Endodontic Applications of Cone-Beam Volumetric Tomography

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Abstract

The ability to assess an area of interest in 3 dimensions might benefit both novice and experienced clinicians alike. High-resolution limited cone-beam volumetric tomography (CBVT) has been designed for dental applications. As opposed to sliced-image data of conventional computed tomography (CT) imaging, CBVT captures a cylindrical volume of data in one acquisition and thus offers distinct advantages over conventional medical CT. These advantages include increased accuracy, higher resolution, scan-time reduction, and dose reduction. Specific endodontic applications of CBVT are being identified as the technology becomes more prevalent. CBVT has great potential to become a valuable tool in the modern endodontic practice. The objectives of this article are to briefly review cone-beam technology and its advantages over medical CT and conventional radiography, to illustrate current and future clinical applications of cone-beam technology in endodontic practice, and to discuss medicolegal considerations pertaining to the acquisition and interpretation of 3-dimensional data. *(J Endod 2007;33:1121–1132)*

Key Words

CBCT, CBVT, cone-beam computed tomography, cone-beam volumetric tomography, digital volume tomography, DVT, endodontics

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Radiographic examination is essential in diagnosis and treatment planning in endodontics. The interpretation of an image can be confounded by the anatomy of both the teeth and surrounding structures. Having the ability to assess an area of interest in 3 dimensions might benefit both novice and experienced clinicians alike. The objectives of this article are to review 3-dimensional (3-D) imaging, specifically cone-beam technology and its advantages over traditional medical computed tomography (CT) and conventional radiography, to illustrate current and future clinical applications of cone-beam technology in endodontic practice, and to discuss medicolegal considerations pertaining to the acquisition and interpretation of 3-D data.

Cone-beam technology has existed since the 1980s (1). However, the convergence of technology and its applications has only recently made cone-beam volumetric tomography (CBVT) (2, 3) or cone-beam computed tomography (CBCT) a viable option for the dental office (4).

Two main innovations have driven development of these imaging systems. The first is the change from analog to digital imaging. Second, advances in imaging theory and volume-acquisition data have allowed for increasingly detailed 3-D imaging (5). Powerful low-cost computers, less expensive cone-beam x-ray tubes, and the development of high-quality flat-panel detectors (6–8) have increased the affordability and quality of these imaging systems and made CBVT imaging in the dental office a reality (4).

Cone-beam technology uses a cone-shaped beam of radiation to acquire a volume in a single 360-degree rotation, similar to panoramic radiography (2, 3). Just as a digital picture is subdivided into pixels, the volume acquired by a CBVT is composed of voxels. Essentially, a voxel is a 3-D pixel. Because the data are captured in a volume as opposed to slices, all the voxels are isotropic, which enables objects within the volume to be accurately measured in different directions. The axial height of a medical CT voxel, however, is determined by the slice thickness or pitch (1–2 mm thick) and results in an anisotropic voxel (9). In other words, unlike the CBVT voxel, a medical CT voxel is not a perfect cube, and measurements made in multiple planes are not accurate. In addition to increased accuracy and higher resolution, CBVT offers significant scan-time reduction, radiation dose reduction, and reduced cost for the patient (9–11). With the help of viewer software (12), the clinician is able to scroll through the entire volume and simultaneously view axial, coronal, and sagittal 2-D sections that range from 0.125–2.0 mm thick. The axial and proximal (sagittal in the anterior, coronal in the posterior) views are of particular value, because they are generally not seen with conventional periapical radiography. The ability to reduce or eliminate superimposition of the surrounding structures makes CBVT superior to conventional periapical radiography (13). In addition to the 2-D slices, 3-D reconstruction enables further assessment of the area of interest.

In the year 2000, the Food and Drug Administration approved the first CBVT unit for dental use in the United States (14). As of 2007, there are at least 12 cone-beam systems specifically designed for dental use. The majority of these machines scan the patient in a seated position, whereas a few scan the patient in either an upright or supine position. CBVT systems can be classified into 2 categories, limited (dental or regional) CBVT or full (ortho or facial) CBVT. The field of view (FOV) of limited CBVT ranges in diameter from 40–100 mm, whereas the FOV of full CBVT ranges from 100–200 mm. Another difference between the limited CBVT and full CBVT is that a voxel is generally smaller for the limited version (0.1–0.2 mm vs 0.3–0.4 mm). Thus, limited CBVT systems offer higher resolution and are better suited for endodontic applications.

Conventional medical CT has been used in dentistry for limited applications. Although CT produces a high level of detail in the axial plane, the high dose and lengthy scanning time of these systems make them impractical for most other dental applications. As low as reasonably achievable (ALARA) principles should be maintained during all dental diagnostic imaging. Newer spiral and multidetector CTs have drastically reduced scan time and effective dosages, but they still are not as accurate and do not limit the dosage as much as CBVT (2, 5).

The effective dose of radiation for CBVT has been shown to be much lower as compared with traditional medical CT (15, 16). Various CBVT machines will have different effective doses determined by the brand and its array of settings. Published effective doses from digital panoramic radiography range from 4.7–14.9 microsieverts (μSV) per scan (17). Mah et al (16) found the effective dose for the Newtom 9000 (Verona, Italy) to be 50.3 μSV. The effective dose for a full mouth series has been reported to range from 33–84 μSV (18), depending on different variables. This indicates that the amount of radiation exposure to the patient is comparable to that received from routine diagnostic imaging and is much less as compared with a medical CT (15, 16). Although CBVT technology is efficient in imaging hard tissue, it is not very reliable in the imaging of soft tissue as a result of the lack of dynamic range of the x-ray detector (10).

Specific endodontic applications of CBVT are being identified as the technology becomes more prevalent. Potential endodontic applications include diagnosis of endodontic pathosis and canal morphology, assessment of pathosis of non-endodontic origin, evaluation of root fractures and trauma, analysis of external and internal root resorption and invasive cervical resorption, and presurgical planning. CBVT has great potential to become a valuable diagnostic and treatment planning tool in the modern endodontic practice. The following case reports will demonstrate some of these endodontic applications.

Figure 1. 3-D Accuitomo CBVT machine located in the Dental Diagnostic Sciences Department, UTHSCSA Dental School.

Case Reports

Case 1: Diagnosis and Canal Morphology

A 33-year-old man was referred to the University of Texas Health Science Center at San Antonio (UTHSCSA) postgraduate endodontic program for consultation and treatment of #30, with a chief complaint that "I need my root canal redone." The patient reported having root canal therapy completed on #30 approximately 15 years prior. The patient had been seen in the postgraduate periodontal clinic since 2006 for placement of implants in the areas of #29 and #31. After obtaining a CBVT with the 3D Accuitomo XYZ Slice View Tomograph FPD (J. Morita Mfg Corp, Kyoto, Japan) (Fig. 1) for implant placement, the periodontic resident noted an apparent untreated distolingual canal on #30. The patient was asymptomatic on presentation to the endodontic clinic in March 2007 and did not report any recent symptoms associated with the tooth in question. The patient's medical history was noncontributory.

Pulp testing revealed that #30 was nonresponsive to cold and nontender to percussion, palpation, and biting. Probing depths were 2–3 mm, and there was no evidence of swelling or sinus tracts. A periapical radiograph of #30 showed an undebrided distolingual canal located in a separate distolingual root (Fig. 2*A*). A widened periodontal ligament space on the distolingual root was noted on the periapical radiograph, whereas the CBVT findings demonstrated an extensive periapical radiolucency readily identified on the distolingual root of #30. The undebrided distolingual canal was clearly observed (Fig. 2*B*).

Tooth #30 was diagnosed as previous root canal therapy with asymptomatic apical periodontitis associated with an undebrided distolingual canal. The patient elected to have nonsurgical retreatment of the root canal (Fig. 2*C*). In this case, CBVT information was invaluable in diagnosing an undebrided distolingual canal with an associated periradicular lesion.

