Vertical Root Fracture in Buccal Roots of Bifurcated Maxillary Premolars from Condensation of Gutta-percha

Herzl Chai, PhD, and Aviad Tamse, DMD†*

Abstract

Introduction: Maxillary premolars are among the teeth most susceptible to vertical root fracture (VRF) from lateral condensation of gutta-percha. These teeth are distinguished by a complex anatomy of the buccal root including a large depression in the dentin wall facing the bifurcation. It is hypothesized that tooth sectioning coupled with 2-dimensional fracture analysis is instrumental in understanding VRF in such teeth. VRF was examined by tooth sectioning following the development of a fracture mechanics analysis to predict VRF in such roots. **Methods:** The fracture morphology in teeth extracted from patients because of VRFs was examined from a series of horizontal cross sections. 2-dimensional fracture mechanics analysis in conjunction with the finite element technique was developed to evaluate VRF caused by canal pressure (q). As in our previous single-rooted tooth model, the apical obturation force (F) was related to q using a simple formula. **Results:** Fracture was mostly limited to the buccal root, exhibiting some competing modes including fracture from the depression peak to the canal surface and the canal surface to the root surface, which may occur either along straight lines or curved trajectories resembling the depression outline. The analysis predicted clinical fractures well, yielding VRF force values in the upper range used by clinicians during lateral condensation of gutta-percha. **Conclusions:** The main etiology for VRF is stress concentration resulting from the combined effect of wedgelike canal depression and the flexibility of periodontal ligament tissue joining the root and bone. This drawback can be alleviated by minimizing canal enlargement and apical condensation force during root canal therapy. *(J Endod 2018;■:1–5)*

Key Words

Bifurcated premolars, buccal root, gutta-percha, vertical root fracture

Significance

This article suggests that to avoid vertical root fracture in buccal roots of maxillary premolar teeth the shape and size of the canal should be altered as little as possible during endodontic treatment.

Maxillary premolars are among the teeth most susceptible to vertical root fracture (VRF) (1–3), a major complication in endodontically treated teeth that often leads to tooth extraction (4, 5). The buccal root in these teeth is characterized by a furcation groove with a highly concave surface, a feature found in 78%–100% of teeth examined (6–11). Although it is recognized that the depression peak in such roots constitutes a danger zone after endodontic treatment that may lead to long-term complications such as perforations and VRF (7, 12), little is known regarding the conditions governing VRF. The aim of this study was to gain insight into the fracture morphology using tooth sectioning and formulate a fracture mechanics methodology for predicting apical obturation force causing VRFs.

Studies on single-rooted teeth (13–17) suggest that a major cause for VRF is pressure transmitted to the canal wall during lateral condensation of gutta-percha. VRF was recently studied from a 2-dimensional (2D) fracture mechanics perspective using a horizontal root slice model containing an elliptic canal subjected to uniform pressure (q) (18). The apical force (F_c) causing VRF was found using a simple formula relating F_c to critical pressure (q_c) driving initial fracture lines (cracks in fracture mechanics terminology) placed on the canal surface all the way to the root surface. The resulting F_c (≈ 100 N) was similar to that found in *in vitro* tests on extracted roots subjected to apical obturation by a spreader, either under a single ramp (13, 19–22) or cyclically (23–25). This study is extended to the more complex case of buccal roots of the bifurcated maxillary premolars.

Materials and Methods

VRF Damage Morphology

Twenty maxillary bifurcated premolar teeth extracted because of VRFs were used; all were treated by lateral condensation of gutta-percha. The teeth, collected from patients 50 years and older by the School of Dental Medicine at Tel-Aviv University, Tel-Aviv, Israel, with patient consent and institutional review board approval, were kept moist up to testing. Sectioning was performed as in our previous study (18); after embedment in polyester resin for support, the teeth were sectioned horizontally, the cut surface polished to mirror quality, and the surface observed for damage using optical microscopy. Cuts were made in 1- to 2-mm increments to cover the entire root length.

