The Performance of a Zirconium-based Root Filling Material with Artifact Reduction Properties in the Detection of Artificially Induced Root Fractures Using Cone-Beam Computed Tomographic Imaging

Aaron Fox, DDS, * *Bettina Basrani, DDS, PhD, FRCD(C),* * *and Ernest W.N. Lam, DMD, MSc, PhD, FRCD(C)*†

Abstract

Introduction: Limited field of view cone-beam computed tomographic (CBCT) imaging has been used to augment clinical testing of vertical root fractures (VRFs); however, the presence of gutta-percha (GP) in the canal space generates substantial imaging artifacts that make fracture detection difficult. The purpose of this study was to evaluate the influence of a zirconium (Zr)-based root filling material with radiologic properties that reduce beam hardening (BH) artifacts using CBCT imaging in the *in vitro* diagnosis of VRFs. **Methods:** One hundred seventy-six single-rooted mandibular premolar teeth were obtained, and half of these teeth were filled with GP or Zr (CPoint; EndoTechnologies, LLC, Shrewsbury, MA). VRFs were induced in 44 decoronated teeth in each group using an Instron (Norwood, MA) Universal Testing Machine. Each root was then placed in a dry human mandible and imaged with the Carestream 9000 3D CBCT system (Carestream Dental, Atlanta, GA). The images were evaluated by 6 oral maxillofacial radiologists (OMRs) and residents. **Results:** The sensitivity was greater for detecting VRFs in the Zr group than the GP group (P = .035). However, the specificity was greater for the GP group than the Zr group (P = .028). Receiver operating characteristic area under the curve values were greater for the Zr group than the GP group, but these differences were not statistically significant. The OMRs outperformed the residents in the detection of VRFs in the Zr group with respect to specificity (P = .006) and positive predictive value (P = .012). **Conclusions:** The reduced BH of the Zr group improved the sensitivity of the detection of artificially induced VRFs. The ability to detect VRFs in the Zr group was further enhanced by clinical experience. *(J Endod 2018;■:1–6)*

Key Words

Beam hardening artifact, cone-beam computed tomography, gutta-percha, vertical root fracture, zirconium

Significance

A zirconium-based root filling material with its reduced K absorption edge improved the sensitivity of vertical root fracture detection using CBCT imaging. Root filling materials with K edge values below 18.0 keV should be explored for continuing research in clinical endodontics.

A vertical root fracture (VRF) is defined as a plane of cleavage in a root that may occur buccolingually or mesiodistally (1). Clinical studies of extracted endodontically treated teeth with the presumption of VRFs suggest a prevalence of between 3% and 13% (2–6). VRFs develop primarily in response to wedging forces within the canal space, such as during post placement and cementation, or condensing root canal filling materials (7). Wedging forces, when excessive, can cause dentinal fatigue, resulting in the formation of material defects that may lead to fracture (8). This complication ultimately leads to tooth extraction.

The use of conventional imaging techniques for VRF detection is somewhat controversial. It has been shown with plain film imaging that to visualize a VRF the primary x-ray beam needs to be aligned to within 4° of the fracture plane (9). Moreover, the superimposition of adjacent anatomic structures makes visualization of a VRF even more difficult. Recently, high-resolution, limited field of view cone-beam computed tomographic (CBCT) imaging has been used to evaluate teeth in endodontic clinical practice with suspected VRFs. Although recent systematic reviews and met-analytic studies on this topic have reported moderate to high performance parameters of sensitivity and specificity (10), Chang et al (11) have noted significant biases in these data sets that question their reliability. Unfortunately, the visualization of fracture planes in teeth that have undergone endodontic and/or restorative procedures with highly dense materials such as gutta-percha (GP), metal posts, and crowns are prone to display image artifacts on CBCT images that can potentially mask abnormalities, including the visualization of fracture planes (12).

Artifacts produced in radiologic imaging represent discrepancies between the reconstructed image and the attenuation features of the actual physical object under

From the Graduate Programs in *Endodontics, and †Oral and Maxillofacial Radiology, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.

Address requests for reprints to Dr Aaron Fox, Graduate Program in Endodontics, University of Toronto, 124 Edward Street, Toronto, Ontario M5G 1G6, Canada. E-mail address: aafox1@gmail.com

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investigation. A beam hardening (BH) artifact occurs when lower-energy x-ray photons in the polychromatic x-ray beam are absorbed by a high-attenuation or radiopaque material in preference to higher-energy photons. The result is that the attenuated x-ray beam exits the material with a higher mean energy than the primary beam (ie, it becomes "harder" and more intense) when it reaches the detector. This results in distortion of the attenuated x-ray beam because of the differential absorption (otherwise known as a "cupping" artifact) and produces streaks and dark bands between 2 adjacent radiopaque objects (13). BH artifacts in the CBCT image degrades image quality and compromises the diagnostic value of the image, making the identification of VRFs both challenging and time-consuming.

In an attempt to improve VRF detection, some CBCT system manufacturers and third parties have developed artifact reduction (AR) software to minimize or eliminate BH artifacts. These algorithms appear to reduce the effects of BH and scattering, increase the contrast-to-noise ratio, and decrease pixel gray value variation on the images (14). The major drawback of these algorithms is incomplete artifact correction, and, indeed, some even produce secondary artifacts (15). Some studies report that the algorithm can sometimes negatively alter an image. For example, when imaging teeth in which root canals have been filled with GP, part of the periphery of the GP can go "missing" compared with an image without AR. This "improper" reduction of artifacts can further accentuate diagnostic difficulties (15).

