Radiology in Endodontics

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KEYWORDS

- Endodontic radiology • Root canal treatment • Periapical radiograph
- Cone-beam computed tomography • CBCT

KEY POINTS

- Periapical radiographs are the most commonly used modality in Endodontics. The paralleling technique is preferred.
- Angulated radiographs are frequently used to identify superimposed objects or fractures. The SLOB rule (same lingual opposite buccal) is a standard technique.
- Cone-beam computed tomography is increasingly used in Endodontics. Its benefit derives from the ability to provide 3-dimensional image volumes.

INTRODUCTION

Radiography is an integral part of Endodontics. Radiographs are used for prevention, diagnostics, therapy, and follow-up. Shortly after Dr Otto Walkhoff took the first dental radiograph of his teeth in 1895, Dr Edmund Kells first determined endodontic working length by using dental x-rays in 1899, and in 1900, Dr Weston Price first suggested the use of radiographs to evaluate the adequacy of root canal fillings.

Periapical radiographs are the most frequently used type of radiographs for endodontic treatment. Bitewing radiographs are often taken to evaluate restorability before initiating treatment or to check for coronal leakage and decay. Occlusal and lateral cephalometric radiographs are used after dental and facial trauma to identify root or alveolar fractures by providing additional views compared with periapical or panoramic radiographs. The introduction of cone-beam computed tomography (CBCT) provides a 3-dimensional (3D) assessment of oral structures. It is now widely used in addition to periapical radiographs or instead of some traditional imaging techniques, such as occlusal radiographs.

This article provides a practical guide for the most common clinical applications for radiology in Endodontics, focusing on digital periapical radiographs and CBCT imaging.

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PERIAPICAL RADIOGRAPHS

Periapical radiographs are a type of 2-dimensional (2D) radiograph imaging, arguably the most important and widely used radiographic technique in Endodontics. For decades, conventional films had been used until the modern digital era in dental radiography started with the introduction of the RadioVisioGraphy system in 1989.[1] The digital systems rely on electronic detection of an radiograph-generated image processed and then reproduced on a computer screen. Various digital imaging modalities are currently available.

Digital radiography is firmly established as an indispensable diagnostic tool in endodontic practice. It demonstrated to be an excellent asset for Endodontics because of the number of radiographs indicated before, during, and after an endodontic procedure. Its benefits include a significant reduction in overall radiation dosage, increased speed of obtaining high-resolution digital images, the possibility of digital enhancement and ease of transmissibility, the elimination of manual processing steps and chemical waste, as well as digital data storage. The introduction of digital radiography allowed for a variety of image enhancements and modifications, including inversion, contrast, flashlight, magnification, pseudo colors, and digital measurements of root lengths and curvature angles.[2]

However, periapical radiographs have limitations because of the 2D nature of the images produced, geometric distortions, and anatomic noise. A 2D projection of a 3D object can only provide suggestive and not final evidence in judging a clinical problem.[3] The most common clinical problem is the difficulty of assessing any buccolingual dimensions, which can only be indirectly assessed by periapical radiographs through eccentric radiographs. Also, the bacterial status of hard and soft tissues cannot be determined, and inflammatory tissues cannot be differentiated from healed fibrous scar tissue. Last, radiographs do not provide information about the true nature of the tissue that replaced the bone. Abscesses, granulomas, or cysts resemble radiographically identical osteolytic lesions in a great majority of situations.[4] Lesions in the medullary bone are undetected in the radiographs until there are substantial bone loss and cortical bone involvement. For a hard tissue lesion to be evident on a radiograph, there should be at least a mineral bone loss of 6.6%.[5]

Paralleling and Bisecting Techniques

The paralleling technique (Fig.1A) is primarily recommended for endodontic periapical radiographs. It allows for projections with minimal geometric distortions[6] and has a

