Cone beam computed tomography and other imaging techniques in the determination of periapical healing

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To be able to determine if endodontic treatment of apical pathosis is successful or not, healing of lesions is followed up by radiographic imaging. This can be done by observing changes in apical radiolucencies. Recently, cone beam computed tomography (CBCT) has been introduced as a method of gaining an unabridged view of dental anatomy, thus eliminating some of the most prevalent problems, such as superimposition and distortion. CBCT reduces false diagnosis and is rapidly replacing other radiographic techniques in diagnosis, quality control of treatment methods and techniques, and outcome assessment. Healing assessment using conventional and newer three-dimensional imaging includes, but is not limited to, periapical osseous lesions, conditions of the maxillary sinus, status after endodontic surgery, hard tissue deposition in regeneration procedures, and horizontal root fractures. Due to a low predictive value of two-dimensional periapical radiographs to distinguish between periapical disease and health, future assessment of endodontic treatment efficacy may include 3D imaging from small field-of-view CBCT units.

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Introduction

Endodontic disease has been characterized by the presence of periapical inflammation (1). The occurrence of disease can remain unnoticed for prolonged periods of time or a patient in pain may seek dental care. Clinically, the existence of apical pathosis may be detected by sensitivity to biting or percussion, but asymptomatic apical periodontitis frequently does not elicit such a response. Symptomatic apical periodontitis is caused primarily by penetration and colonization of root canal space by a wide-ranging microbial flora (2). Continuous egress of pro-inflammatory microbial products from an endodontically infected tooth stimulates the host to develop periapical inflammation and bone loss (3,4), frequently as a chronic process with little or no symptoms (5–7). To rule out problems with adjacent teeth or other local factors as source of any symptoms, routine pulp sensibility testing is typically executed. Unfortunately, these clinical tests are not always accurate (8,9). A significant weakness of most such tests is that they only give an assessment of the neural reaction to thermal stimuli and no information about the state of pulpal vasculature and blood supply (10). Both false positive and false negative results can occur. Thermal tests may indicate or support suspected pulpal pathosis or apical periodontitis but they are unreliable in the presence of pulp canal obliteration (11) immature teeth (12), trauma (13) and multirooted teeth (14). Unless there
is an obvious indication of an acute or chronic abscess, such as localized swelling or a sinus tract, determination of the location and progression of an apical periodontitis lesion is not feasible without radiographic imaging.

A dental practitioner will then expose the affected tooth or area site to one or more radiographs (11,15). Radiography is an irreplaceable adjunct to clinical examination and is often the only way to determine the presence of disease, as periradicular inflammatory or cystic lesions with bone resorption are mainly detected by their radiological features. To diagnose pathosis and to determine the extent and location of dental infection, clinicians have used radiographic images since the late nineteen hundreds (16). Conventional intraoral periapical radiography remains the standard for radiological diagnosis of existence, persistence or healing of apical periodontitis. Digital radiography has become widespread since the 1980s; it reduced patient dose and eliminated development time (17). Cone beam computed tomography (CBCT) has been introduced in the 1990s and has found a variety of indications in endodontics (18,19). It has also been suggested to be superior in detecting periapical bone loss in situations where no pathosis was detected in periapical radiographs (20).

Non-surgical and surgical root canal treatment for cases with periapical pathosis predictably results in a high frequency of success, as determined by healing of the osseous lesion (21). Diagnostic procedures that show such healing are required for root canal treatment outcome assessment. However, endodontic healing may also be defined in a wider sense (see Table 1) to include hard tissue deposition after vital pulp therapy or pulp regeneration as well as root fracture healing. The following text will explore the ability and limitations of radiographic techniques to detect presence and resolution of periapical periodontitis, with a focus on cone beam computed tomography (CBCT).

### Imaging techniques to detect periapical changes

An important question when deciding about success or failure of an endodontically treated tooth with apical periodontitis is: What is the best tool to evaluate outcomes?

Factors cited to verify that treatment was successful include functionality, with retention of the tooth in the patient’s mouth, a symptom-free situation, radiographic healing of the radiolucency and absence of inflammation (21–24). Methods to evaluate bone healing include clinical examination, radiographic images taken with intraoral and extraoral techniques, radiographic subtraction techniques (25,26), ultrasound (27,28), MRI (29,30), tuned aperture computed tomography (TACT) (31,32), computed tomography (CT) (33,34) and CBCT (18,35).