Case 2: Non-Endodontic Pathosis

A 29-year-old dentist was self-referred to the UTHSCSA graduate endodontic clinic for consultation and treatment of tooth #8, with the chief complaint that "I had a filling done in November 2006 and there was a pulp exposure. They started the root canal and then the dentist noticed internal resorption." On presentation, the patient reported no pain since the original pulpectomy had been completed. Tooth #8 had been restored temporarily, and the patient reported no history of trauma, orthodontic treatment, or intracoronal bleaching. The patient's medical history was noncontributory.

Pulp testing revealed that #8 was nonresponsive to cold and nontender to percussion and palpation. Probing depths were 2–3 mm, and there was no evidence of a sinus tract or intraoral swelling. Interpretation of off-angle radiographs revealed the presence of a lingual radiolucency. The canal was clearly visible through the radiographic defect, and the radiolucency appeared to shift almost entirely off the root structure (Fig. 3*A, B, C*). The appearance was suggestive of either an external resorptive defect or, more likely, pathosis within the palatal bone.

A CBVT revealed a large incisive foramen/canal in intimate contact with the lingual aspect of #8. The bony lesion measured approximately 5 mm in diameter and 6 mm in height. Differential diagnosis included but was not limited to enlarged incisive foramen or nasopalatine duct cyst (Fig. 3*D*).

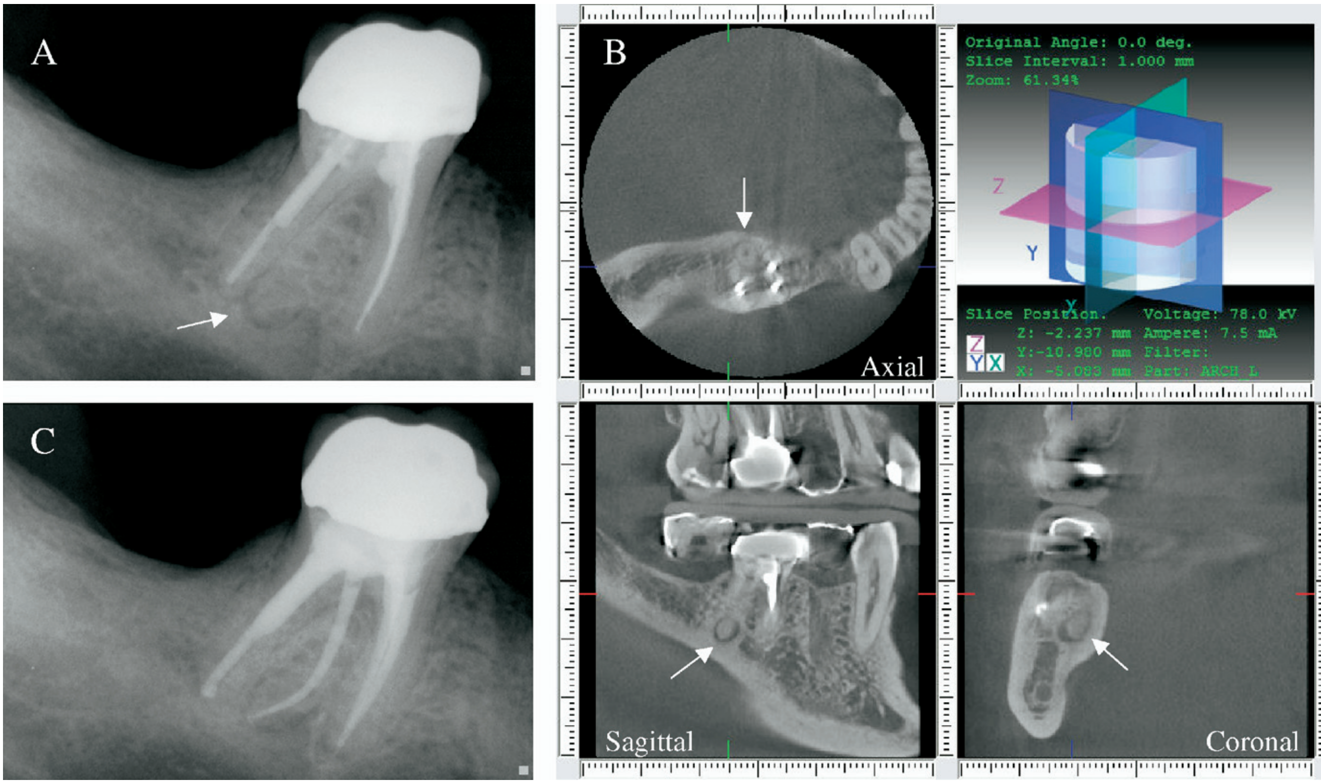

Figure 2. (*A*) Preoperative periapical radiograph depicts an undebrided distolingual root canal with a widened periodontal ligament space. (*B*) CBVT demonstrates axial, sagittal, and coronal 2-D slices of the undebrided distolingual canal and its associated periapical lesion. (*C*) Postoperative periapical radiograph of retreatment including obturation of the distolingual canal.

The patient was referred to the Oral and Maxillofacial Surgery (OMS) Department for evaluation and possible enucleation. After evaluation, OMS diagnosed the lesion as an enlarged incisive foramen/canal and recommended a follow-up CBVT in 1 year. The pulpal and periradicular diagnosis was previous partial treatment with normal periapex and no resorption. Root canal treatment and build-up were subsequently completed (Fig. 3*E*). CBVT information helped to confirm the position and the size of the lesion and ultimately in the diagnosis of an enlarged incisive canal (Fig. 3*F, G*).

Case 3: Root Fracture

A 45-year-old woman was referred by her general dentist for consultation and treatment of #9, with a chief complaint that "I've been told my front tooth is fractured and I need an implant." The patient reported a history of trauma to #8 and #9 approximately 10 years prior, resulting in complicated crown fractures of both teeth with no associated luxation-type injuries. Root canal therapy was performed on #8 and #9 the day of the trauma. Shortly after, #9 had a post placed, and both #8 and #9 were restored with crowns. The patient was asymptomatic on presentation to the UTHSCSA postgraduate endodontic clinic in January 2007 and did not report any recent symptoms associated with the teeth in question. The patient's medical history was noncontributory.

Pulp testing revealed that #8 and #9 were nonresponsive to cold and non-tender to percussion, palpation, and biting. Two millimeters of facial recession was noted on #9, with the presence of a deep periodontal pocket at its distolingual aspect. All adjacent teeth responded normally to clinical testing. A periapical radiograph of #9 showed signs of vertical bone resorption on the distal and a widening of the periodontal ligament space (Fig. 4*A*). The patient was referred for CBVT imaging.

CBVT findings revealed a shearing-type crown-to-root fracture with a corresponding loss of bone isolated to the lingual portion of #9 (Fig. 4*B*). The images also showed the fracture beginning at the junction of the prosthetic crown and the cervical 1/3 of the root, extending to the junction of the middle and apical thirds. The fracture did not involve the root canal space. This fracture was further confirmed by removal of the crown and clinical observation.

The pulpal and periradicular diagnosis of #9 was previous root canal therapy with an uncomplicated crown-to-root fracture with a severe, localized periodontal defect and normal periapex. Because of the extent of the fracture, the patient elected to have tooth #9 removed and began the process of implant restoration in March 2007. CBVT information confirmed the existence of an oblique, shearing-type fracture.

Case 4: Internal Resorption

An 18-year-old woman was referred to the UTHSCSA postgraduate endodontic clinic by her orthodontist for emergency consultation and treatment of tooth #9, with the chief complaint that "I have a throbbing toothache." The patient reported a history of trauma at age 13 years in which the tooth was slightly displaced. The patient did not seek dental care at that time. Orthodontic treatment was initiated in November 2006. The patient's medical history was noncontributory.