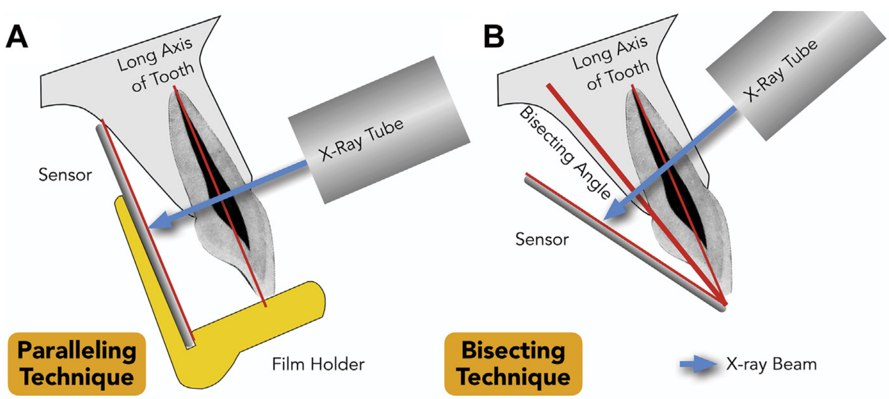

Fig. 1. (*A*) Paralleling technique, and (*B*) bisecting technique.

high level of reproducibility, which is beneficial for comparison with other radiographs throughout a procedure.[7] Briefly, a sensor is placed parallel to the long axis of the tooth undergoing treatment and exposed using radiographs perpendicular to the sensor surface. Special sensor holding devices, such as radiograph holders or hemostats, are required to align the sensor precisely with the radiograph tube. In the maxilla, the sensor may have to be placed at the palatal vault's height in the midline and in the mandible must displace the tongue toward the midline. Compromises may be necessary for patients with limited mouth opening, a severe gag reflex, or poor tolerance to the sensor.[6]

The bisecting angle technique (Fig.1B) lets radiographs pass perpendicular to the angle bisector of the angle formed by the tooth's long axis and the radiograph sensor. No holding devices are required. For conventional periapical and bitewing radiography, this technique is unreliable to achieve geometric accuracy, and distortions of anatomy are common. It is difficult to use rectangular collimation with this technique, as extension cone paralleling techniques are used with rectangular collimation to achieve maximum geometric sharpness and increased contrast of the resultant image. Although, when done with proper technique, it produces an only minimal distortion of the tooth length on the resultant images, the superimposition of adjacent anatomic landmarks or pathologic features may lead to difficulties in interpretation.[7] For example, the superimposition of the maxilla's zygomatic process over the root apices of molar teeth will often occur, which results in a characteristic radiopacity that renders interpretation difficult.[7]

Although similar diagnostic results are achievable with either technique, more studies favor the paralleling technique for effectiveness and superior diagnostic quality.[8,9] Whether a radiograph with good quality can be obtained will depend on the proper sensor placement in the patient's mouth and the correct angulation of the radiograph cone in relation to the sensor and oral structures. Proper exposure time and intensity of the radiograph beam must be chosen.

Adjustments in Vertical and Horizontal Angulation

Changes in horizontal radiograph angulation are employed by using the same lingual opposite buccal rule (SLOB), a technique helpful in identifying the relative spatial or buccal-lingual location of an object within the tooth or alveolus (Fig. 2). It combines an orthoradial periapical radiograph taken at zero horizontal angulation with additional mesial and/or distal eccentric radiographs. The orthoradial radiograph may lead to the superimposition of buccal and palatal objects on the sensor (Fig. 3A). In Endodontics,