### Intraoral radiography

Worldwide, conventional periapical radiographs continue to provide the primary means of pre-treatment and follow-up evaluation of endodontic therapy and are used in most retrospective assessments (Fig. 1) (21). Ørstavik recalled patients with preoperative periapical lesions to monitor healing. After 4 years 75.4% of the lesions had healed and

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<th>Condition/procedure</th>
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<td>bone fill</td>
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<td>dog</td>
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<td>bone fill</td>
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<td>trauma</td>
<td>horizontal fracture healing?</td>
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<td>direct pulp capping</td>
<td>hard tissue bridge?</td>
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<tr>
<td>Regenerative endodontics</td>
<td>root lengthening, root bulk increase</td>
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$ no published cases (Dr. Lars Bjørndal, personal communication)
12.7% demonstrated signs of “incomplete healing” (23). Molven’s group (36,37) compared radiographic diagnoses by comparing endodontic outcomes in two series of intraoral radiographs that were exposed 10–17 and again 20–27 years after initial therapy. Healing of lesions after more than 17 years was observed in 6.4% of the roots that had radiolucencies at the first follow-up appointment. This gives reason to believe that outcome tracking may need to be extended. On the other hand statistical analyses based on periapical radiographs suggest that the vast majority of lesions heal in a 4-year time frame (38).

Histological assessment of serial bone sections, with the treated tooth embedded in alveolar bone are the gold standard that allows a final decision about if healing was successful. However, these studies are not clinical and mostly limited to examination of teeth in deceased patients. Green et al. (39) studied 29 cadaver teeth and discovered that 26% of teeth that appeared radiographically healthy showed histologic evidence of slight to moderate inflammation. The authors concluded that periapical lesions correlated with inflammation, but the absence of a radiolucency did not signify histologic health.

Fig. 1. Classical follow-up series with conventional periapical radiographs. Pre-operative and post-operative films of the tooth apex are mounted for assessment. Note: The final six digits show date of exposure (e.g. 870626 = June 26, 1987). Reprinted with permission from Ørstavik & Pitt Ford, 2008 (139).
Subtraction radiography

Subtraction radiography is a technique to enhance contrast and detection ability for subtle changes in conventional radiographic films; the technique uses standardized intraoral radiographs taken with film holders that are individualized with impression material. Using appropriate image editing software, pre- and postoperative images can be subtracted, eliminating all structures that are identical in the two images. Digital subtraction radiography was more sensitive to detect small changes in cortical and cancellous bone in periapical lesions than conventional radiography that used morphometric analysis with outlining and area calculation (40). In addition, more changes in bone were observed with healing evident very early after treatment (41,42) (Fig. 2).

Extraoral radiography (panoramic)

Panoramic radiographs are good screening and overview images for teeth, TMJ, sinuses, nasal cavity and maxilla and mandible. However, this type of image is not recommended to detect details in caries diagnostics, periodontal bone assessment, apical pathosis and as tool to follow up on healing of radiolucencies. Molander (43) compared diagnostic yields of panoramic and periapical radiographs. The consensus reached between the two radiographic techniques in periapical diagnosis was 55% for the extraoral and 46% for the intraoral technique. The conclusion of the authors was that there is not sufficient radiographic agreement for panoramic radiography to be used as a stand-alone tool to diagnose periapical lesions, marginal bone loss or caries and that additional, intra-oral radiographs are required to assure comprehensive evaluation of both periapical and periodontal status (43,44).

Computed tomography (CT)

The usefulness of three-dimensional techniques for the detection of periapical osseous lesions has been described specifically when preparing for surgical endodontics (34). Indeed, well-documented limitations of two-dimensional radiographic techniques such as
conventional periapical films make 3D assessment of periapical lesions attractive (45) (Fig. 3).

Medical-grade CT units have been used in oral and maxillofacial surgery since the 1970s, but there are several disadvantages in comparison to CBCT that have led to a rapid decline in use. Firstly a two-hundred fold higher patient dose limits the use to select cases after a risk-benefit calculation has been performed. The field of view has become more suitable for the head and neck region, but it is not possible to restrict it to small regions such as quadrants of a patient. Metal and movement artifacts can pose a considerable problem due to longer scanning times (30).

