisk to the radiographer
5 d. Technique used to localize the buccal and lingual position of objects
6 b. Higher
7 b. Compromise diagnostic image quality
8 b. The recommendations are evidence based
9 b. Periapical intraoral imaging
10 b. Apical radiolucency around a root with a restorative post
11 a. HRF

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