Cone beam computed tomography: a new era in diagnosis and treatment planning

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Clinical examination and diagnostic imaging are both essential components of endodontic preoperative diagnosis and treatment planning. Clinical examination must be carried out before considering any radiographic examination. Accurate diagnostic imaging supports the clinical diagnosis and allows the clinician to better visualise the area in question. Preoperative imaging is an essential part of endodontic practice, from diagnosis and treatment planning to outcome assessment.

Conventional two-dimensional radiographs continue to be the most popular method of imaging today. However, the diagnostic potential of periapical radiographs is limited. Information may be difficult to interpret, especially when the anatomy and background pattern is complex. Intraoral radiographs have inherent limitations due to the compressed three-dimensional structures in a two-dimensional image. Interpreting the film-based radiograph or digital image continues to be a somewhat subjective process. Goldman and colleagues showed that the agreement between six examiners was only 47% when evaluating healing of periapical lesions using two-dimensional periapical radiographs (1972). In a follow-up study, Goldman and colleagues also reported that when examiners evaluated the same films at two different times, they only had 19%-80% agreement with their previous interpretations (1974). In a recent study, interobserver and intraobserver reliability in detecting periradicular radiolucency by using a digital radiograph system was evaluated. Agreement among all six observers for all radiographs was less than 25%, and agreement for five of six observers was approximately 50% (Tewary, Luzzo and Hartnell, 2011).

New radiographic imaging systems have recently become available for use in dentistry. Among these new imaging technologies is cone beam volumetric tomography (CBVT). In 2000, the US Food and Drug Administration approved the first cone beam computed tomography (CBCT) unit for dental use in the USA. CBCT systems are available in different field of views (FOV): CBCT limited (dental) ranges in diameter from 40-100mm or full (ortho or facial) CBCT ranges from 100-200mm. The voxel size is generally smaller for the limited version (0.1-0.2mm vs 0.3-0.4mm), thus offering higher resolution and greater utility for endodontic applications. For endodontic application, the limited field of view is the most acceptable as it is capable of providing images at a low radiation dose and with sufficient spatial resolution for applications in endodontic diagnosis and treatment planning.

The advent of CBCT can overcome these issues by visualising the dentition and the relationship of anatomic structures in three dimensions. CBCT units reconstruct the projection data to provide interrelational images in three orthogonal planes (axial, sagittal and coronal). For most endodontic applications, limited or focused FOV CBCT is preferred over large volume CBCT. This article will review the utilisation of CBCT in endodontic diagnosis and management of periapical pathology, diagnosis of pain, cracked teeth and vertical root fractures, internal and external resorptive defects.

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Figure 1: Patient presented for diagnosis of a non-localised pain in the left quadrant. Periapical radiographs of the upper and lower quadrants were inconclusive (A and B). All vitality, periodontal and palpation tests were WNL. Tooth #14 was slightly tender to percussion. Anaesthetic test was performed by administering 2% lidocaine 1:100:1000. Pain was not relieved. CBCT was taken for both quadrants; C is a sagittal view of tooth #18 demonstrating an internal resorptive defect in the distal root. Line in C represents the axial section in E; D is a three-dimensional reconstruction of the cropped distal root showing the extent of the resorptive defect; F is a clinical image of a distal crack that extends into the distal canal.

Figure 2: This represents the complex anatomy of tooth #18 that was referred for root canal therapy. A – axial view of the mesial and distal roots of tooth #18. Note the mid-mesial canal in the mesial root [black arrow]; B is a three-dimensional rendering of tooth #18 demonstrating the mid-mesial canal (blue arrow); C – coronal view of tooth #18 demonstrating the complexity of the three mesial canals (red arrow); D is a working length measurement of the three mesial canals; E is postoperative axial view demonstrating the root canal fillings in three mesial canals; F – three-dimensional rendering and coronal view demonstrating the root canal filling in the mesial canals. Note the similarity from the preoperative coronal view in C; G – three-dimensional rendering.
Imaging application
While there are presently no definitive patient selection criteria for the use of CBCT in endodontology, the use of CBCT in endodontic diagnosis and treatment should not be avoided or ignored. In May 2015, an updated joint position statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology was published, with the intention of providing scientifically based guidance to clinicians regarding the use of cone beam computed tomography in endodontic treatment and reflect new developments since the 2010 statement. The updated statement addressed the potential applications of cone beam computed tomography in different phases of treatment.

Potential applications of cone beam computed tomography in endodontic practice are as follows.

