The Effect of Isthmus on Vertical Root Fracture in Endodontically Treated Teeth

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Abstract

Introduction: Vertical root fracture (VRF) from apical condensation of gutta-percha is a common failure mode in endodontically treated teeth. Virtually all previous studies of VRF are limited to 1-canal roots. In this study, we consider experimentally and analytically VRF in roots with 2 canals. **Methods:** The interior root morphology in mandibular molar teeth extracted from patients due to VRF or other reason was examined from a series of polished horizontal cross sections. A 2-dimensional fracture mechanics analysis was used to determine crack growth from the canal surface to the outer root surface and evaluate the apical load needed to cause VRF, F_{max}. **Results:** From a mechanistic viewpoint, the isthmus connecting root canals can be regarded as a natural weak plane or crack. The results expose the prime role of isthmus in reducing F_{max}, from $\approx$ 50 N with no isthmus present to $\approx$ 10 N. **Conclusions:** Two-canal mesial roots are much more prone to VRF than 1-canal distal roots. We suggest that VRF may occur during clinical condensation of gutta-percha in mesial roots of mandibular molars as well as other roots with canals connected by isthmus. *(J Endod 2015;41:1515–1519)*

Key Words

Crack, gutta-percha, isthmus, root canal, vertical root fracture

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Vertical root fracture (VRF) is a major complication in endodontically treated teeth that often leads to tooth extraction. Wedging forces and pressure transmitted to the canal wall during condensation of gutta-percha (GP) are primary causes for VRF (1, 2). This form of VRF was studied *in vitro* by loading to fracture root canals filled with GP, with the load applied apically by a spreader (3–8). VRF was taken to occur once a noticeable drop in the machine's load versus displacement curve occurred. As discussed in Figure 2 of the study by Chai and Tamse (9), the corresponding load F_{max} was approximately 100 N for oval canals and somewhat greater for round ones. Similar tests but with the apical force applied repeatedly in increasing amplitudes (10–12) yielded similar F_{max} values, a coincidence that points to the clinical relevance of the single-ramp loading case.

Analytic studies of VRF caused by apical condensation of GP are generally limited to elucidating stresses in uncracked, 1-canal roots having circular or elliptic canal cross sections (4, 13–15). Although correctly identifying the location on the canal wall where the fracture initiates, such studies provide no information on the evolution of fracture or the apical force causing VRF. Recently, the process of crack growth in 1-canal roots was studied using a simplified 2-dimensional fracture configuration consisting of a horizontal root slice containing an elliptic canal section (9). Initial cracks placed on the inner canal wall were driven to the outer one by uniform pressure acting on the canal surface. This pressure was tied to the apical GP condensation force F using a simple formula. The predicted F_{max} agreed quite well with the test data of several studies (3–8).

Most studies on VRF are limited to teeth with a 1-canal root. The clinical relevance of such studies is somewhat muted by the fact that the corresponding VRF load well exceeds the 15- to 30-N range used by endodontists during root canal obturation (16). The purpose of this study was to explore VRF in 2-canal roots, for which clinical experience suggests that VRF is more common. This study had 2 major thrusts. The first was to gain information on the distribution of interior damage in mandibular molar teeth extracted because of VRF. This was achieved by observing horizontal sections of teeth using optical microscopy. The results of this part were then used to develop a fracture mechanics model for predicting VRF load F_{max}.

Materials and Method

Tests

Twenty-five mandibular molar human teeth having 2 roots, distal with 1 canal and mesial with 2 canals, were used. The teeth were extracted from 30- to 50-year-old patients at the School of Dental Medicine at Tel-Aviv University. Eighteen of these teeth exhibited a visible fracture extending over a part or the entire root axis, whereas the rest had no VRF symptoms when extracted. The roots, embedded in an epoxy resin for support, were first ground and then polished perpendicularly to their axis on a rotating cloth to a mirror surface quality using a 1-μm grade diamond paste. The polished surface was cleansed for 15 minutes in an ultrasonic bath of distilled water before it was observed under an optical microscope. This process was repeated in 1- to 2-mm increments until the entire root length was covered.

Analysis

As shown in Figure 1, the fracture model used consists of a thin horizontal root slice containing 2 canals connected by an isthmus. The external root surface is attached to a bone via a 0.2-mm-thick periodontal ligament. In view of the geometric and