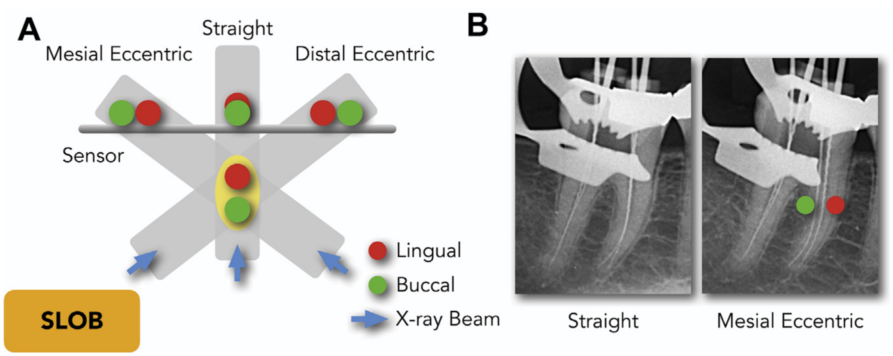

Fig. 2. (*A*) The SLOB rule. (*B*) Clinical example for comparison.

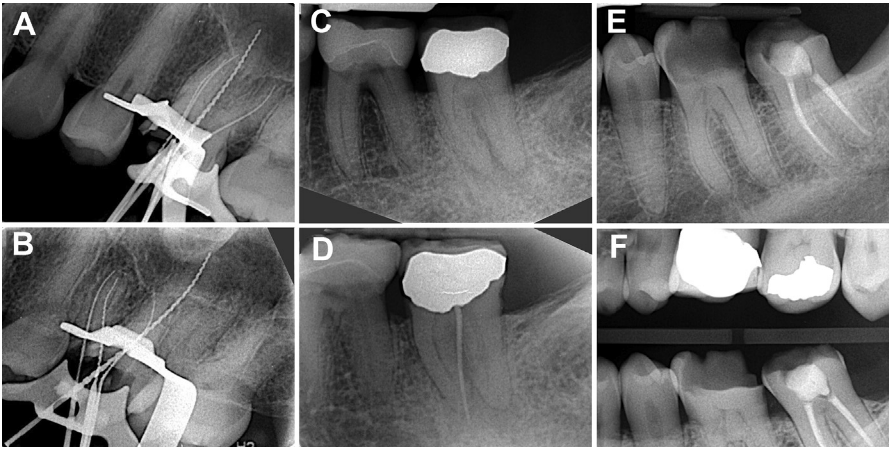

Fig. 3. (*A*) Orthoradial working length radiograph. Note superimposition of files in the mesiobuccal canals. (*B*) Eccentric working length radiograph. Note the visual separation of files in the mesiobuccal canals, allowing precise assessment. (*C*) Mandibular left second molar. Clinically, a sinus tract was present midroot below the furcation area. (*D*) Radiographic sinus tract tracing with a gutta-percha point. The gutta-percha traces to the periapical area, allowing to aid in the diagnosis of periapical, endodontic disease versus periodontal disease deriving from the furcation. (*E*) Periapical radiograph of mandibular left first molar showing deep distal decay with questionable restorability. (*F*) Bitewing radiograph demonstrates amount of sound supracrestal tooth structure. Tooth was deemed restorable.

these objects include roots, canals, instruments, or foreign objects. A secondary radiograph is then acquired with a slightly altered horizontal angulation of the radiograph beam (Fig. 3B). An object closest to buccal will appear to move in the opposite direction of the movement of the radiograph tube head, when compared with the orthoradial image. In turn, an object closest to lingual will appear to move in the direction of the movement of the radiograph tube head. For example, in the case of a working length film, if the eccentric direction of the radiograph beam is directed from mesial, a lingual canal will appear mesially on the image. In contrast, if the radiograph beam is directed from distal, the lingual will appear distally. Other than its utilization during root canal treatment, the SLOB rule can be applied to verify the presence or absence of foreign bodies or periapical lesion if radiopaque or radiolucent shadows are superimposed on an orthoradial radiograph.