**Tuned aperture computed tomography (TACT)**

TACT represents yet another form of radiographic imaging and is essentially a three-dimensional image-forming algorithm that can be used with any type of digital imaging system (46). It produces 3D data from several regular radiographs of a given area. Unlike other 3D images, the raw images used are not required to have a rigid, identical orientation. TACT was able to accurately detect osseous healing in surgical defects (32).

Nair et al. used a common digital x-ray source that they moved along a curved plane around the region of interest where surgery had been performed. On this plane, nine arbitrary projections were taken between 9 degrees and 20 degrees to either side of the central projection axis (47). The gray level measurements calculated from conventional radiographs, TACT slices and iteratively restored TACT (with artifacts subtracted) were correlated with histological analysis. Iteratively restored TACT showed the best correlation between radiographic findings and biopsy histology (46). The diagnostic performance of TACT has been described as comparable to CT (32).

A single digital radiograph exposes a patient to approximately 1–5 μSv of radiation dose (48–50). TACT requires several radiographs to be exposed. Taking into account that a small field-of-view CBCT scans is roughly the size of a periapical film, with a patient dosage of 1 to 3 conventional periapical radiographs, TACT does not appear to be in widespread use at this point.

Fig. 3. The use of computed tomography to track periapical healing after surgical endodontic treatment of tooth 39 (#19). (A) Periapical radiograph for initial diagnosis. (B) Sagittal slice showing the outline of the periapical lesion (arrows). (C) Periapical radiograph: follow-up, 8 years after surgical treatment. (D) Sagittal slice showing bone repair (arrows) between the mesial and distal roots of tooth 19. Modified with permission from Tanomaru-Filho et al., 2010 (45).
Cone beam computed tomography (CBCT)

CBCT units were introduced for use in the maxillofacial region in the late 1990s by two groups of researchers, an Italian group led by Mozzo (51) and a Japanese group spearheaded by Arai (52). In the past twelve years, the technique has rapidly gained acceptance by specialties, in particular orthodontics, endodontology, implantology and oral and maxillofacial surgery. Research and clinical applications increased in the fields of restorative dentistry (53) and periodontology (54). The dental community in general is becoming more aware of the advantages that this technique can offer to them and their patients, in particular for diagnosis and treatment planning. Position statements and guidelines about indications for CBCT in dental diagnosis and treatment of surgical and non-surgical cases have been issued jointly by the American Association of Endodontists and American Academy of Oral and Maxillofacial Radiography (55) as well as other organizations (56,57).

While medical CT scans have been used for improved surgical treatment planning in oral and maxillofacial surgery since the 1970s (34,58,59), CBCT scans afford a three-dimensional view of the oral and maxillofacial region at increased resolution, reduced radiation dose to the patient, shorter scanning time and lower cost compared (50,60,61). CBCT is not indicated as a routine technique in detection of apical periodontitis. Current recommendations stipulate that CBCT is to be used for specific clinical indications only and as possibly an adjunctive imaging technique (18). This includes cases that exhibit pain and clinical signs of inflammation but no periradicular correlate on periapical radiographs (62). Only recently, CBCT has been introduced as possible means for follow-up of periapical healing (Fig. 4).

Problems in radiological diagnosis of periradicular pathosis

Image quality

Ideally, follow-up digital dental radiographs are taken with an individual x-ray holder to ensure that the depicted area corresponds to the target region. Tube voltage and current, exposure time, type of radiograph and film size should be the same on recall images as on the original that it is compared to. All radiographs should be obtained by using the same digital imaging system to ensure similar quality. In a study that investigated the implementation of quality assurance requirements, conducted by Hellstern & Geibel, 8.5% of the images were classified as distorted, i.e. elongated or foreshortened (49).

In CT and CBCT images, dental fillings, root canal fillings, posts and dental implants, often show dark bands and cupping artifacts due to attenuation and scattering of x-ray beams (63,64). These image faults can considerably downgrade the diagnostic quality of a scan, influence decision-making and reduce the accuracy of CBCT-based treatment planning. Software for artifact reduction can adapt to the atomic number (Z) of implants and thus to the amount of backscatter or attenuation. Projections through high-Z implants,
like gold, can lead to almost complete extinguishing of x-ray caused gray values while projections through low-Z implants, like titanium, are corrected for the hardening of x-ray beams. An automatic regulation method can replace these values by estimates based on other projections or correct beam hardening accordingly (63). Computer hardware modifications with built-in copper pre-filtration were used to suppress but not completely eliminate cupping artifacts caused by beam hardening. Additional corrections with a subtraction algorithm address scatter contamination and eliminated cupping on CBCT images (65).