Pulp tests revealed that tooth #9 was normally responsive to cold, acutely tender to percussion, and slightly tender to palpation on the facial mucosa of #9. Probing depths were 2–3 mm, and there was no evidence of a sinus tract or intraoral swelling. All adjacent teeth tested normal to pulp vitality tests. Interpretation of the periapical radiographs revealed the presence of a distinct radiolucency at the junction of the middle and apical thirds of root #9. The lesion remained centered in off-angle radiographs, and the canal outline was contiguous with the defect. The appearance was suggestive of a large internal resorptive lesion (Fig. 5*A*).

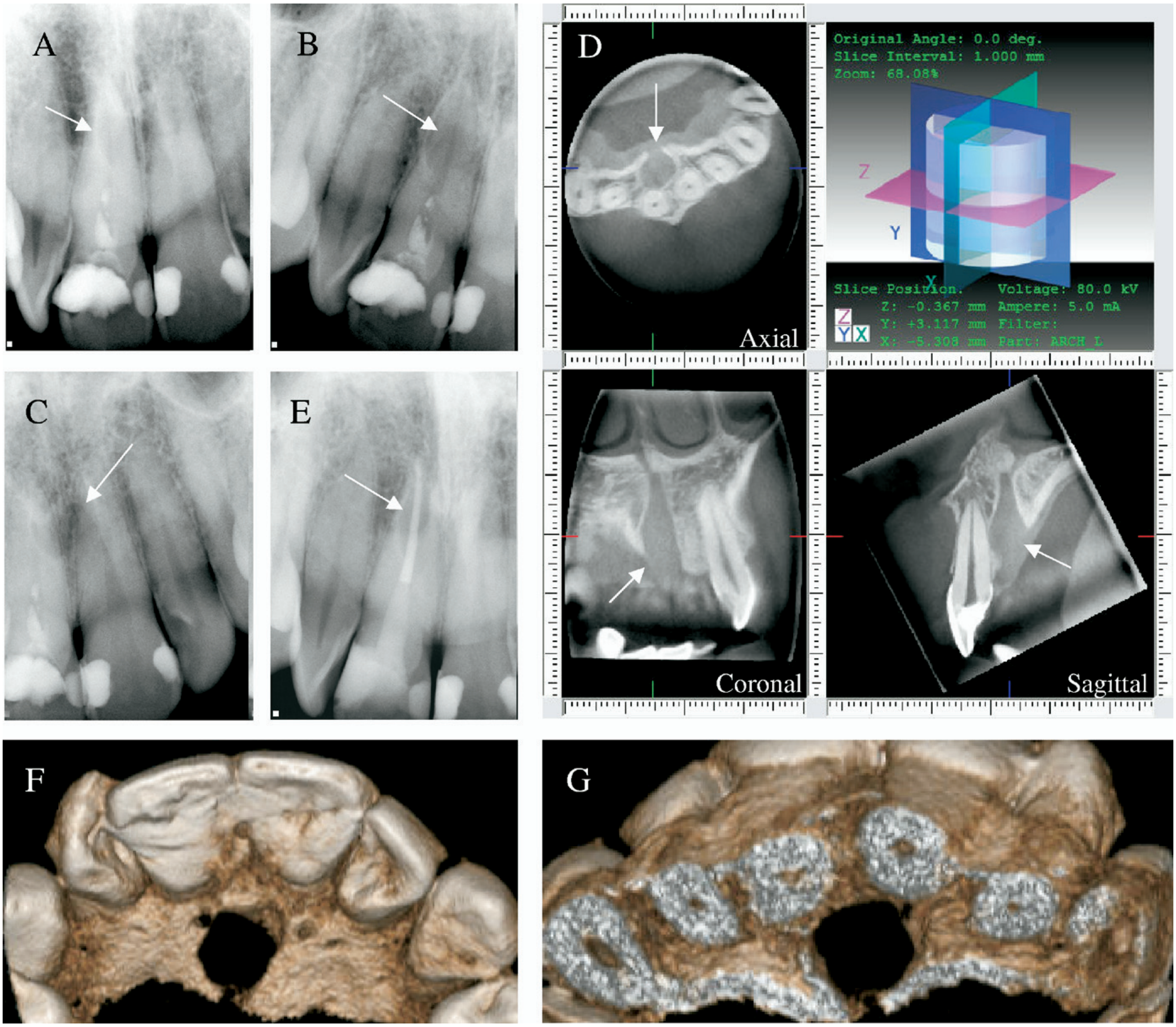

Figure 3. (*A*) Preoperative periapical radiograph depicts a radiolucent lesion superimposed over the canal in the apical third of tooth #8. (*B*) Preoperative periapical radiograph exposed from a distal angulation shows the radiolucency moving distally, indicating a lingually positioned lesion. (*C*) Preoperative periapical radiograph exposed from a mesial angulation shows the radiolucency moving mesially, indicating a lingually positioned lesion. (*D*) CBVT demonstrates the enlarged incisive foramen in the axial, sagittal, and coronal 2-D slices. (*E*) Postoperative periapical radiograph depicting the enlarged incisive foramen superimposed over the obturated canal of #8. (*F*) 3-D CBVT reconstruction of the enlarged incisive foramen by using Accurex processing software (CyberMed International, Seoul, Korea). (*G*) 3-D CBVT reconstruction of the enlarged incisive canal located mid-root of tooth #8 by using Accurex processing software.

The patient was anesthetized for comfort and immediately taken for a CBVT survey, which revealed a large oblong area of low density within the pulp space of #9. Further interpretation indicated a near-perforation of the root by the lesion with a considerable decrease in root dentin thickness (Fig. 5*B*).

The pulpal and periradicular diagnosis of #9 was irreversible pulpitis and symptomatic apical periodontitis. Because of the extent of the internal defect, there was concern that condensation forces associated with gutta-percha obturation could lead to root fracture. In addition, it was difficult to entirely rule out a perforative defect when interpreting the periapical radiographs, whereas the CBVT provided a much better 3-D perspective. A modified treatment plan was discussed, and tooth #9 was obturated with gutta-percha and mineral trioxide aggregate by using indirect ultrasonic vibration (Fig. 5*C*). CBVT information assisted with determining the extent of the resorptive defect and aided in devising an appropriate treatment plan.

Case 5: Invasive Cervical Resorption

A 43-year-old woman was referred to the UTHSCSA postgraduate endodontic clinic from the postgraduate periodontics department for consultation of tooth #9, with the chief complaint that "I was told I have resorption on a front tooth." The patient reported no history of pain or trauma. Orthodontic treatment was initiated in 2004. The patient's medical history was noncontributory.

Clinical tests revealed that #9 was responsive to cold and normal to percussion and palpation. Probing depths were 2–3 mm, and there was no evidence of a sinus tract or intraoral swelling. All adjacent teeth tested normal to pulp vitality tests. Interpretation of the radiographs