In trauma, both vertical and horizontal angulations are of importance. Angulation changes may reveal a fracture line that otherwise could be concealed by hard tissue structures if the radiograph beam hits the fracture line within a $\pm 3^\circ$ angle. Horizontal angulation changes of 10° to 15° from the orthoradial direction should be used to identify a vertical crown, root, or alveolar fracture. Similarly, changes in vertical radiograph beam angulation are used for horizontal fractures. However, it must be appreciated that increases in vertical angulation will lead to a shortening of a tooth's length. Buccal roots will appear shorter than lingual roots in multirooted teeth, as they are at a greater distance from the sensor. A more accurate visualization of lingual roots and their apices is possible by increasing the vertical angulation. Increasing the vertical angulation also alters the vertical relationship of anatomic landmarks and root apices. This effect can determine whether anatomic landmarks lie buccally or lingually, an assessment that has benefit during endodontic surgery.[7] Last, identifying a "double periodontal ligament" by using a 20° horizontal angulation may hint at additional canals in a root with an hourglass cross-section.[10]

Sequence of Periapical Radiographs in Root Canal Therapy

Periapical radiographs are essential for endodontic therapy. They are used for diagnosis, preoperative assessment and patient communication, interpretation of root and root canal system morphology, verification of procedural steps, postoperative assessment of the root filling (obturation), as well as the long-term evaluation of the treatment outcome (follow-up).[5]

Diagnostic and preoperative radiographs

Periapical radiographs intended for endodontic therapy must include the complete area of interest with the full length of the root and at least 3 mm of periapical bone (**Fig. 4**A, B).[11] Ideally, these radiographs should be taken using the paralleling technique, which provides a consistently high quality without shortening or elongation.[6] One radiograph may be sufficient for a single-rooted tooth. For a multirooted tooth, roots and the root canal system may become superimposed (see **Fig. 4**A). A second radiograph with the radiograph beam shifted mesially or distally following the SLOB rule should be taken. A bitewing image may be necessary to assess restorability (see **Fig. 4**B).

Periapical radiographs allow both description of anatomic features and structures and detection of other conditions of the teeth and jaws related or not related to Endodontics. As an overview, **Table 1** lists the most common normal anatomic landmarks and relevant findings related to Endodontics. Because of the 2D imaging of 3D structures, periapical radiographs may see the projection of radiolucent or radiopaque anatomic shadows superimposed on the periapical tissues. Examples of radiolucent

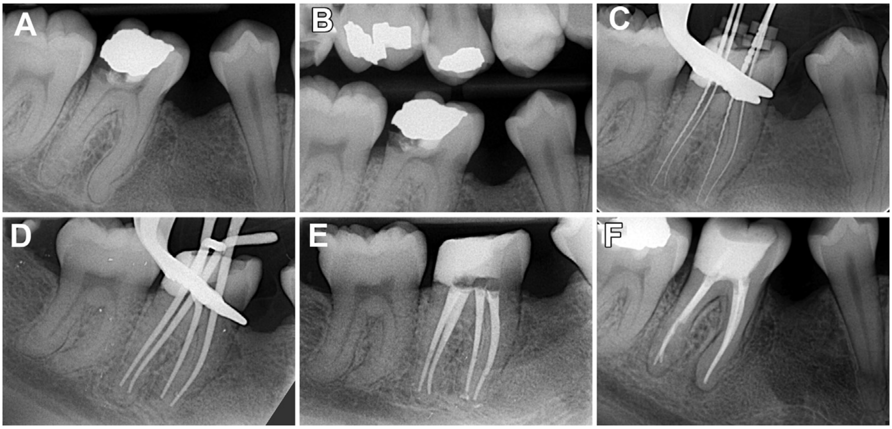

Fig. 4. Endodontic treatment of a mandibular right second molar. (*A*) Preoperative periapical radiograph. Note the radiolucent line representing the periodontal ligament space, depicted by the thin continuous dark line around the root outline. The radiopaque area close to the periodontal ligament of the premolar represents the lamina dura. The trabecular pattern and density the mandibular bone are relatively denser than in the maxilla. (*B*) Corresponding bitewing radiograph to assess restorability. (*C*) Working length radiograph. (*D*) Masterpoint radiograph before root filling. (*E*) Postoperative radiograph. Note temporary filling with radiolucent space indicative of a space holder such as a Teflon band or a cotton pellet. (*F*) Six-month follow-up radiograph. Note that the temporary filling has been replace by a build-up before permanent full-coverage restoration.