Detection threshold for lesions

On the one hand, periapical radiographs are taken to determine number and location of roots and root canals but on the other hand to confirm absence or presence of periapical pathosis (66). In initial stages, radiographic widening of the periodontal ligament space indicates destruction of apical tissues by an inflammatory process. This widening increases to a typical radiolucency with or without clear borders that progressively becomes more pathognomonic (67,68).

Superimposition

In studying the periapical region for visibility of pathologic changes, a clinician has to extrapolate the true diagnosis by ignoring so-called anatomical noise, which refers to superimposition of overlapping anatomy and by factoring in geometrical distortion (19,30,69). CBCT scans allow a 3D rendering instead of a 2D assessment as in dental radiographs. Because of the ability to see details without overlapping anatomy, detection of otherwise undetectable apical lesions is possible (70).

Distortion

While distortion, elongation or foreshortening may present a problem in any area of the dentition, the maxillary molar area can be particularly challenging because skewed images occur together with projection of anatomy over the area of interest. Ideally, the film or sensor is placed as parallel as possible to the tooth, using a film or sensor holder with a biting surface. A low palatal vault can require the film to be placed at an angle to the long axis of the tooth. If the x-ray beam is directed too much from an apical direction, this will result in projection of the zygomatic bone and arch onto the roots. At the same time, depending on the chosen angle, this technique will produce a distorted image of the roots (66). Divergent roots will present different levels of elongation of foreshortening in periapical radiography, while fused roots or roots that lie close together may not be viewed separately in spite of images taken from different horizontal angulations (66).

Differential diagnosis of apical periodontitis

To avoid unnecessary surgical treatments and in turn avoid fruitless monitoring of true cysts for healing that is unlikely to occur, non-invasive methods of differentiating apical granulomas from cysts have been investigated (71). That study compared CT scans with histology in 8 cases with apical pathosis. The authors were able to distinguish between a cyst and a periapical granuloma in CT images due to a “marked difference in density between the content of the cyst cavity and granulomatous tissue” (71). Because cysts contain fluid, debris and cholesterol, their corresponding radiographic density will be lower than that of tissue in inflammatory lesions.

Aggarwal et al. (72) evaluated 12 tissue samples of periapical lesions histologically and compared the cytological diagnosis with a preliminary diagnosis based on CT values and ultrasound with color-power Doppler flowmetry. The tentative diagnosis was confirmed in all cases (72). In a similar study design, Simon et al. used CBCT gray value measurements for pre-surgical diagnoses and found that histopathology of tissue biopsies coincided in 13 out of 17 cases (73). In contrast, Rosenberg et al. found that of 45 periapical samples, the accuracy of two radiologists to render a correct periapical diagnosis was low (74).

Evaluation of periapical status: conventional radiography

Numerous studies using meticulous asepsis and up-to-date root canal disinfection practices have shown that if microbial contamination is removed to levels that are undetectable by sampling, a high level of success for
resolution of apical periodontitis can be anticipated (75,76). While detection of a radiolucency associated with an endodontically treated tooth typically has a high positive predictive value (67,77) absence of a radiolucency does not guarantee apical health. Negative predictive values, i.e. the ability to predict that no radiographically visible lesion in fact means absence of pathosis, ranged from 25% (78), 53% (67), 67% (68) to 74% (39). Radiographic healing encompasses bony fill of the radioluency or shrinking of the visible area, a continuous periodontal ligament and regular bone pattern.

Images should be taken with a bisecting-angle technique, or, if measurements taken off images are to be more accurate, with a paralleling technique. Two intraoral periapical radiographs obtained with a paralleling technique are recommended to evaluate presence or absence of bone radiolucencies: one at a right angle and one at a 10-degree horizontal angle (79). Even though this alleviates some of the limitations of conventional radiography, multi-rooted teeth have roots that can curve in different planes bucco-lingually, and no radiograph will be able to show a paralleling or bisecting angle take of all roots at the same time. In other words, severe distortion may be present in one root, while another is depicted more or less accurately. Considering these limitations, reconstructing the original three dimensions in a patient’s tooth from periapical radiographs is a problematic task (80).