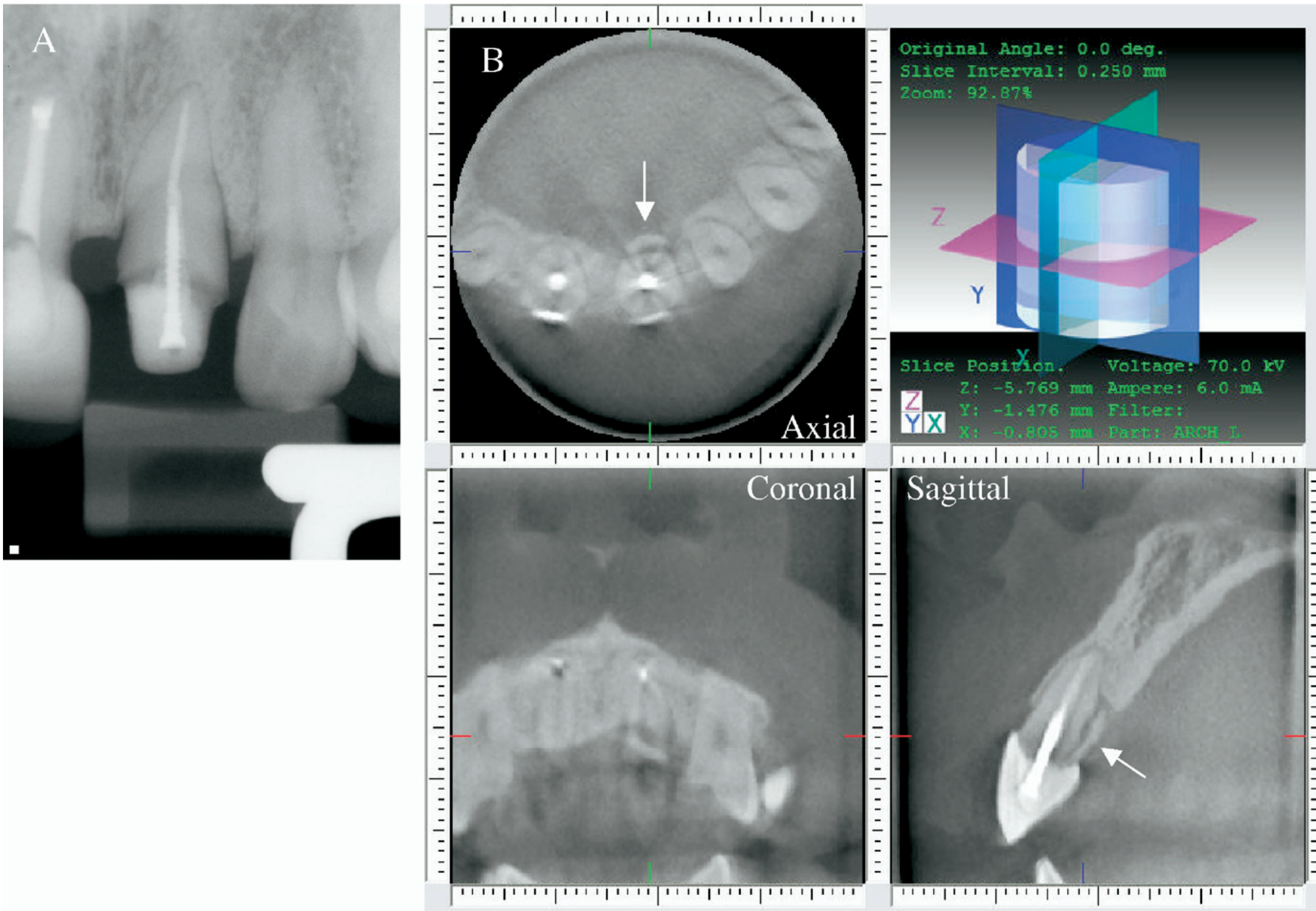

Figure 4. (*A*) Periapical radiograph of tooth #9 with its crown removed. (*B*) CBVT demonstrates the axial, sagittal, and coronal 2-D slices of the shearing-type crown-to-root fracture with corresponding loss of bone isolated to the lingual portion of #9.

revealed the presence of a radiolucent lesion in the cervical third of root #9 (Fig. 6*A*). Off-angle radiographs demonstrated the presence of a lingual radiolucency (Fig. 6*B*). The canal was visible through the radiographic defect, and the radiolucency appeared to shift in the same direction as the radiation source. The appearance was suggestive of invasive cervical resorption (ICR).

The CBVT survey revealed an area of low density on the mesiolingual aspect of tooth #9 (Fig. 6*C*). Further interpretation indicated that the resorptive defect extended approximately 3–4 mm subosseously. The portal of entry was identified in the axial view, and the lesion was consistent with Heithersay Class 2 ICR (19).

The pulpal diagnosis of #9 was normal. The periradicular diagnosis was listed as normal and qualified by noting the presence of ICR. Various treatment plans were discussed with the patient and the periodontic resident. These treatment options included: 1) orthodontic extrusion followed by treatment with trichloracetic acid and restoration with glass ionomer with potential need for endodontic treatment and guided tissue regeneration or 2) root canal therapy and intentional replantation with concurrent restoration of the defect. CBVT information aided in treatment planning of a complex multidisciplinary case.

Case 6: Presurgical Anatomic Assessment

A 65-year-old woman was referred by her general dentist for evaluation, with a chief complaint that "I have a pin pricking feeling from the corner of my mouth to my chin." Endodontic treatment had been completed 2 weeks prior on tooth #29 (Fig. 7*A, B*). The patient's medical history included rheumatoid arthritis, anxiety, hypertension, gastroesophageal reflux disease, type II diabetes, hyperlipidemia, and glaucoma. Her medications included etanercept, methotrexate, etodolac, citalopram, cyclobenzaprine, omeprazole, atenolol, simvastatin, metformin, brimonidine tartrate, and folic acid.

The patient described the sensation as "pins pricking" her skin and likened it to the feeling one gets when their foot falls asleep. The area of paresthesia was mapped to the mental nerve distribution. The patient also noted that the area would itch uncontrollably for 3–4 minutes about 3–4 times per day. The patient reported that the paresthesia began in the afternoon the day after her root canal was completed, and it had continued for the past 2 weeks without change. The first report of her paresthesia came 2 weeks after endodontic treatment when she presented to her general dentist for the build-up of #29.

Clinical findings revealed tooth #29 to be nonresponsive to cold and tender to percussion. All adjacent teeth tested clinically normal. Periapical radiography revealed the extrusion of material apical to #29 (Fig. 7*B*). A CBVT was taken to better inspect the periradicular tissues.

The CBVT revealed the mental nerve exiting buccal and slightly coronal to the apex of #29. A radiopaque substance assumed to be sealer was noted lingual and apical to the apex of #29 (Fig. 7*C*). The material appeared to be immediately lingual and coronal to the mental nerve as it exited off the inferior alveolar nerve. The patient was advised that the extruded material and/or inflammation associated with the material could be putting pressure on the neurovascular bundle, resulting