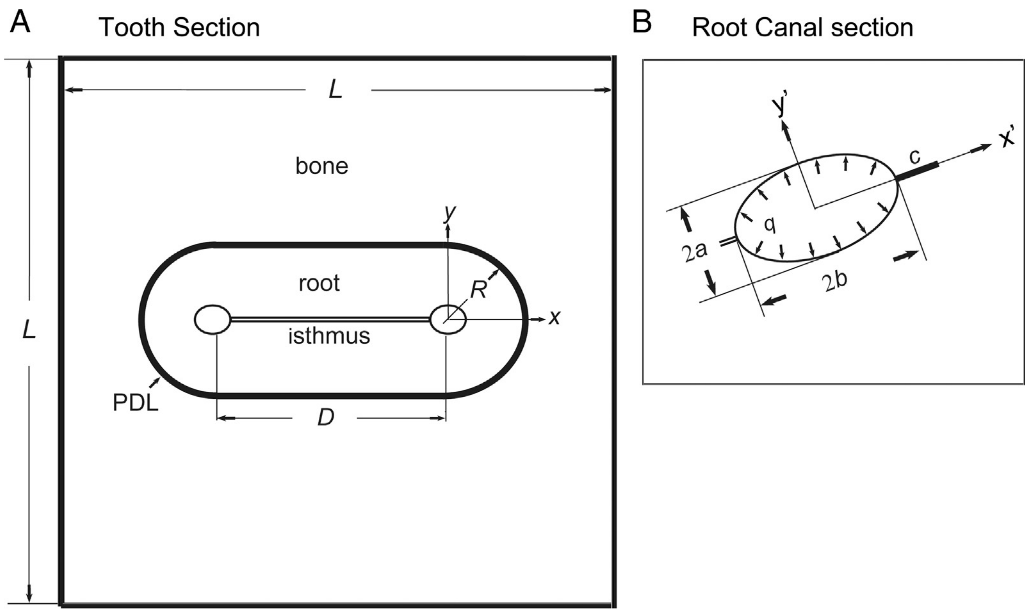

Figure 1. (*A*) A 2-dimensional fracture mechanics model for VRF in 2-canal roots. The specimen consists of a thin horizontal root slice containing 2 canals having an elliptic cross section. The wall of 1 or both canals is subjected to a uniform pressure, q, which drives an initial crack c to the outer root surface to cause VRF. As shown in (*B*), the orientation of the canal section may vary.

material complexities posed by this fracture problem, the following simplifications were invoked:

1. The external root surface was taken to be oblong (rectangle length D = 5 mm and surface radius R = 1.5 mm), whereas the bone was assumed to be square (L = 10 mm). The canal section was assumed to be elliptic (axes a and b). As shown in Figure 1*B*, the orientation of the canal section may differ from that of the root section.
2. The isthmus connecting the canals was considered as an open crack.
3. All materials were assumed to be isotropic and linearly elastic as characterized by Young's modulus E and Poisson's ratio ν (Table 1).

In order to study root fracture, a small initial crack (length c) was placed at a given location on the canal wall(s), typically along the long axis of the canal section (Fig. 1*B*). The surface of 1 or both the canals was subjected to a uniform pressure q. The latter produces circumferential tensile stresses on the wall of the canal section, which may enlarge the initial crack. The growth behavior of the crack was determined using a commercial finite element (FEM) code (Version 11; ANSYS Inc, Cannonsburg, PA) specified to plane stress conditions. The calculations were similar to a previous study on 1-canal roots (9). Briefly, the crack was incremented gradually along the path where the tensile stress responsible for crack growth is maximized. During this growth, the wall pressure, $q(c)$, was adjusted such that $K(c) = K_C$, where K is the stress intensity factor at the crack tip and K_C the fracture toughness of dentin. As done in the study by Chai and Tamse (9), K_C was taken to increase linearly from 1 to 3 MPa $m^{1/2}$ over the first 0.5 mm of crack growth while remaining fixed thereafter (17). VRF was taken to occur when the crack reached the external root wall. The analysis was completed by relating the wall pressure to apical force via $F = Aq$, where $A = \pi ab$ is the canal's cross-sectional area (9).

The FEM calculations were implemented in the fracture model by creating a fine grid near the crack tip. The grid was refined until the stress intensity factor converged to within 2%–3% (9).

TABLE 1. Material Data in This Study*

Material	Young's modulus E (GPa)	Poisson's ratio ν
Dentin	18.0	0.31
Periodontal ligament	0.05	0.45
Bone	1.4	0.30

*The material data used are taken from Chai and Tamse (9).

Results

Tests

Figure 2 shows 3 micrograph sequences representing the root morphology and damage distribution observed in this study: an unobturated tooth (Fig. 2*A*) and obturated teeth extracted because of VRF (Fig. 2*B* and *C*). In the case of Figure 2*A*, the canals in the 2-canal root are nearly round with a diameter ≈ 0.27 mm. These canals are connected by a ribbonlike material structure called an isthmus, which in a given section can be fully open or closed. The fine, straight dark lines noted by arrows in the print suggest that for mechanical modeling purposes the isthmus can be viewed as a weak plane or crack. No other forms of damage are seen in the 2-canal root. The canals in the obturated roots (Fig. 2*B* and *C*) are considerably larger than in Figure 2*A*, whereas the isthmus remains intact. The damage is conclusively limited to the 2-canal roots, attesting to the prime role of the isthmus in causing root failure. The fracture in Figure 2*B* is limited to the coronal part of the crown, whereas the isthmus is fully open throughout the root axis, again showing the material weakness of the isthmus.

Other noteworthy observations from the sectioning study are as follows:

1. All teeth extracted because of VRF have been subjected to endodontic treatment with GP.
2. The shapes of the external surface in the 1-canal and 2-canal roots resemble oblong and hourglass shapes, respectively.
3. Although the intact canal sections are nearly round, obturated ones are ellipticlike with a size and orientation that may vary greatly along the root axis.