Table 1
Normal anatomic landmarks and relevant findings for endodontics

Normal Anatomic Landmarks	Relevant Findings for Endodontics
• Enamel, dentin, cementum, and alveolar bone • Pulp chamber, root canal system, and apical foramen • Periodontal ligament space • Lamina dura • Zygomatic process • Inferior border of the maxillary sinus • Neurovascular canals in the walls of the maxillary sinus • Intermaxillary suture • Incisive foramen • Nasolacrimal duct • Coronoid process of the mandible • Mandibular canal • Mylohyoid ridge • Mental foramen • Lingual foramen • Nutrient canal • Genial tubercles	• Number, course, shape, and length of root canals • Calcification or obliteration of pulp cavity and/or canals • Presence of caries that may threaten to affect the pulp • Widening of periodontal ligament • Nature and extent of periapical and alveolar bone destruction • Internal and external resorptions • Crown and root fractures • Abnormalities like dilaceration and taurodontism • Luxation and intrusion due to trauma • Foreign bodies following trauma • Iatrogenic errors (perforations, fractured instruments, and so forth) • Dens invaginatus with radicular lesion • Apical condensing osteitis • Enostosis (sclerotic bone) • Periradicular cemental dysplasia • Circumferential dentigerous cyst • Hereditary hypophosphatemia • Radicular lingual groove • Estimation and confirmation of root canals before instrumentation (working length determination) • Confirmation of position and adaptation of master cone • Evaluation of outcome of root canal therapy (postoperative radiograph)

shadows include superimposition of the mental foramina, the nasopalatine foramen, or the maxillary sinus, including its recesses. From an endodontic perspective, the effect of bone density reduction by these intrabony cavities may increase the radiolucent effect of the periodontal ligament, making it appear widened, yet still well demarcated and continuous. On the other hand, the effect on the lamina dura's radiopaque line may be the opposite, making it less discernible. Radiopaque shadows may derive from the body of the zygomatic arch, the mylohyoid ridge, and sclerotic bone areas, complicating the assessment of periradicular radiolucencies.

Clinicians must be trained to identify the normal anatomic landmarks and variations owing to pathologic condition.[7] Much of radiographic interpretation is based on the differentiation of normal versus abnormal conditions. Radiographs aid in making an endodontic diagnosis; however, clinical tests and examination, and the patient's medical and dental history must be considered. Endodontics aims to prevent or eliminate apical periodontitis. Diagnostic radiographs allow identifying periapical lesions. Although there is significant variation in jaw lesions, the majority, in particular, proximal to root apices, are odontogenic and inflammatory in nature.[12] Osteolytic processes owing to endodontic disease result from the irritants within a necrotic and infected root canal system. Changes in mineralization and structure of the periapical bone, visualized by radiographic techniques, are the primary indicators of the presence of apical periodontitis and its healing after endodontic treatment.[5,13] If pathologic condition is evident on the radiograph, the complete rarefaction plus normal bone should be recorded on the image. In cases with extensive lesions, a panoramic radiograph or larger-volume CBCT may be indicated.