Utilisation of cone beam computed tomography in endodontic diagnosis of pain and detection of periapical lesions
Endodontic diagnosis is dependent upon evaluation of the patient’s chief complaint, medical and dental history, clinical and radiographic examination. Preoperative imaging is an essential part of endodontic practice, from diagnosis and treatment planning to outcome assessment.

CBCT imaging has the ability to detect periapical pathology prior to being apparent on two-dimensional radiographs (De Paula-Silva et al., 2009). This was validated in clinical studies in which periapical periodontitis detected in intraoral radiographs and CBCT was 20% and 48% respectively (Patel et al., 2012). Ex vivo studies in which simulated periapical lesions were created showed similar findings (Sogur et al., 2012; Patel et al., 2009a).

Diagnosis of pain is a challenging process for the clinician prior to and after treatment. In challenging diagnostic pain cases, the clinical and radiographic evaluation of the patient is inconclusive. Inability to determine the aetiology of the pain can be attributed to the limitations in both clinical vitality testing and intraoral radiographs to detect the aetiology of the source of the pain.

Persistent pain following root canal therapy presents with a diagnostic challenge to the clinician. Atypical odontalgia (AO) is an example of persistent dentoalveolar pain (Nixdorf and Moana-Filho, 2011). The diagnostic yield of intraoral radiographs and CBCT was evaluated in the differentiation between patients presenting with apical periodontitis and suspected AO without the evidence of periapical bone destruction. CBCT imaging detected 17% more teeth with apical bone loss (apical periodontitis) than intraoral radiographs (Pigg et al., 2011). Figure 1 is an example of a case that presented with non-localised pain. CBCT imaging information was able to aid in the determination of the aetiology of the odontogenic pain.

Utilisation of cone beam computed tomography in preoperative anatomy assessment
The success of endodontic treatment depends on the identification of all root canal systems so that they can be treated. The efficacy of CBCT as a modality to accurately explore tooth anatomy and identify the prevalence of a second mesiobuccal canal (MB2) in maxillary molars when compared to the gold standard (clinical and histologic sectioning) has been well documented (Blattner et al., 2010; Michetti et al., 2010). CBCT showed higher mean values of specificity and sensitivity when compared to intraoral radiographic assessments in the detection of the MB2 canal (Vizzotto et al., 2013). Figure 2 is an example of using the three-dimensional rendering in determining the presence and location of canals in lower mandibular molar (UR8) prior to root canal therapy.

Utilisation of cone beam computed tomography in endodontic diagnosis and detection of cracked teeth and vertical root fracture
Two-dimensional radiographs are of limited value for the diagnosis of VRFs and usually only provide indirect evidence of the presence of a VRF. Several studies have demonstrated the validity of utilising CBCT to detect VRFs. In a comparative study evaluating the sensitivity and specificity of CBCT and periapical radiographs (PR) in detecting VRFs, sensitivity and specificity for VRF detection of CBCT were 79.4% and 92.5% and for PR were 37.1% and 95%, respectively. The same study reported that the specificity of CBCT was reduced in the presence of root canal filling material (Hassan et al., 2009). Higher sensitivity and specificity were observed in a clinical study where the definitive diagnosis of vertical root fracture was confirmed at the time of surgery to validate CBCT findings, with sensitivity being 88% and specificity 75% (Edlund, Nair and Nair, 2011).

Several case series studies have concluded that CBCT is a useful tool for the diagnosis of vertical root fractures. In vivo and laboratory studies (Metska et al., 2012; Brady et al., 2014) evaluating CBCT in the detection of vertical root fractures agreed that sensitivity, specificity, and accuracy of...
CBCT were generally higher and reproducible. The detection of fractures was significantly higher for all CBCT systems when compared to intraoral radiographs. However, these results should be interpreted with caution because detection of vertical root fracture is dependent on the size of the fracture, presence of artifacts caused by obturation materials and posts, and the spatial resolution of the CBCT. In a recent study, the diagnostic ability of a CBCT scan to assess longitudinal root fractures in prosthetically treated teeth was evaluated (Melo et al, 2010). The presence of gutta-percha or cast-gold posts reduced the overall sensitivity and specificity. This was attributed to star-shaped streak artifacts that mimics fracture lines in axial spatial views.

One significant problem, which can affect the image diagnostic quality and accuracy of CBCT images, is the scatter and beam hardening caused by high density neighboring structures, such as enamel, metal posts and restorations. If this scattering and beam hardening is associated close to or with the tooth being assessed, the overall sensitivity and specificity is dramatically reduced.