Bender & Seltzer found that even large lesions in cancellous bone may remain undetected in periapical imaging as long as the cortical bone plate stays intact (81). More than thirty years later, Barbat & Messer (82) compared conventional and digital images in detecting increasingly larger artificial bone defects around molar roots. For all image types, bone cavities were readily detectable after taking away the lamina dura only. Detection became easier with further bone removal, in particular when the cortical plate became eroded (82).

Time has been described as the fourth dimension regarding healing (80). In order to visualize decreasing gray-levels in apical periodontitis, images need to be taken from the same perspective, using the same exposure parameters to show similar density and contrast. If this is not the case, summation of anatomy to the buccal or lingual of the scrutinized lesion can mimic healing and bone fill. The clinician will then assume that radiolucency is changing to a healthy state, when in reality there is no change or even increase of the area. To show detectable differences in gray-level, radiolucencies that are not entirely located at or near the cortico-medullary junction or surrounded by thick bone must change more in size than a lesion situated in less dense or thin bone.

**Surgical wound healing versus apical periodontitis**

In endodontic surgery, CT and CBCT scans have been used for decades to assess optimal access through bone, sinus extension between the roots, lesion sizes and locations in reference to sensitive anatomical structures such as the maxillary sinus or mandibular canal and to optimize the choice of surgical instruments (34,83). Surgical wound healing has a faster time-course than healing of apical periodontitis (84). Initial healing, followed by reoccurrence of an apical radiolucency has been observed as a sequel after incomplete disinfection or omitted retreatment before surgery. Additional problems, such as cracks and root fracture that may or may not have been caused by surgical procedures involving ultrasonic root end preparation have been described (85).

**Assessment of failure**

To reduce the rate of false-positive diagnoses, evaluators have developed indices and definitions of periapical disease (23,86–88). Only cases with lesions that can be identified accordingly were recorded. However, the rate of false-positive diagnoses is much less than false-negative diagnoses, up to 12–40% of lesions that are present are overlooked of periapical radiography (66,79,89–93). During follow-up, the time during which lesions are expected to heal is up to 4 years, after which the treatment is typically considered to have failed if no signs of healing are present (94).

**Conclusions about radiographic diagnosis of periapical status**

Paredes-Vieyra et al. state that “radiographic images of periapical bone lesions range from impossible or difficult to see to being easily seen” (95). Clinically,
this suggests that if no lesion is visible on a periapical film, it often still is present in vivo (81,96). Research has shown that CBCT is significantly better in terms of sensitivity, positive or negative predictive values, and diagnostic accuracy than digital or conventional radiographs (61,89,91,97–99).

**Evaluation of periapical status: CBCT**

As stated before, apical periodontitis lesions can be obscured by overlapping structures and they are often wider bucco-lingually than they are mesio-distally. Christiansen et al. measured periradicular lesions and discovered that periapical bone defects calculated on periapical radiographs were roughly 10% smaller than on coronal sections of the radiolucency as view by CBCT (91).

When comparing osseous changes, gray scale values obtained from CBCT are correlated with micro-computed tomography measurements (100) and histopathologic bone densities (101). Gray scale Hounsfield units (HU) (102) were originally conceived as metrical descriptors to associate CT gray levels to tissue type and condition. For example, air is assigned an HU value of -1000 and water one of zero, while bone may range from 400 to 700 to 3000 HU. An increase in HU parallels bone fill and can be used to track osteoblastic response in healing using CT (103). CBCT units are typically not calibrated to conform to HU measurements because they provide wider gray level ranges (14 bit and more); however both pixel gray values as well as derived extrapolated Hounsfield units (104,105) may be used to track periapical healing (99).

CBCT volumetry with specific software has recently been evaluated for the evaluation of osseous healing using a tibia model. This method showed significantly correlated results for non-invasive quantitative monitoring of bone defect healing in comparison to histological findings (106) shows promise for the assessment of endodontic outcomes using CBCT in the future.