If a sinus tract is present, it should be traced by inserting a gutta-percha cone into the tract up to the point of resistance and a radiograph taken with it in place. This radiograph will allow determining the path and termination of the sinus tract, revealing its origin, and thus identifying the affected tooth during diagnostic examination (**Fig. 3**C, D). This procedure may be of great benefit if pulpal sensibility tests cannot be adequately performed or multiple teeth present with periapical radiolucencies. Additional exposures with 10° to 15° changes in horizontal and/or vertical angulation need to be considered for diagnosing traumatic dental injuries, including root fractures, luxation, and avulsion injuries.[14]

Working length radiographs

Endodontic working length is an important concept to allow root canal instrumentation and root filling to reach as close to the cemento-dentinal junction as possible (**Fig. 4**C). Working length films are taken with root canal instruments inserted into the canals 0.5 to 1 mm short of the root length estimated on the preoperative radiograph or based on the reading of an electronic apex locator. Working length radiographs must always be taken with the rubber dam in place, to avoid contamination from the oral cavity or accidental swallowing or aspiration of an endodontic instrument. Any file inserted should be equipped with a rubber stop as a length indicator measured from a reproducible reference point. To allow for a correct reading of the instrument tip, a minimum size 15 is indicated (see **Fig. 4**C). The use of smaller file sizes may mislead and result in a wrong length determination. Besides length verification, radiographic imaging at this stage of root canal treatment gives additional information about the root canals' course, shape, and length.

A bisecting angle technique can be used but bears the risk of shortening or elongating individual roots. To avoid having a patient use a finger to support the sensor and expose it to unnecessary radiation, a hemostat or a sensor-holding device (eg, Rinn film holder system) should be used. Film holders will also allow for greater accuracy by applying the paralleling technique if the sensor and radiograph tube are correctly aligned. The sensor should be placed perpendicularly to the radiograph beam. This placement will also allow for greater accuracy and less likelihood of obtaining a partial radiograph if the radiograph beam misses a part of the sensor (cone out). However, sensor placement may still be difficult because of the patient's restricted opening with the rubber dam and sometimes also a frame in place. In the mandibular posterior area, the mouth's closing may relax the mylohyoid muscle, permitting the sensor to be placed further apically. In areas with increased difficulty, such as anterior maxillary teeth with a shallow palate, the placement of a cotton roll between sensor and crowns may be advised to obtain a better angulation.

Following the SLOB rule, for multirooted teeth or roots with more than 1 canal, at least 2 radiographs, one at the direct, standard angle, and the other with an eccentric angulation should be taken. The clinician should place different types of instruments, such as K- and Hedström files, in buccal and lingual canals, respectively, to allow for proper identification of the individual canals.

Masterpoint/master apical file

Before root filling, canal instrumentation and working length should be verified by taking a radiograph with either the final root canal instrument (master apical file [MAF]) or gutta-percha masterpoints selected for obturation (Fig. 4D), inserted to the full working length (see Fig. 4D). This step will allow for identifying potential iatrogenic errors, such as transportations or perforations before root filling and helps avoid short filling or overfilling. The master point size typically corresponds to the MAF but may require individual adjustment. Certain endodontic filling techniques may require 1 additional radiographic step to verify progression of the obturation. This step includes the lateral compaction (condensation) technique, which incorporates a midobturation image, verifying the placement of the masterpoints with sealer and 2 to 3 accessory cones, as well as warm techniques, such as vertical compaction (condensation) or continuous wave, verifying the apical fill at a downpack stage before the backfill of the canals. The technique for all masterpoint/MAF and midfilling films follows the recommendations for working length radiographs.

Postoperative radiographs

The evaluation of a root filling is mainly based on its radiographic appearance, including proper length, the absence of voids, or extruded filling materials. A postoperative radiograph must only be taken after the placement of a temporary or permanent restoration to ensure an excellent coronal seal (Fig. 4E). The rubber dam will be removed before taking postoperative radiographs. The paralleling technique should be used to allow reproducibility and a comparison with preoperative and follow-up radiographs. The importance of these images extends beyond the evaluation of treatment and includes medicolegal documentation.

