RESEARCH

Comparison of cone beam CT scans with enhanced photostimulated phosphor plate images in the detection of root fracture of endodontically treated teeth

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Objectives: Two-dimensional intraoral radiography is the most common tool for diagnosing root fractures (RFs). Cone beam CT (CBCT) is widely used to depict RFs in endodontically treated teeth. Beam hardening and other artefacts caused by gutta percha may result in an incorrect diagnosis when using CBCT only. A comparison of two CBCT machines with photostimulated phosphor (PSP) plate images enhanced with the equalization tool was carried out to detect RFs in endodontically treated teeth.

Methods: 66 roots were collected, decoronated and treated endodontically using the same technique with gutta percha. 33 of these roots were randomly selected and fractured; the 2 root fragments were glued together with 1 layer of methyl methacrylate and placed randomly in 8 prepared beef rib fragments. Large fields of view (FOVs) were acquired with one CBCT unit and small FOVs with the second CBCT unit. Periapical radiographs (using intraoral PSP plates) were also acquired. A contrast enhancement tool was used when evaluating the PSP plate images.

Results: Small FOV images had significantly higher accuracy (area under the receiver operating characteristic curve) and sensitivity in detecting RFs than PSP plates and large FOV images. The specificity of the enhanced PSP images was higher than, although not significantly higher than, the small FOV images and was significantly higher than the large FOV images.

Conclusions: CBCT small FOVs should be acquired for depicting RFs of endodontically treated teeth. Images obtained using PSP plates had the lowest rate of false-positive results and their use can save the patient a radiation dose.

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Keywords: cone-beam computed tomography; root fracture; diagnosis; endodontics

Introduction

Root fracture (RF) often leads to tooth extraction.^{1,2} RF may take place after the insertion of screws or posts in a root after endodontic treatment. In addition, vertical compaction of the root filling material may lead to

a fracture. Excessive occlusal forces are a common cause of RF, especially in endodontically treated and restored teeth. Endodontically treated and uncrowned posterior teeth have the highest risk for RF.³ The diagnostic tool that is used most commonly in dental practices for RF depiction is conventional digital two-dimensional (2D) intraoral radiography. To be able to detect an RF, the X-ray beam should pass directly along the fracture line, or the RF may not be diagnosed.^{4,5}

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Cone beam CT (CBCT) significantly augments 2D intraoral imaging in endodontic applications.⁶ Limited CBCT volumes have been shown to be more reliable in diagnosing RFs in studies when the teeth were not treated endodontically.⁷ In both *in vivo*⁸ and *in vitro*⁶ studies, CT was found to perform better than intraoral techniques in RF detection. The common advantages of CBCT imaging in clinical practice are accurate images, easy image acquisition, lower radiation doses than medical CT and enhanced cost-effectiveness.^{9,10}

It is well established that high-density structures cause artefacts on the radiographic image that interfere with the diagnostic quality of CT and CBCT images.¹¹ The presence of high-density bodies within the maxillofacial area of the patient causes beam hardening and streak artefacts¹² and ultimately will lead to a limited diagnostic field of the images by obscuring anatomical structures, reducing the contrast between adjacent objects and impairing the detection of areas of interest.^{13–15} A beam hardening artefact caused by gutta percha, which is a high-density root canal filling material, is usually noted on CBCT. This artefact may decrease the ability to detect RFs using CBCT images.

The Picasso Master 3D[®] machine (Vatech, Gyeonggi-do, Republic of Korea) offers large fields of view (FOVs) and the Promax[®] (Planmeca, Helsinki, Finland) smaller ones. For both CBCT machines, the dose delivered to the patient is higher than that received from a periapical image.¹⁶ Many enhancing tools for digital 2D radiographs are available. One tool is the “equalizer” algorithm of the MiPACS[®] Dental Enterprise Viewer (Medicor Imaging, Charlotte, NC), which is used to accentuate a small region of the image. This algorithm is easy to use and maximizes the contrast by performing histogram equalization on a selected area of an image.¹⁷ RF is diagnosed on a 2D radiograph when a radiolucent line is noted on the radio-opaque dentine, and an enhancement in contrast will help diagnose the fracture line.