Clinically, a thorough dental history, classic clinical and radiographic signs and symptoms such as pain, swelling, presence of a sinus tract and/or presence of an isolated deep periodontal pocket can be helpful hints to suggest the presence of a VRF. Radiographically, a combination of periapical and lateral root radiolucency ‘halo’ appearance is valuable information, indicating the possible presence of VRF. Several of the previously mentioned clinical and radiographic elements have to align to establish a presumptive diagnosis of VFR (Tsesis et al, 2010); however, dye examination, usually requiring surgical exposure, is still the gold standard for diagnosis of VRF.

In a case series, the following five findings on CBVT exam were consistent with confirmed VRF (Fayad, Ashkenaz and Johnson, 2012): 1) loss of bone in the mid-root area with intact bone coronal and apical to the defect; 2) absence of the entire buccal plate of bone in axial, coronal and/or three-dimensional reconstruction; 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) visualisation of the VRF on the CBCT spatial projection views. Figures 3, 4 and 5 are different examples of the sensitivity of CBCT imaging in the diagnosis of cracked teeth and VRF.

Figure 3: A – periapical radiograph of tooth #30. B – coronal view of the distal root demonstrating the space between the distal root and the buccal cortical plate (black arrow); C – axial view of the distal root demonstrating the space between the distal root and the buccal cortical plate (white arrow); D – three-dimensional reconstruction of the distal root demonstrating the space between the distal root and the buccal cortical plate; E – clinical digital image after surgical sectioning and extraction and confirmation of distal root VRF.
Utilisation of cone beam computed tomography in non-surgical and surgical treatment planning

Diagnostic information directly influences treatment planning and clinical decisions. Accurate data leads to better treatment decisions and potentially more predictable outcomes (Liang et al, 2011). Ee and colleagues compared endodontic treatment planning with CBCT and periapical radiography (2014). Thirty endodontic cases completed in a private endodontic practice were randomly selected to be included in this study. Each case was required to have a preoperative digital periapical radiograph and a CBCT scan. Three board certified endodontists reviewed the 30 preoperative periapical radiographs. Two weeks later, the CBCT volumes were reviewed in random order by the same evaluators. The evaluators were asked to select a preliminary diagnosis and treatment plan based solely on interpretation of the periapical and CBCT images. Diagnosis and treatment planning choices were then compared to determine if there was a change from the periapical radiograph to the CBCT scan.

Under the conditions of the previous study, CBCT was a more accurate imaging modality for diagnosis of endodontic pathology when compared to diagnosis using only periapical radiographs. An accurate diagnosis was reached in 36.6% to 40% of the cases when using periapical radiographs compared to an accurate diagnosis in 76.6% to 83.3% of the cases when using CBCT. This high level of misdiagnosis is potentially clinically relevant, especially in cases of invasive cervical root resorption and vertical root fracture where a lack of early detection could lead to unsuccessful treatment and tooth loss. The previous study also demonstrated that the treatment plan may be directly...
The use of CBCT has enabled the clinician to evaluate the true extent of the periapical lesion and their spatial relationship to important anatomical landmarks and vital structures (Figures 8-10).

Utilisation of cone beam computed tomography in endodontic diagnosis and detection of inflammatory restorative defects

Diagnosis and detection of root resorption is often challenging due to the quiescent onset nature and varying influenced by information gained from a CBCT scan as the examiners altered their treatment plan after viewing the CBCT scan in 62.2% of the cases overall (range from 56.6% to 66.7%). This high number indicates that CBCT had a significant influence on the examiners’ treatment plan (Figures 6 and 7).

The use of CBCT has been recommended for treatment planning of endodontic surgery (Venskutonis et al., 2015; Bornstein et al., 2011; Low et al., 2008). CBCT visualisation of the true extent of periapical lesions and their proximity to important vital structures and anatomical landmarks is superior to that of periapical radiographs. The use of CBCT has enabled the clinician to evaluate the true extent of the periapical lesion and their spatial relationship to important anatomical landmarks and vital structures (Figures 8-10).