Follow-up radiographs

Follow-up (recall) radiographs are taken to evaluate the prognosis of an endodontically treated tooth (Fig. 4F). Radiographs exposed at different points in time should be compared (see Fig. 4F).[15] The follow-up radiograph assesses periapical health or status of healing and may aid in identifying treatment failures. Preoperative, postoperative, and follow-up radiographs should be standardized with respect to their radiation geometry, density, and contrast to allow reliable interpretation of any changes that may have occurred in the periapical tissues owing to treatment.[5] Poorly standardized radiographs may lead to underestimating or overestimating the degree of healing or failure.[16] It has been recommended to use customized stents in order to maximize reproducibility. Elastomeric impression materials may be placed onto the paralleling device's bite block, which is then positioned in the most favorable position, and the patient is asked to bite on it until it sets.[17] The bite block with the patient's impression should be kept for later evaluations. A 1-year follow-up may be sufficient for most endodontic treatments. However, additional radiographs may be necessary if the tooth had presented with a large periapical lesion.

BITEWING RADIOGRAPHS

Bitewing radiographs are a type of 2D radiograph depicting crowns of teeth in either left or right maxillary and mandibular sextants. In Endodontics, they provide useful information regarding the proximal surfaces of the teeth, allow for the detection of interproximal caries, and aid in identifying coronal leakage and restorability, otherwise not visible on a periapical radiograph (Fig. 3E, F).

CONE-BEAM COMPUTED TOMOGRAPHY

CBCT is similar in many ways to multidetector computed tomography for the 3D imaging of hard tissue structures. CBCT allows for faster image processing and reduced radiation in comparison to conventional CT, because of its radiograph distribution in a cone shape.[18] In Endodontics, the most common format is a limited field-of-view (FOV) volume in the form of a cylinder with approximately 40 to 50 mm in diameter