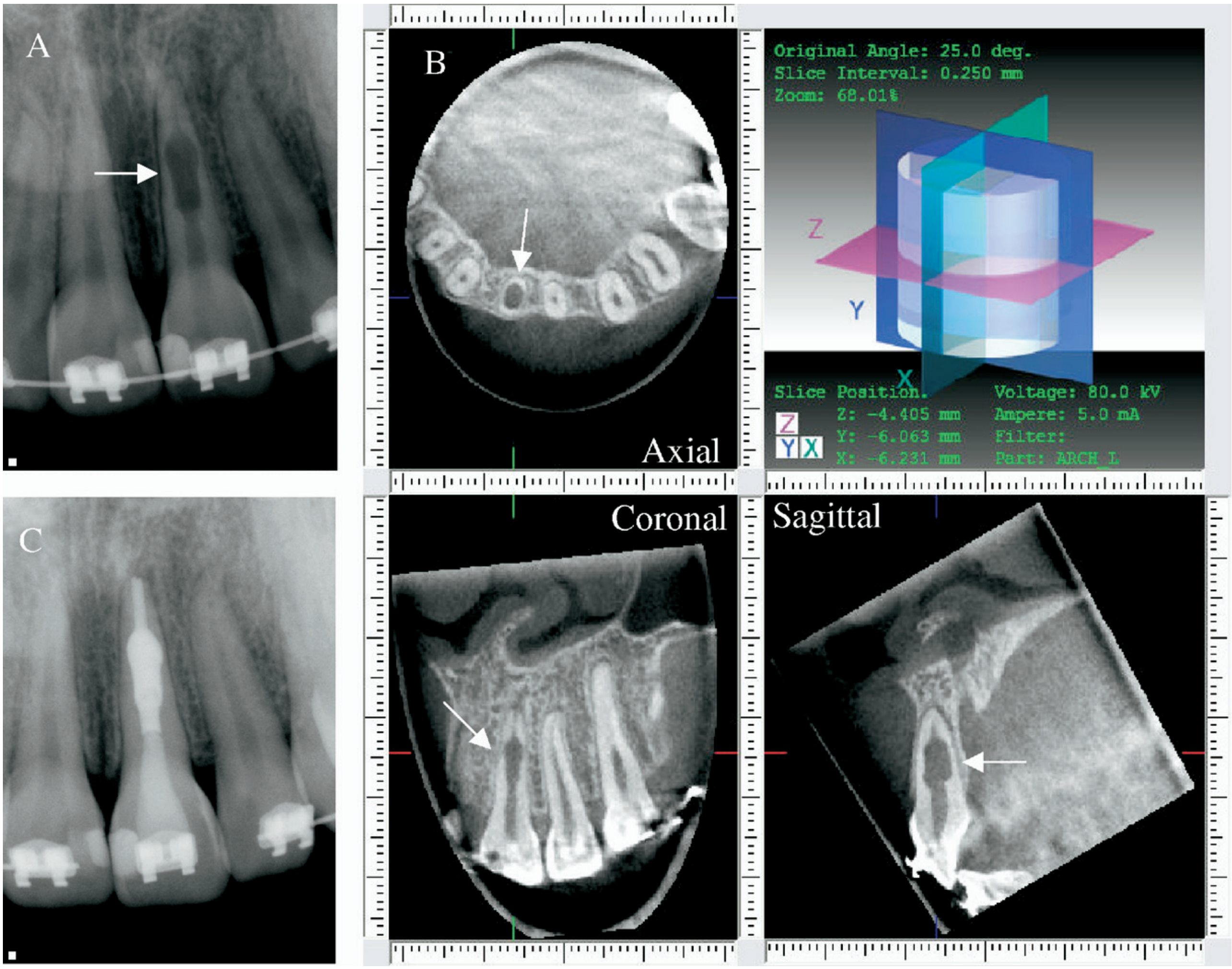

Figure 5. (*A*) Preoperative periapical radiograph depicts a distinct radiolucency associated with the root of #9 at the junction of the middle and apical thirds. (*B*) CBVT demonstrates the extent of the internal resorptive lesion in axial, sagittal, and coronal 2-D slices. (*C*) Postoperative periapical radiograph of the gutta-percha and mineral trioxide aggregate obturation of tooth #9.

in her current symptoms. The patient left with a 1-month recall appointment and instructions to call if the feeling became worse.

On examination at the 1-month recall, complete resolution of her paresthesia was noted. The radiopaque material was still present radiographically, and #31 and #27 tested normal to cold, percussion, and palpation. The patient was advised to call if further problems arose. CBVT information allowed for the assessment of critical anatomy related to the root end of #29.

Case 7: Diagnosis of a Failed Implant

A 74-year-old man was referred to the UTHSCSA postgraduate endodontic clinic for consultation regarding tooth #29, with a chief complaint that "I have pain on the lower right side since the placement of implants." The patient's medical history included gastroesophageal reflux disease, asthma, osteoporosis, and a history of basal cell carcinoma removal from his face. His medications included albuterol/ipratropium, esomeprazole magnesium, montelukast sodium, and pravastatin. He also had a 3-year history of taking biphosphonate but discontinued its use about 1 year before the endodontic appointment.

Treatment history included 2 implants placed at site #30 and #31 by a graduate periodontic resident in October 2006. In early January 2007, the patient reported to the graduate periodontic clinic with sensitivity to percussion and hyper-responsiveness to cold on #29. The resident noted a periapical implant lesion (PIL) at the apex of the implant at site #30, and antibiotics were prescribed. The patient was seen again in mid-January for sensitivity to biting on the lower right premolar. A PIL was still noted around the apical extent of #30 implant. At that time the occlusion on #29 was adjusted, and the patient was referred to graduate endodontics for further consultation.

On presentation to the graduate endodontic clinic in late January 2007, the patient stated that the sensitivity to biting had subsided after the occlusal adjustment on #29. Clinical findings revealed #28 and #29 to have normal responses to cold, percussion, and palpation with normal periodontal probings. The implant at site #30 was normal to percussion and palpation. Radiographically, a large radiolucency was still noted at the apex of the implant at #30 and appeared to be encroaching on the apex of #29 (Fig. 8*A*).

A limited CBVT was taken to better appreciate the size and extent of the lesion associated with the implant. The CBVT findings indicated a rather extensive lesion surrounding the implant at site #30. The lesion appeared in close proximity to the apex of #29 (Fig. 8*B*).

The pulpal diagnosis for #29 was normal. Because of the proximity of the apex of #29 to the lesion associated with the adjacent implant, the

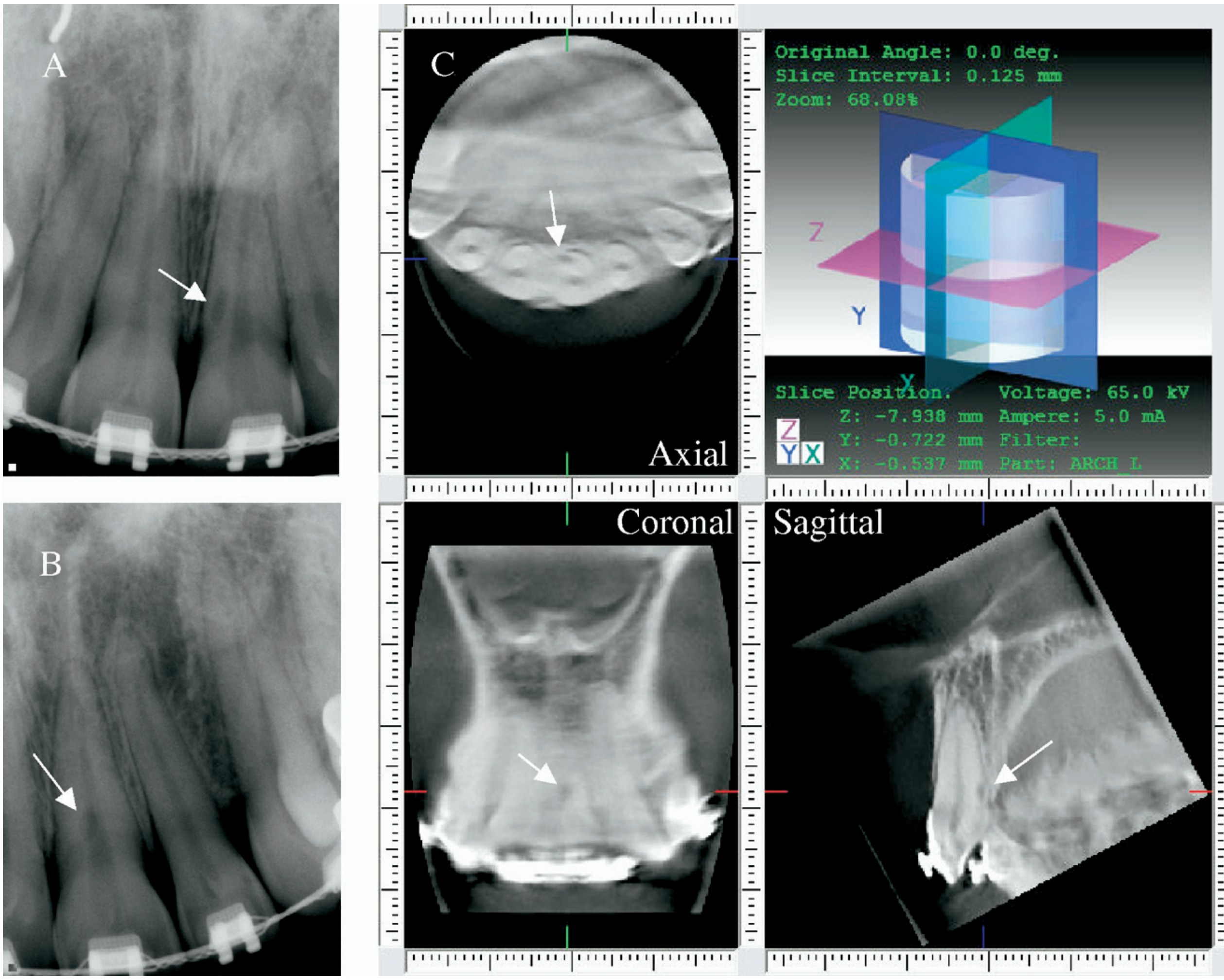

Figure 6. (*A*) Periapical radiograph demonstrates a radiolucent lesion in the cervical third of root #9. (*B*) Periapical radiograph exposed from a distal angulation shows the radiolucency superimposed over the canal, indicating a lingually positioned lesion. (*C*) CBVT demonstrates the axial, sagittal, and coronal 2-D slices of the Heithersay Class 2 ICR, located mesiolingually on tooth #9.