Modern GP cones are composed of inorganic components such as zinc oxide and barium sulfate, and the proportions of these contribute to the radiopacity of the material (16). Recently, EndoTechnologies LLC (Shrewsbury, MA) has produced a zirconium (Zr) root filling material with a central core comprised of a Zr particle suspension, which imparts different radiologic properties relative to conventional GP (17). The Zr atom absorbs or attenuates less of the incident x-ray beam through the material because of its lower K absorption edge (18.0 keV). Compared with barium, which has a K absorption edge of approximately 37.4 keV, Zr is a weaker radiologic attenuator for the mean energy of the polychromatic intraoral x-ray beam (approximately 33 keV) (18). Because the barium atom in the barium sulfate component of GP has a higher K absorption edge, barium is a stronger attenuator of the incident x-ray beam than Zr.

The aim of this study was to determine the ability to detect artificially induced VRFs using CBCT imaging in a single root canal–treated tooth with a conventional GP root filling material (Tulsa Dentsply Sirona, Tulsa, OK) versus a Zr root filling material (EndoTechnologies, LLC). Furthermore, the reduction in artifact production from the zirconium-based material on CBCT images may enable more reliable interpretation of VRFs in endodontically treated teeth.

Materials and Methods

An *a priori* power analysis was performed, and it was determined that a total of 176 teeth would be required to attain 80% confidence with the limits of a 2-sided 90% confidence interval to exclude a difference between visualizing and not visualizing VRFs of more than 25% (effect size). This study was independently reviewed and approved by the Human Research Ethics Board at the University of Toronto, Toronto, Ontario, Canada.

One hundred seventy-six extracted human single-rooted mandibular premolar teeth and 1 dry human mandible were used for this investigation. The extracted teeth were obtained from the Oral and Maxillofacial Surgery Clinic in the Faculty of Dentistry, University of Toronto and stored until use in formalin. The teeth were inspected to ensure that the roots were uniformly straight and conical in shape. All tooth roots with asymmetric curvature were excluded as were those that had been previously endodontically treated. The teeth were further inspected with the aid of a surgical operating microscope (Zeiss Meditec AG, Jena, Germany) using fiberoptic transillumination (Microlux Transilluminator; Addent, Danbury, CT) to exclude teeth with VRFs.

All 176 teeth were decoronated at the level of their cementoenamel junctions using a double-sided diamond disk (NTI Flex; Kerr Dental, Orange, CA). All canal systems were evaluated by using the surgical operating microscope under 10× magnification after decoronation. This permitted visualization of the root canal system to the apex in its entirety. Moreover, the shaping process was also conducted under high magnification for all samples. Canals were initially negotiated and patency confirmed with a 10 K-file (Flexofile, Tulsa Dentsply Sirona). The canals were instrumented using rotary files (Vortex, Tulsa Dentsply Sirona) according to the manufacturer's instructions up to a 45.06 master apical file and irrigated with 2% sodium hypochlorite (Clorox Company, Oakland, CA) between the introduction of each instrument with a 30-G needle (Tulsa Dentsply Sirona) 2 mm from the working length.

The prepared teeth were divided into 2 root filling groups: GP and Zr (Fig. 1). For the GP group (n = 88), 45.06 GP (Vortex GP, Tulsa Dentsply Sirona) points were placed, and for the Zr group (n = 88) 45.06 Zr (CPoint, EndoTechnologies, LLC) points were used. All of the points were inserted into the prepared root canals 0.5 mm short of the working length with a light application of EndoSequence BC Sealer (Brasseler, Savannah, GA) using the single-cone technique. All orifices were sealed with a thin layer of composite resin (Filtek Bulk; 3M ESPE, St Paul, MN).

Forty-four teeth in the GP group and 44 teeth in the Zr group were imaged without being subjected to the fracture protocol. Eighty-eight teeth (44 from each fill group) were embedded in a layer of baseplate wax (Patterson Baseplate Wax; Patterson Dental Supply, St Paul, MN), surrounded by microstone within a copper tube cap (13-mm diameter × 20-mm height), and placed on a fixed platform of an Instron (Norwood, MA) Universal Testing Machine. The machine was programed for the crosshead to apply a force at 1 mm/min until a drop in force by 20% was recorded, suggesting a fracture (17). The tooth was then removed from the matrix and inspected using a surgical operating microscope (Zeiss Meditec AG) at 10– magnification to verify the presence of a VRF.

Micro–computed Tomographic Evaluation

Three representative samples each from the GP and Zr groups also underwent micro–computed tomographic (micro-CT) (μCT 40; SCANCO Medical AG, Bruttisellen, Switzerland) scanning to investigate fracture width, variations in fracture pattern, and extension. Imaging was performed at a voxel resolution of 18 μm, and 3 regions of interest were systematically selected from the midpoints of each third of the root canal (ie, midcoronal, midmiddle, and midapical). The axial sections were uploaded into ImageJ software (National Institutes of Health, Bethesda, MD) (15), and fracture widths were measured at the external root surface and at the widest region of the fracture (Fig. 2).

CBCT Imaging

A reproducible jig was manufactured that was secured onto the platform of a Carestream 9000 3D (Carestream Dental, Atlanta, GA) CBCT unit. The lower border of a dried human mandible was fixed to the surface of the bite plane with Krazy Glue (Krazy Glue, Westerville, OH) and polyvinyl siloxane impression material (President; Coltene/Whaledent AG, Alstatten, Switzerland). The mandible was positioned so that the long axis of the tooth under investigation was oriented perpendicular to the supporting platform. A 5-mm thickness of baseplate wax (Patterson Baseplate Wax) was placed around the body of