The purpose of this study was to investigate whether RF detection using photostimulated phosphor (PSP) plate intraoral radiographs, enhanced with the equalization tool, was as accurate as that obtained using CBCT volumes when the roots were treated with a high-density material such as gutta percha. If this is the situation, the use of PSP plate-enhanced images with the equalization tool will save the patient a radiation dose and the dental practitioner time.

Material and methods

Phantom preparation

66 teeth were collected and decoronated. Single roots were shaped and prepared to be filled with gutta percha. The root canals were prepared using the same technique for all of the 66 roots. 33 roots were chosen randomly and fractured by using a tapered nail inserted in the root canal coronally and tapped gently with a hammer. Eight bovine rib fragments were prepared to receive the

roots; two fragments contained nine roots and the remainder contained eight roots each. The roots were distributed randomly to the eight bovine rib fragments and placed within prepared holes. Wax was added around the roots within the holes to simulate the periodontal ligament space and to keep them stable. To simulate soft tissues, the ribs were wrapped with three layers of wax. Rib fragments were scanned in pairs.

Radiographic data acquisition

Each pair was scanned once with the Picasso Master 3D machine, using a 16 × 7 cm FOV with a 0.2 mm voxel size, and once with the Promax machine, using an 8 × 8 cm FOV with a 0.2 mm voxel size. Two periapical radiographs were taken for each bone fragment to cover all inserted roots and depict the fractured roots. A polyvinyl siloxane putty matrix was prepared to hold the PSP plates in place. A Planmeca Intra[®] intraoral machine was used; it was set at 63 kV, 8 mA, 0.32 s. The PSP plates used were manufactured by Air Techniques Inc. (Melville, NY).

Data

In total, 4 CBCT scans were made using the Planmeca[®] machine, 4 using the Master 3D and 16 digital periapical radiographs were acquired. Five observers classified each image separately for the presence of RFs using a five-point scale: (1) definitely absent, (2) probably absent, (3) unsure, (4) probably present and (5) definitely present. At the beginning of the first session, observers were calibrated. After calibration, the observers independently classified each of the images twice during two distinct viewing sessions. The sessions were separated by at least 14 days. When viewing the images of the PSP plates, the observers used the equalization tool that enhanced the contrast.¹⁷ For CBCT data, the whole volume was analysed. The observers were two oral and maxillofacial radiology (OMR) faculty members who had 21 and 8 years of experience, respectively, two OMR residents and one endodontics resident. The same calibrated monitor was used for all the reviews. The monitor used was a medical monitor from ExorVision (Seattle, WA) with a resolution of 1280 × 1024 pixels, and the screen size was 48.26 cm. OnDemand 3D[™] (Cybermed, Seoul, Republic of Korea) was used to review the images; the same cross-section reconstructions were inspected with a 0.2 mm section width. Reviewers were allowed to set the contrast and brightness.

Statistical analysis

The kappa statistic¹⁸ was used to assess interobserver and intraobserver agreement. The area under the receiver operating characteristic (ROC) curve was used to determine the accuracy of assessment of the presence or the absence of an RF. Sensitivity and specificity were calculated using a two-category classification constructed by considering a score of three or greater as positive. The area under the ROC curves, sensitivity and specificity by diagnostic tool (three tools: two CBCT units and the PSP plates), readers (five readers) and readings (two

readings for each reader) were analysed using analysis of variance.¹⁹ All calculations were carried out using the SAS[®] statistical software v. 9.3 (SAS Institute, Cary, NC), which computes the non-parametric *c*-statistic that is equivalent to the trapezoidal area under an empirical ROC curve.¹⁹

Results

Interobserver and intraobserver agreement

Interobserver agreement using the five-category classification is given, by machine, in Table 1. A two-category classification was constructed by considering a score of three or greater as positive. Interobserver agreement using this two-category classification is also given in Table 1. Intraobserver agreements using the five- and two-category scales are given in Table 1. Kappa values for all three machines indicate greater agreement than that owing to chance for both interobserver and intraobserver agreements.