**Assessment of failure**

On cone beam CT data, streaking and beam hardening artifacts from metallic structures, and radiopaque root fillings, can make diagnosis of lesions and root fractures difficult and can lead to misinterpretation of remaining dentin thickness (80,107). Beam hardening is a frequently found artifact in dental CT scanning due to the increased occurrence of metal objects, such as fillings, implants, and stents with metal components or surgical materials, e.g. plates, screws or wires. Beam hardening causes margins of objects to fade into streaks or cupping. The dark lines streaking from posts or radiopaque root canal sealers can mimic radiolucent lines associated with root fracture. Potentially, this may lead to overtreatment due to misinterpretation of dark areas as fractures or osseous lesions related to pulp necrosis.

Radiolucent zones next to a post caused by beam hardening can erroneously suggest root perforation. To circumvent misdiagnosis, Bueno et al. (108) recommended a map reading strategy for CBCT image data, which focuses on axial slices of a volume. This study used images with a resolution of 200 micron and navigated in a coronal to apical direction near the post tip. Looking at each slice allowed visualization and localization of root perforations associated with lateral radiolucencies (108). In conclusion, the success rate determined by CBCT appears to be 10–40% lower than that diagnosed by evaluation of periapical radiographs (66,79,89,91,92).

**Healing of apical lesions**

Kirkevang et al. (109) followed up patients between 1997 and 2008 and looked at teeth with apical periodontitis on full-mouth radiographic surveys. They noticed that although techniques and treatment quality may have improved, the number of patient that had teeth with apical pathosis enlarged with age, and that effect remained unaltered by the time period the treatment was completed in. In that respect, Paula-Silva et al. (78,98) state that periapical radiography had a negative predictive value of 0.25 (0.46 for CBCT), this indicates a low ability to detect absence of periapical periodontitis. Ricucci and colleagues (110) investigated root canal treated teeth with no signs of inflammation on digitized conventional radiographs. The investigators resected root ends and compared the histological status of the teeth to the radiographic diagnosis. In cases where they found no widening of the periodontal ligament, interruption of the lamina dura, or apical radiolucencies, it was rare to find
significantly inflamed tissue during histology. However, moderate inflammation in the apical area was displayed as normal on conventional periapical radiographs (110). It is important to distinguish lesions after root canal treatment in order to be able to both treat and monitor improvement of such defects. Bornstein investigated root-filled molars and discovered 25.9% more periapical lesions on CBCT images than on radiographs (111). The discrepancy was due to the fact that preoperative bone destruction caused by apical granulomas and bone regeneration after treatment can be monitored in 2D by periapical radiographs and in three planes by CBCT.

Yoshioka and colleagues, using two different types of small-FOV CBCT units, examined 532 teeth with periapical lesions in 427 patients. CBCT accurately identified the type of bone defect for persistent periradicular lesions, as opposed to conventional periapical radiographs. In addition, axial and coronal images were able to determine the type of cortical bone plate defect created by the lesion (112).

To standardize healing outcomes after endodontic treatment, Estrela et al. used a modified periapical index on CBCT scans. The group scored radiolucencies on a 6-point (0–5) scale with 2 additional variables, expansion of cortical bone and destruction of cortical bone (89) (Fig. 5).

In follow-up of apical lesions before and after endodontic treatment, Kaya et al. measured bone density by recording Hounsfield units in periapical radiolucent areas. The value assessed in the bucco-palatal direction was compared to the value measured after 2 years and an increase in density equivalent to healing of the lesion was noted (99).

**Healing of surgical bone defects**

In cases with refractory periradicular lesions after endodontic treatment, apical microsurgery is performed to remove the root tip, prepare a root end cavity and seal the root canal from a retrograde aspect to allow healing. While this treatment shows a high success
rate, follow-up is important to ensure successful resolution and bone regeneration. On average, radiolucencies measured from periapical radiographs are at least 10% smaller than seen in CBCT (70,89,91). Using CBCT, a higher number of cases still had remaining lesions 1 year after endodontic surgery compared the conditions apparent in periapical radiographs (91). On the other hand, it has been argued, based on conventional periapical radiographs, that the vast majority of cases that ultimately will heal will show signs of healing after 6 months to 1 year. Moreover, using CBCT has the potential to move the window of predictability to even earlier time points (91,99) (Fig. 5).