periradicular status was classified as uncertain. However, percussion testing indicated a normal periradicular diagnosis. The diagnosis for the implant at site #30 was retrograde periimplantitis. No root canal treatment was recommended unless #29 became devitalized during subsequent implant removal and curettage of the site. The patient was referred back to the graduate periodontic clinic for evaluation and treatment of site #30. In mid-February, the implant was removed without devitalizing #29 as confirmed by subsequent pulp tests. CBVT information aided in determining the size and extent of a lesion associated with a failing implant.

Discussion

Diagnostic information directly influences clinical decisions. Accurate data lead to better treatment-planning decisions and potentially more predictable outcomes. CBVT is an emerging technology that can offer the clinician clinically relevant information that cannot be gathered from conventional radiography. The ability to assess an area of interest in 3 dimensions eliminates the superimposition that is inherent in conventional radiographic imaging. Cone-beam technology currently has numerous applications in the dental field such as implant treatment planning (20–22), surgical assessment of pathosis (23–25), temporomandibular joint assessment (26, 27), orthodontic evaluation of growth and development (28), preoperative/intraoperative/postoperative assessment of craniofacial trauma, craniofacial reconstruction, and oral surgery (5, 11, 29–31). In addition, CBVT has been used to localize foreign bodies in soft tissues (32), for the evaluation of cleft lip and palate (33), and for the assessment of caries depth in teeth (34, 35). Potential endodontic applications of CBVT include diagnosis of endodontic pathosis (13, 36, 37) and canal morphology (38), evaluation of root fractures and trauma (39), analysis of various types of root resorption (40), assessment of pathosis of non-endodontic origin (23–25), and presurgical planning (41, 42).

CBVT allows each root and its surrounding structures to be evaluated and accurately measured through slices ranging from 0.125–2.0 mm. Regions of interest can be compared over time without the need to replicate the radiation geometry (43). Lascala et al (44) determined that although CBVT images underestimate the distances between skull sites, it was only found to be significant for the skull base. They determined that linear measurements for other structures are reliable. CBVT has been determined to be an accurate, practical, and noninvasive method to reliably determine osseous lesion size and volume in all 3 planes (45). Ludlow et al (46) concluded that both 2-D and 3-D techniques of CBVT provide accurate measurements of mandibular anatomy, regardless of skull orientation during acquisition of the image.

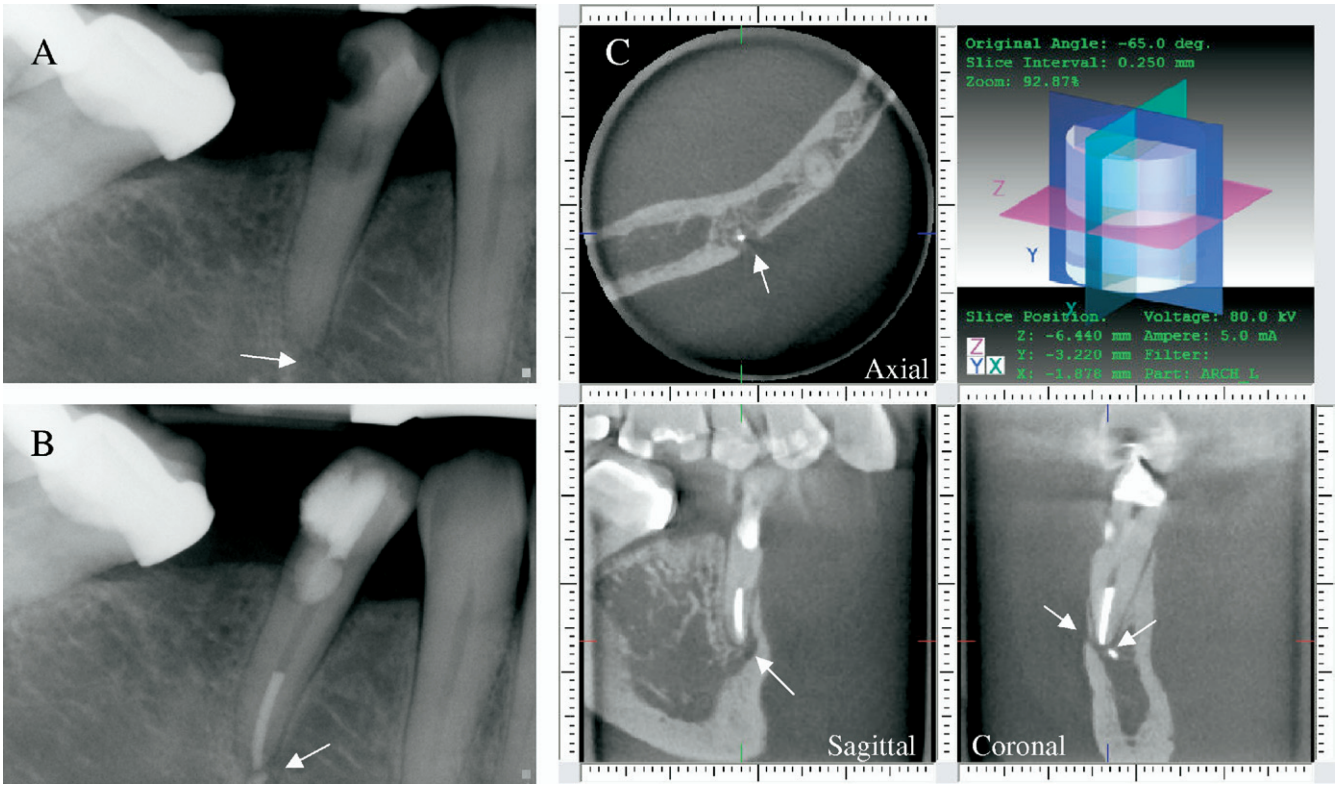

Figure 7. (*A*) Preoperative periapical radiograph depicts the proximity of the mental foramen to the apex of #29. (*B*) Postoperative periapical radiograph shows the obturated root of #29 with extruded material beyond the apex. (*C*) CBVT taken 2 weeks postoperatively demonstrates axial, sagittal, and coronal 2-D slices of the mental foramen as it exits the cortical plate and its proximity to the apex of #29. In addition, the extruded material is visualized to be superior to the mental nerve.

Hashimoto et al (47) compared the image quality of CBVT with medical CT. They found that for both tooth and bone quality, the CBVT yielded higher resolution of images. In the subjective analysis of evaluation of length and homogeneity of root canal fillings, Sogur et al (48) found storage phosphor images to be as good as conventional film images and superior to CBVT. This supports our assertion that cone-beam technology is not meant to replace conventional radiography but rather to serve as an adjunct in acquiring additional diagnostic information.