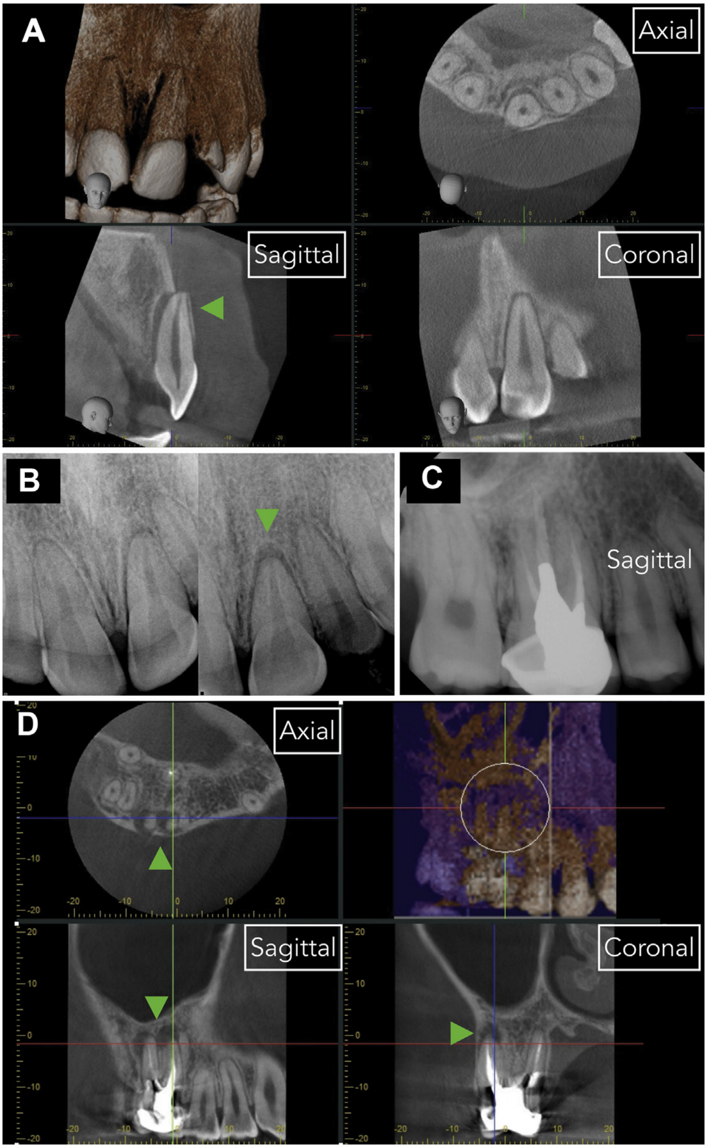

Fig. 5. Three-dimensional information provided by CBCT imaging. (*A*) Limited FOV CBCT. Note luxation of maxillary left central incisor with fracture of alveolar buccal plate and buccal displacement of the root apex (*arrowhead*). (*B*) Corresponding periapical radiographs in 2 vertical angulations, indicative of vertical luxation. No indication of horizontal displacement. (*C*) Periapical radiograph of maxillary right first molar with history of previous endodontic treatment. No indication of periapical lesions. (*D*) Corresponding limited FOV CBCT. Note apical radiolucencies on both buccal roots in axial, sagittal, and coronal views (*arrowheads*).

(Fig. 5A, D), depending on the manufacturer. This format provides for the imaging of approximately 4 teeth in the posterior and 6 teeth in the anterior area, ideal for most endodontic diagnostic, treatment planning, and problem-solving tasks. Limited FOV volumes allow for high-resolution scans with minimal distortion, an important aspect considering the minute details necessary to assess in Endodontics. Besides these benefits, a radiation dose up to 15 times lower than conventional CT scans[19] increased the ability to use CBCT imaging in private practice. A 2017 survey of 1083 endodontists found that 80.3% of the practitioners had access to either an on-site or an off-site CBCT machine.[20]

In Endodontics, CBCT is used to aid in the diagnosis of endodontic or nonodontogenic diseases; to identify root and root canal anatomy,[21] external, internal, and apical resorptions[22]; to detect missed canals,[23] intracanal foreign body materials (eg, separated instruments); to evaluate dental trauma[24] (Fig. 5A, B); to identify and assess the extent of apical periodontitis[25] (Fig. 5C, D); for healing assessment and follow-up of previous endodontic treatments with unclear clinical signs or symptoms[26]; and for surgical treatment planning.[27] CBCT imaging has been shown to demonstrate greater sensitivity and specificity to detect periapical lesions compared with conventional periapical or panoramic radiographs.[28]

For large periapical lesions, where apex locator measurements may be compromised, preoperative CBCT measurements were suggested for working length determination, demonstrating great accuracy.[29] CBCT "guided" techniques were proposed for nonsurgical endodontic treatment, for example, to minimize overall tooth structure loss detecting calcified canals,[30] and for surgical endodontics in close proximity to vulnerable anatomic structures.[31] Most recent applications saw the combination of CBCT imaging with artificial intelligence algorithms for the automated detection of periapical lesions[32] or crown and root fractures.[33]

For many patients and practitioners, the biggest concern regarding CBCT imaging remains radiation exposure. About 48% of the average annual radiation dose per person in the United States (6.2 mSv) derives from diagnostic tests and medical treatments, with 24% of the total radiation dose from any medical CT.[34] The overall guiding principle for practitioners to minimize exposure to radiation remains ALARA ("as low as reasonably achievable"), as stated in Title 10, Section 20.1003 of the Code of Federal Regulations.[35] Clinicians should be aware of and avoid any unnecessary radiation exposure of the patient.

CLINICS CARE POINTS

- Sitting a patient upright for periapical and bitewing radiographs will allow for better visualization of the x-ray beam direction.
- Changing horizontal or vertical angulations of a periapical radiographs for maxillary molars may allow to avoid superimposition of the zygomatic arch.
- Utilization of a metal artifact reduction option in a CBCT imaging software may greatly reduce scatter in the three-dimensional volume.

DISCLOSURE

The authors have nothing to disclose.

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