This line of reasoning is based on the assumption that all post-endodontic radiolucencies signify persistent pathosis or inflammation (67) that could pose a cardiovascular risk factor. Hence, to remove the risk, all lesions of endodontic origin would require treatment (113). Other authors could not confirm this association (114) and explained such results by a high age of the participants (115).

Occasionally, healing may result in fibrous scar tissue, which is radiographically indistinguishable from an apical granuloma. The tissue removed by endodontic surgery may thus be a healed periapical scar (116). More clinical studies are needed to support or negate if persistent apical periodontitis can predispose or lead to coronal heart disease or other detrimental health effects.

What is the most clinically relevant method of imaging to determine periapical healing?

Risks and benefits

CBCT units offer a wide range of exposure parameters such as tube current, exposure time, size of the scanned area and the degree of rotation of the gantry around a patient’s head (83). Task-dependent individualizing of these parameters can help avoid unnecessary exposure to radiation dose (117). Recently, a change from a 360° to a 180° rotation of the gantry has been proposed to halve radiation for patients. The image resolution remains unchanged, however, a 180° rotation reduces the number of beam projections, which in turn reduces radiation exposure.

The downside of this approach is that this results in a lower resolution images because less raw data slices are included in image. An exchange of image quality versus imaging dose can be achieved in order to establish optimal low-dose CBCT scan protocols that maximize dose reduction while minimizing image quality loss (118).

Durack et al. compared the ability of periapical radiographs, 180° rotation CBCT scans or 360° rotation CBCT scans to allow detection of artificial external inflammatory root resorption lesions (119). The ability of small volume CBCT to identify simulated external root resorption was not influenced by rotations of 180° or 360° in CBCT scans. CBCT, had higher negative predictive values and higher positive predictive values than periapical radiography, no matter what degree of rotation was preset.

Dawood et al. (83) tested the image quality of a lower-dose 180° protocol versus 360° rotation when measuring bone width and anatomic structures in future implant sites. This task requires less sharp images than certain endodontic diagnoses, for example the intricacies of root canal anatomy are more difficult to assess with reduced image resolution. The reconstructed image at 180°only marginally affected the reviewer preference of the resulting images but patient dose was significantly less (83).

It appears that variable amount of radiation a patient is exposed to is correlated to the quality of the image obtained, however image quality has little degradation over a large range of dose variation (118). Effective patient dose is directly proportional to the size of the field of view (FOV) or scanned area. The effective dose for different scanned sections of a patient’s cranium with CBCT devices can show a 20-fold range (117). A cost-benefit calculation should be carried out in deciding if a small-, medium- or large-field CBCT is obligatory for a specific diagnostic task.

CBCT: availability in clinical practice

Because of the expected increase in use of CBCT in dentistry, the U.S. Food and Drug Administration (FDA) has developed a web site in August 2012 that serves to give patients and healthcare providers the up-to-date information about use and safety of dental CBCT. Market reports divide practitioners into two groups, CBCT non-users (resistors, undecided, potential users) and CBCT users (low potential for
purchase, recent purchase, potential upgrade purchase and repeat purchase) (120).

The dental equipment market includes dental units, instruments and chair-side equipment, CAD/CAM systems, small device units, dental lasers, intra-oral and extra-oral radiology units, and CBCT scanners. Worldwide diagnostic imaging market growth is calculated to increase from $20.7 billion in 2010 to $26.6 billion by 2016, at a Compound Annual Growth Rate of 4.2% from 2011 to 2016. An increasingly aged population and expanded applications of diagnostic imaging as well as constantly new developments are cited as main drivers for adoption of CBCT (121).

Consequences for treatment decision-making

In view of the high rate of undetectable lesions on other images, CBCT yields a greater number of incidental findings. Such findings are discovered as chance observations on the scanned field of view. Nevertheless, unexpected diagnoses cannot be ignored and must be included into a treatment plan or referred to a specialist (122). This leads this review back to the question of what is success or failure. Should all lesions detected outside the region of interest lead to treatment? Or will treating all asymptomatic lesions lead to overtreatment? There is a possibility that the presence of periapical radiolucencies do not represent inflammation but healing by scar tissue (116,123). In 100 cases with histological evaluation of periapical lesions, Love & Firth found only two periapical scars, one after apicoectomy with an amalgam root-end filling and the other case surrounding extruded root filling material (124). Eighty percent of the other periapical lesions were periapical granulomas and 18% were cysts. In 125 samples, Schulz et al. found 70% granulomas, 23% cysts and 5% abscesses, 1% scar tissues, and 1% keratocysts (125). It therefore appears to be reasonable to assume that, in most cases, periapical lesions are true pathosis and not scars.