Intraoral radiography produces images that have objects superimposed upon each other. The observer has to make 3-D decisions on the basis of a 2-D film. CBVT technology now provides the clinician with the ability to observe an area in 3 different planes and thus acquire 3-D information. Lesions confined to cancellous bone with little or no cortical plate erosion can be difficult to diagnose with intraoral film (49–52). Lofthag-Hansen et al (13) compared intraoral radiography with CBVT in the diagnosis of periapical pathosis in human subjects. They found that CBVT enabled the diagnosis of at least 1 periapical lesion in each of 42 teeth as compared with only 32 teeth by using intraoral periapical radiographs. When observing individual roots, 53 lesions were identified with conventional radiography, and an additional 33 lesions were diagnosed with CBVT. It was also found that 70% of CBVT images provided additional, clinically relevant information not found in the periapical radiographs. Stavropoulos et al (36) showed that CBVT has a higher sensitivity, positive predictive value, and diagnostic accuracy than intraoral radiography when evaluating the presence of artificially created bone defects. The additional information provided by a CBVT might allow the clinician to detect a lesion not readily seen with intraoral radiography (13, 36, 37).

The major advantage of CBVT is the elimination of the superimposition of anatomic structures such as the cortical plates or other "complex background" structures (13). An additional advantage is the clinician's ability to view CBVT images in the proximal and axial planes. These advantages make identification of root canals, such as the distolingual canal in Case 1, virtually guaranteed. Small periapical lesions can be properly identified because one no longer needs to "see" through cortical bone to view the cancellous erosion. In addition, this applies to large periapical lesions that have ill-defined borders, in which the cortical bone masks the transition of healthy cancellous bone to pathosis (13, 36).

The interpretation of an image can be confounded not only by the anatomy of surrounding structures but also the teeth themselves. Case 2 demonstrates the use of CBVT in eliminating the superimposition of teeth to view a lesion of non-endodontic origin. In addition, the isotropic nature of CBVT allowed for the accurate calculation of the lesion size without the inherent distortion of conventional periapical radiography. Historically, Roper-Hall (53) concluded that any incisive canal less than 6 mm in diameter could be considered normal. Measurements taken from the CBVT assisted the oral maxillofacial surgeons in confirming the diagnosis of an enlarged incisive canal/foramen.

CBVT might also be used to determine the nature of the periradicular lesion. Simon et al (54) compared the differential diagnosis of large periapical lesions (granuloma vs cyst) by using CBVT with traditional biopsies. Seventeen patients were scanned before root-end surgery and biopsy. Gray values were determined and associated with either fluid-filled or soft tissue-filled lesions. This was used to determine the diagnosis of cyst versus granuloma. Thirteen of 17 cases had a consistent diagnosis between the biopsy and the CBVT. The 4 cases that had a split diagnosis were labeled cysts by CBVT and granulomas by the pathologist. In 2 of the 4 cases, very little tissue was submitted, and in the third case a fluid-filled cavity was found at the time of surgery. In the last

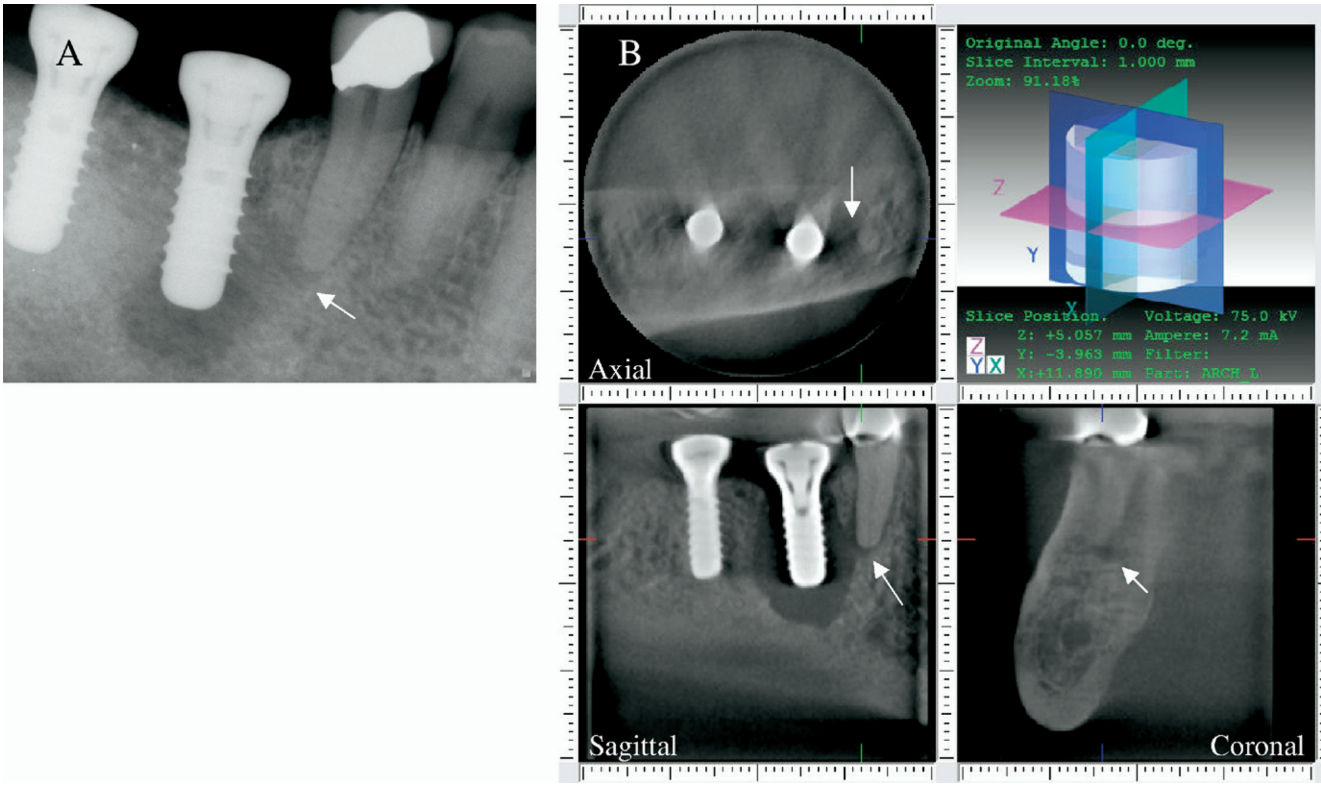

Figure 8. (*A*) Periapical radiograph demonstrates an extensive PIL and its proximity to the apex of #29. (*B*) CBVT shows axial, sagittal, and coronal 2-D slices of the PIL in relation to the apex of #29.

case of the split decision, the pathology report stated "histomorphology also consistent with apical radicular cyst that has undergone inflammatory epithelial destruction." This indicates that CBVT technology and assignment of gray values might aid in the diagnosis of cyst versus granuloma.

Case 3 demonstrated the use of CBVT to aid in the evaluation of root fractures. A standard periapical radiograph would not have discerned the type of fracture seen. According to Gassner et al (55), 86% of traumatic injuries to the maxillofacial region involve either the dentition only or the dentition and the adjacent soft tissues. Film-based intraoral radiography has been the common method for diagnosing root fractures but with poor sensitivity (56). Recently, Cohenca et al (39) specifically addressed the subject of CBVT with regard to its use in the diagnosis of traumatic injuries. Elimination of superimposition of anatomic structures allows the clinician to analyze the fracture clearly. In addition, a 3-D reconstruction can be fabricated of both the tooth and alveolar bone. As stated by Scarfe (5), "CBCT is now able to provide the clinician with the ability to view the dental trauma in multi-planar format."

Treatment of resorption can be complex and unpredictable. Imaging is critical to accurate diagnosis and appropriate treatment. Classically, Gartner et al (57) described the radiographic features of internal and external resorption. Off-angle radiographs have proven to be very useful in differentiating these entities. However, conventional radiography does not provide a true and full representation of the lesion. Conventional radiography is often unable to identify the true extent, location, or the portal of entry of a resorptive lesion. CBVT has been shown to help determine treatment complexity as well as aid the clinician in offering an accurate prognosis on the basis of the extent of the resorptive lesion (40). As a result, both treatment and treatment outcomes are likely to become more predictable.