Area under the ROC curve

Areas under the ROC curve for each machine are shown in Figure 1. Areas under the ROC curve are significantly ($p \leq 0.0001$) greater than 0.5, indicating that all three machines are able to classify the presence of a fracture above the accuracy that could be achieved by chance, that is, all machines had at least some ability to discriminate between teeth with and those without fractures.¹⁹ The area under the ROC curve for the Promax machine (area = 0.84) was significantly ($p \leq 0.0001$) greater than that for the Master 3D (area = 0.66) and PSP plates (area = 0.70). There was no significant ($p = 0.1339$) difference between the Master 3D and PSP machines.

Sensitivity and specificity

The average sensitivity for each machine is shown in Figure 2. The sensitivity of the Promax machine (sensitivity = 81%) was significantly ($p \leq 0.0012$) greater than that for the Master 3D (sensitivity = 61%) and PSP plates (sensitivity = 51%). There was no significant ($p = 0.1522$) difference between the Master 3D and the PSP plates.

The average specificity for each machine is shown in Figure 3. The specificity of both the Promax (specificity = 78%) and the PSP plates (specificity = 82%) was significantly ($p \leq 0.0046$) higher than that of the Master 3D machine (specificity = 61%). There was no significant ($p = 0.7495$) difference between the Promax machine and the PSP plates.

Figure 4 shows images from the three modalities. The image resulting from the small FOV is sharper and the RF is noted clearly. The effect of contrast enhancement using the equalization tool on the PSP plate image is also seen.

Discussion

There was no difference noted between the enhanced PSP plates and the Master 3D machine concerning area under the ROC curve and sensitivity. In contrast, the enhanced PSP plates were more specific, which means that they were better at correctly classifying teeth without RF. The FOV used was the smallest offered by the Master 3D machine (16×7 cm), which is a large FOV for the detection of an RF. This finding suggests that a large FOV did not increase the diagnostic accuracy of RFs in endodontically treated teeth when compared with the enhanced PSP plate images; thus, with a lower patient radiation dose and with less time, the accuracy of RF detection was maintained.

Librizzi *et al*²⁰ found that the diagnostic efficacy of CBCT scans for the evaluation of erosive changes in the temporomandibular joint was the highest for the 6-inch FOV and the lowest for the 12-inch FOV. They used a Hitachi CB MercuRay[®] CBCT scanner (Tokyo, Japan). These findings suggest that the smallest, but still adequate, CBCT FOV should be acquired when high spatial and contrast resolutions are needed to achieve the diagnostic task. The voxel size was the same for both CBCT machines that we studied; however, the FOV size differed. Bechara *et al*²¹ found that using a smaller FOV increases the contrast-to-noise ratio (CNR). Although the machines are not made by the same manufacturer, the machine with the smallest FOV performed the best in all aspects.

The equalization tool is the MiPACS Dental Enterprise Viewer, and, according to the manufacturer, it maximizes the contrast in a selected area of an image. An RF shows as a radiolucent line on the root. An enhanced contrast will help in depicting that line on the root of teeth. In addition, the enhancing tools are easy to use and do not require additional time. With the use of this enhancing tool, PSP plates were the most specific modality although specificity was not significantly higher than with the use of the small FOV machine. Thus, they were the best tool to rule out an RF (fewer false positives) owing to the fact that artefacts that show on CBCT images as low-density lines do not show up on PSP plates. A low-density line on a PSP plate is more

Table 1 Interobserver and intraobserver agreement

Machine	Interobserver agreement		Intraobserver agreement	
	Five-category scale	Two-category scale	Five-category scale	Two-category scale
	κ (95% CI)	κ (95% CI)	κ (95% CI)	κ (95% CI)
Master 3D	0.16 (0.12–0.20)	0.24 (0.17–0.32)	0.18 (0.12–0.24)	0.32 (0.22–0.41)
Promax	0.22 (0.18–0.26)	0.51 (0.43–0.58)	0.30 (0.24–0.36)	0.53 (0.44–0.62)
PSP plates	0.13 (0.09–0.18)	0.31 (0.23–0.39)	0.22 (0.15–0.30)	0.32 (0.22–0.43)

CI, confidence interval; PSP, photostimulated phosphor.