In an editorial for the International Endodontic Journal entitled “Radiographs and CBCT—time for a reassessment,” the authors recommend the use of CBCT imaging to verify presence or absence of apical periodontitis, especially in light of its diagnostic value and the limited radiation exposure (126).

From recent literature that compares imaging techniques to measure outcome of endodontic treatment, it may be concluded that in some instances up to half of all cases that are diagnosed as healthy based on periapical radiographs display radiolucencies in CBCT scans after endodontic treatment (66,91). Therefore, it would only be logical to assume that the assessment of success of endodontic treatment derived from PA radiographs may be insufficient. Similarly, the differentiation of best clinical techniques based on periapical radiographs might not be feasible.

An example for a treatment dilemma that requires better resolution imaging is fracture diagnosis—early identification of a vertical root fracture is crucial to avoid unwarranted extractions or widespread bone loss along the affected root (127) and healing of fractures (128). Edlund et al. diagnosed vertical root fractures on CBCT scans, verified the diagnosis during apical surgery and found that CBCT was better qualified to accurately diagnose vertically fractured roots (129). However, microscopic cracks that are below the resolution of a CBCT scan will continue to stay undetectable, but a larger number of cases will be assessed than with periapical imaging alone (130).

Patient dose and costs have continuously decreased since the introduction of CBCT to the dental market;
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at the same time resolution and availability have improved. If this trend continues, then CBCT units will be readily available in private practice. At this point in time, there is no existing optimal dose guide for CBCT. Reasons include the complicated x-ray beam geometry of CBCT and the reality of quality control measurements for CBCT units (131). Clinical research is required to justify possible dose directories and to determine how these recommendations translation to patient dose.

The guidelines for the use of CBCT are clear at this point: only with a specific indication should such a scan be prescribed. However, the list of these specific indications may be expanded to include diagnosis and follow-up for cases with horizontal root fracture or regenerative procedures in the future (see Table 1 and Fig. 6).

Concluding remarks

CBCT will undoubtedly affect the expected standards of care, and this has implications for increased practitioner responsibility both in the performance, optimal visualization and interpretation of volumetric datasets. (132). Once the root canal system has become infected to an extent that apical periodontitis becomes visible on PA radiographs, chances for successful endodontic treatment decrease (133).

If earlier diagnosis prompts treatment at a smaller stage of the radiolucency, healing after endodontic treatment might be faster or more complete (50). Estrela et al. measured increasing sizes of radiolucencies with a modified periapical index. The smallest lesions were 0.5–1.0 mm in diameter (134). Treating such initial stages of pathosis as opposed to larger, established lesions may influence outcomes (70).

Other, future and current situations where a successful outcome could be measured with 3D imaging in endodontics include healing after apical surgery (45) healing after trauma with alveolar fractures or luxation injuries (50), stabilization of resorptive defects (135), healing of inflammation and membrane thickening in paranasal sinuses (136) and healing of furcal or lateral defects after perforation repair (137).

Liang identified two outcome predictors for periapical healing from CBCT data, which were density of the root filling and a leakage-free coronal restoration (92). A second, follow-up CBCT scan may be needed to reliably confirm or negate healing of preexisting lesions (138).

CBCT imaging offers a new direction to minimize false diagnoses and is rapidly replacing other radiographic techniques in the fields of diagnosis, quality assessment of treatment modalities and techniques as well as outcome assessment. Tracking of healing with both conventional methods and newer 3D imaging can include apical radiolucencies, maxillary sinus membrane thickening, hard tissue regeneration, root fractures and regenerative treatment of immature necrotic teeth.

Because of the low predictive value of two-dimensional periapical radiographs to detect periapical disease or confirm periapical health, future assessment of endodontic treatment efficacy may include small field-of-view CBCT scans.

References

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29. Carvalho FB, Gonçalves M, Guerreiro-Tanomaru JM, Tanomaru-Filho M. Evaluation of periradicular changes following endodontic therapy: digital subtraction...


68. Barthel CR, Zimmer S, Trope M. Relationship of radiologic and histologic signs of inflammation...
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