CBVT used in Case 4 demonstrated the extent of an internal resorptive defect and ultimately aided in determining the type of obturation technique used. In 1973, Frank and Weine (58) described a technique for the repair of a perforation caused by internal resorption. Calcium hydroxide was used to effect lateral periodontal repair, creating a matrix against which to obturate. "Considerable condensation" was required to fill the defect. The axial sections in Case 4 demonstrated minimal residual root thickness. A treatment plan that minimizes condensation force seemed prudent to prevent root fracture and subsequent treatment failure.

Radiographic interpretation is crucial to the diagnosis and treatment of ICR (59). ICR is often misdiagnosed as internal resorption; therefore, identification of the portal of entry is critical (19, 60). Gulsahi et al (61) recently discussed the benefits of 3-D imaging in the diagnosis of ICR. Although they admitted that 3-D imaging is not necessary for all cases of ICR, select cases might benefit from this additional survey. In Case 5, we were able to not only identify the size, location, and portal of entry of the lesion but also the exact subosseous extent of the lesion. This information was invaluable in determining the amount of extrusion needed if orthodontic extrusion was used to manage this multidisciplinary case. Little or no extrusion could lead to a massive bony defect. Too much extrusion could result in a drastic change in the emergence profile and make an esthetic restoration difficult to achieve.

The use of CBVT technology in presurgical endodontic planning allows for assessment of the location of the lesion, position of the roots within the bone, and the proximity of vital structures including the inferior alveolar nerve, mental foramen, maxillary sinus, and nasal cavity (44–46). Traditionally, a surgeon would request a medical CT scan if an intraoral or panoramic radiograph was insufficient. With the arrival of CBVT, clinicians can view images that have much better tooth and bone quality as compared with a medical CT scan (47).

Tsurumachi and Honda (42) presented a case report with CBVT technology as a diagnostic aid in a hemisection surgery that involved removing a separated instrument. A study by Rigolone et al (41) used CBVT to assess the horizontal distance from the buccal cortical plate to the palatal root. In 43 maxillary first molars, they found a mean distance of 9.73 mm. In addition, the maxillary sinus was found to be present between the buccal and palatal roots 25% of the time. This presurgical information could influence the surgical approach to the palatal root. Ito et al (62) found that CBVT technology provided excellent diagnostic information for evaluating the morphology of the mandible and the location of the inferior alveolar nerve and mental foramen. Nakagawa et al (63) showed that the presurgical application of CBVT was an asset in locating lesions, mandibular canals, and the maxillary antrum.

Case 6 provided a good example of locating the inferior alveolar nerve and mental foramen in relation to the apex of a mandibular premolar. The CBVT allowed for better visualization of extruded material and its proximity to the mental nerve. Although surgery was not needed in this case, CBVT clearly demonstrated the association of vital structures to a potential surgical site.

The management of a failing implant might require removal and curettage. Proper assessment of the extent of the lesion might influence the clinician's approach to treatment as a result of the proximity of critical adjacent structures. Case 7 demonstrated the value of CBVT to determine the exact size and extent of the lesion associated with #30 implant. Sussman and Moss (64) introduced the idea of implant periapical pathology. A PIL or retrograde periimplantitis can result from bacterial contamination during insertion, overheating or fenestration of the bone during surgery, premature loading resulting in microfractures, preexisting bone disease, residual root tips, or the presence of preexisting inflammation (65–68). Brisman et al (69) also attributed implant failures to adjacent asymptomatic endodontically treated teeth. Therein lies controversy, as addressed by Hutter (70) in his letter to the editor. Regardless, endodontists may be called on to determine whether adjacent teeth are contributing to implant failure. Although a CBVT was not necessary in Case 7 for the normal pulpal diagnosis of #29, the ability of CBVT to eliminate superimposition of cortical plates allowed for a more accurate assessment of the extent of #30 PIL. Most importantly, the CBVT data assisted the surgeon in planning the removal of the implant and curettage of the lesion with the objective of preserving adjacent vital structures.

Despite the obvious advantages CBVT technology offers to dentistry, there are some drawbacks and limitations. At this point in time CBVT is limited to major metropolitan areas and is not found in every state. As the technology evolves and is embraced by clinicians, the availability of CBVT will become more widespread.

Although CBVT technology has been in the marketplace for several years, it is still very expensive. Machines range from \$150,000–\$400,000. This is cost-prohibitive for most clinicians. An alternative would be to refer a patient to an imaging center in which the CBVT scan is performed and read by a dental radiologist. This follows the medical model of imaging. Although surveys might cost as much as \$300–\$400, the additional information in properly selected cases may be worth the added expense.

Limitations also include medicolegal issues pertaining to the acquisition and interpretation of CBVT data. Various dental applications of CBVT (e.g., oral and maxillofacial surgery) require a large FOV to capture all maxillofacial structures within the volume. There is growing concern among oral and maxillofacial radiologists that dentists without proper training should not perform or interpret CBVT surveys (9). Interpretation of these images requires extensive knowledge of various maxillofacial structures as well as training in cross-sectional anatomy. A recent case report illustrated the need to have a qualified radiologist interpret imaging studies (71). Nair et al (71) described an incidental finding of an intracranial aneurysm during the CBVT evaluation of a mandibular swelling. It is crucial that the entire captured volume is read in detail to prevent missing a potentially life-threatening lesion.

Most endodontic applications only require a small FOV (40×40 mm). Limiting the FOV not only reduces dosage, scan time, and scatter artifacts, but it also focuses the volume on structures familiar to dentists. Scarfe et al (9) argued that dentists with proper training and experience should not be excluded from performing CBVT imaging. In addition to using a limited FOV, we suggest that graduate endodontic programs incorporate training that reflects the new reality of 3-D imaging.

The routine use of CBVT technology in endodontics is fast approaching. What does the future hold with regard to endodontics and cone-beam technology? Whether clinicians choose to purchase a machine or have the imaging done by a dental radiologist at an imaging center, it is certain that more and more endodontists will be incorporating this technology into their practice.

Future applications of CBVT might include concepts such as virtual 3-D learning. High success rates of nonsurgical root canal treatment (72–75) and nonsurgical retreatment (76) have lead to a decline in endodontic surgical procedures. Because repetition is essential in mastering surgical techniques and developing the necessary skills to achieve predictable surgical outcomes, virtual periradicular surgery training might prove to be of great benefit. Virtual surgery can offer a 1:1 visualization of bony reduction and a realistic drilling sensation by using force feedback, shutter glasses, and 3-D reconstructions of CBVT data (77). Von Sternberg et al (78) have shown that novice surgeons who received presurgical virtual training had a 6-fold increase in the probability of preserving critical adjacent structures. Experienced surgeons might also find surgical simulation useful in planning complex surgical procedures (78).

In conclusion, CBVT technology aids in the diagnosis of endodontic pathosis and canal morphology, assessing root and alveolar fractures, analysis of resorptive lesions, identification of pathosis of non-endodontic origin, and presurgical assessment before root-end surgery. When compared with medical CT, CBVT has increased accuracy, higher resolution, reduced scan time, a reduction in radiation dose, and reduced cost for the patient (10, 11). As compared with conventional periapical radiography, CBVT eliminates superimposition of surrounding structures, providing additional clinically relevant information (13). Drawbacks of CBVT include limited availability, significant capital investment, and medicolegal considerations. As CBVT technology evolves, clinicians will be able to adopt 3-D imaging into their diagnostic repertoire. Because accurate diagnostic information leads to better clinical outcomes, CBVT might prove to be an invaluable tool in the modern endodontic practice.

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