Figure 1 Average area under the receiver operating characteristic (ROC) curve, by machine. Error bars represent 95% confidence intervals. Dashed reference line represents an area of 0.5, that is, classification no better than chance. a, Significantly different from 0.5; b, significantly different from Master 3D; c, significantly different from photostimulated phosphor (PSP) plates

likely to represent an RF, whereas a low-density line on a CBCT scan for an endodontically treated root may represent an artefact or an RF.

CBCT was more sensitive than the enhanced PSP plate images because clinically, if the X-ray beam does not pass by the line of fracture, the RF will not be noted, leading to an increase in false-negative classifications when using PSP plates. From a clinical standpoint, in an endodontically treated root, if the fracture is noted on an enhanced PSP plate image, it means that the root is fractured. On the other hand, if the patient is symptomatic and no fracture shows on the PSP plate image, this may be owing to the presence of anatomy that may be superimposed on the fracture and a small FOV CBCT scan will be indicated. Wenzel *et al*²² had found that high-resolution i-Cat[®] (Imaging Sciences International,

Figure 2 Average sensitivity, by machine. Error bars represent 95% confidence intervals. a, Significantly different from Master 3D; b, significantly different from photostimulated phosphor (PSP) plates

Figure 3 Average specificity, by machine. Error bars represent 95% confidence intervals. a, Significantly different from Master 3D. PSP, photostimulated phosphor

Hatfield, PA) CBCT images resulted in an increase in sensitivity (ruling in) without jeopardizing specificity (ruling out) for detection of transverse RFs compared with lower resolution CBCT images, which were not more accurate than the periapical PSP images. The voxel sizes used were 0.125 mm and 0.25 mm. In the current project, a large CBCT FOV with a 0.2 mm voxel size led to similar results; the diagnostic accuracy and sensitivity were the same as the enhanced PSP plates images.

A decrease in voxel size may not lead necessarily to enhanced accuracy in detecting RFs of endodontically treated teeth as the noise in these scans will be increased owing to the presence of high-density gutta percha. Bechara *et al*²³ found that decreasing the voxel size from 0.200 mm to 0.076 mm increased the noise and decreased the CNR in small FOV CBCT scans.

Software providing various image-processing operations and enhancement with algorithms that either affect the whole image or a selected portion of it is currently available commercially. These are referred to as global and local algorithms, respectively. A local algorithm, such as the algorithm used in this project, works on a designated region within an image. The region of interest is located within a circle of varying diameter, which can be moved along the roots. The contrast will be maximized, thus the contrast between the radiolucent line caused by the fracture and the radio-opaque dentine will be visualized better. It is important to note that adequate image density is

Figure 4 Example of images of the same fractured root visualized with both cone beam CT machines and enhanced photostimulated phosphor (PSP) plate image

a requirement for all image enhancement algorithms as what is not captured cannot be improved.¹⁷

Recent studies have evaluated the effectiveness of artefact reduction algorithms on the CNR^{4,5} and RF detection accuracy.²⁴ It was found that the artefact reduction algorithm available in the Master 3D enhances the CNR of the images. However, the initial grey values were not regained and the periphery of the high-density material deteriorated.^{4,5} The RF detection accuracy of endodontically treated teeth was decreased after the use of artefact reduction algorithms available in the Master 3D and Promax.²⁴

This study is an *in vitro* study that simulated the clinical situation of teeth placed in dental arches. However, it is clear that the presence of high-density material in the roots such as gutta percha will decrease the accuracy of RF depiction using CBCT, and the use of 2D radiographs can give comparable results when using a large FOV. Other enhancement tools are available and evaluating them will

be helpful to investigate whether they increase the accuracy of a diagnostic task such as RF.

Conclusion

The Promax small FOV CBCT images resulted in the highest area under the ROC curve and sensitivity in depicting RFs of endodontically treated roots. The specificity of enhanced PSP plate images was similar to the Promax CBCT scan and superior to the Master 3D scan. Enhanced PSP plate images were more accurate than large FOV CBCT images in depicting RFs of endodontically treated roots. These results suggest that PSP plates are as good as a small FOV CBCT, within the limitation of this study, to diagnose an RF when the root is treated endodontically. Clinically, if a tooth presents symptoms of RF and the fracture is noted on a PSP plate radiograph, it will be unnecessary to acquire a CBCT scan.

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