Figure 6: A – a periapical radiograph of teeth #7 and 8. Treatment was initiated on both teeth before referral to an endodontist. Treatment was initiated on both teeth (initial treatment #7 and retreatment attempt on #8); B – a clinical picture showing normal soft tissue color and architecture; C and D are sagittal CBVT images showing buccal perforations on teeth #7 and 8, respectively

Figure 7: Continued: A and B are three-dimensional reconstructions showing the buccal perforations on teeth #7 and 8 (black and blue arrows); C – reflection of a full-thickness mucoperiosteal flap confirmed the presence of perforations on both teeth. The perforations were repaired with Geristore (Denmat). Both teeth were then treated via an orthograde approach with subsequent surgical root end resection and filling of tooth #8; D and E – one-year recall radiograph demonstrating soft and hard tissue healing
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offers a limited diagnostic potential when compared to three-dimensional imaging (Estrela et al, 2009; Durack et al, 2011) (Figures 11-13).

clinical presentation. Definitive diagnosis and treatment planning is ultimately dependent on the radiographic representation of the disease. Two-dimensional imaging

Figure 8: A – periapical radiograph of tooth #3 that was referred for periapical surgery. A non-surgical retreatment attempt was performed prior to periapical microsurgery. Mesiopalatal canal was blocked. The black line corresponds to the level of the axial view in E; B – sagittal view demonstrating the extent of the periapical defect; C – three-dimensional rendering of the periapical defect; D – clinical picture demonstrating the endodontic/periodontal communication; E – axial view of the mesial, distal and palatal roots. Note the fused distal and palatal roots; F and G are the coronal view of the mesial root and the fused distal-palatal roots respectively.

Figure 9: Continued: A – three-dimensional rendering demonstrating the periodontal defect at the marginal bone (black arrow); B – after flap reflection demonstrating the periodontal defect communicating with the periapical defect (blue arrow); C – root resection of the fused distal and palatal roots prior to ultrasonic preparation; D – MTA root end filling of the ultrasonically prepared distal and palatal preparation; E – periodontal and periapical defects grafted with Purus allograft (Zimmer Dental) material; F – grafted defect covered with Copios membrane (Zimmer Dental)
Figure 10: Continued: A1, 2, 3 and 4 – immediate surgical CBCT scan. Note buccal defect (red and yellow arrows); B1, 2, 3, and 4 – six months recall CBCT scan. Note the initial regeneration of the defect including the buccal cortical plate; C1, 2, 3, and 4 – one-year recall CBCT scan demonstrating complete remodeling of the defect and the buccal plates (red and yellow arrows).

Figure 11: A is a periapical radiograph of tooth #14 that was referred for experiencing spontaneous pain as well as temperature sensitivity. Clinical testing revealed an irreversible pulpitis and symptomatic apical periodontitis; B – CBCT sagittal view of tooth #14 showing an invasive cervical resorptive defect (ICR) class IV that cannot be detected on the periapical radiograph; C – axial view demonstrating the palatal and mesial location of the defect; D is a coronal view demonstrating the internal aspect of the (ICR) rendering tooth #14 non-restorable. Change in treatment plan was made and patient was referred for extraction.
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Several studies have evaluated the use of CBCT in endodontics (Patel et al, 2015; Cotton et al, 2007; Patel et al, 2009b; Patel, 2009; Scarfe, Farman and Sukovic, 2006; Nair and Nair, 2007). Cone beam computed tomography overcomes many of the limitations of periapical radiography. The increased diagnostic information provided by a CBCT image should result in more accurate diagnosis and improved decision-making for the management of complex endodontic problems. It is a desirable addition to the endodontist’s armamentarium.

The effective radiation dose to patients when using CBCT is higher than conventional two-dimensional radiography and the benefit to the patient must therefore outweigh any potential risks of the additional radiation exposure. Radiation dose should be kept as low as reasonably achievable (ALARA) (Farman and Farman, 2005a; Farman, 2005b). The value of CBCT for endodontic diagnosis and treatment planning should be determined on an individual basis to assure that the benefit/risk assessment supports the use of CBCT.

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Conclusion

Figure 12: Patient was referred for evaluation and treatment of an internal resorptive defect on tooth #9. A is a periapical radiograph of tooth #9. The three lines correspond to the axial section views in D, E and F. Note mid-root radiolucency; B is a three-dimensional reconstruction of maxillary anterior teeth demonstrating the internal resorptive defect (black arrow); C is a sagittal view of tooth #9 with the 3.3x4.8mm dimension measurement of the defect; D, E, and F are axial views of tooth #9. Note the normal canal anatomy coronal and apical sections to the defect (D and F). The maximum width of the defect is demonstrated in axial view (E)
References
Hassan B, Metska ME, Ozok AR, van der Stelt P,