From the *School of Mechanical Engineering, Faculty of Engineering and †Goldschleger School of Dental Medicine, Tel-Aviv University, Tel-Aviv, Israel.
Address requests for reprints to Prof Herzl Chai, Tel Aviv University, Levanon St, 61390 Tel Aviv, Israel. E-mail address: herzl@eng.tau.ac.il
0099-2399/$ - see front matter

https://doi.org/10.1016/j.joen.2018.03.017

Fracture Mechanics Analysis

The buccal root in maxillary premolars exhibits a furcation groove with a highly concave surface (Fig. 1*A*). VRF tends to initiate from the deepest depression site and run axially (Fig. 1*B*). Guided by such observations, Figure 1*C* shows the slice model used for predicting VRF in buccal roots; by virtue of symmetry, only half of the specimen was considered. To help elucidate major trends, as in our previous study (18), some simplifications in the complex root anatomy were invoked; all were found to be inconsequential. The root cross section is rectangular (dimensions L and W), except that 1 of its sides has a wedgelike depression characterized by angle ϕ, which extends from the root surface to height $b/2$ above the horizontal aspect. The root is attached to a square bone (D = 5 mm) via a 0.2-mm-thick periodontal ligament (PDL). The canal is assumed circular with radius a. The remaining dentin thickness is given as $r_t = S - a$, where S is the distance from the specimen center to the depression peak. Motivated by experimental data presented in the next section, we considered the growth behavior of 3 cracks (c_1, c_3, and c_4) emanating from the canal surface at points A, C, and D and 1 crack (c_2) emanating from the depression peak (point B).

The fracture behavior under increasing canal pressure (q) was studied with the aid of a commercial finite element (FEM) code (Ansys, Inc, Canonsburg, PA) specified to 2D plane-strain conditions. To start the analysis, initial cracks of length c_F = 0.07 mm representing natural flaws in dentin (18) were placed at points A to D (Fig. 1*C*). These cracks were made to propagate simultaneously along their respective principal stress trajectories where tensile stresses are maximized. A crack grows when $K(c)$ reaches K_C, where c, $K(c)$, and K_C are the concurrent crack length, the stress intensity factor at the crack tip, and the fracture toughness of dentin, respectively. K_C was taken to increase linearly from 1 to 3 MPa $m^{1/2}$ over the first 0.5 mm of crack growth and then remain fixed (18). The calculation of K under increasing pressure (q) was similar to that in our previous study (18). The crack trajectory was collinear for c_1, c_2, and c_4, whereas it was curved for c_3. Similarly to the study of Chai and Ravichandran (26), the incremental angle in this case was determined by trial and error in repeated FEM runs until K was maximized. VRF was determined to occur when a crack had traversed the entire dentin thickness. The apical VRF force was found using $F_c = Aq_c$, where $A = \pi a^2$ is the canal cross-sectional area and q_c the pressure needed to advance a crack across the dentin wall (18).

All materials were assumed isotropic and linearly elastic with Young's modulus E and Poisson's ratio ν given as E_d, E_{pdl}, and E_b = 18, 0.05, and 1.4 GPa and ν_d, ν_{pdl}, and ν_b = 0.31, 0.45, and 0.30, where subtext d, pdl, and b indicate dentin, PDL, and bone, respectively (18). The FEM mesh was refined to insure convergence of all stresses of interest to within 1%–2%.

Results

Tests

Figure 2*A*–*C* shows selected micrographs for 3 teeth extracted because of VRFs. All sections exhibit buccal and palatal roots each having 1 canal, the canals that are joined in the coronal region. The buccal root is kidney shaped with the greatest depression at its midlength (7). Fracture is mostly limited to the buccal root where 3 modes are evident: cracks extending along either side of the horizontal aspect and a pair of curved cracks initiating on the canal surface and deflecting toward the depressed outline as they grow. In Figure 2*A*, only horizontal cracks occur, splitting the root in 2, whereas in Figure 2*B* all 3 fracture modes occur, with all cracks spanning the dentin wall to cause a severe form of VRF. The behavior in Figure 2*C* is similar except that only the right-side horizontal crack is fully open. Fracture may also occur in the palatal root (Fig. 2*A* and *B*), tending to grow downward from the coronal part where the roots are joined (Fig. 2*A*).

Measurements made on all buccal roots studied yielded the following mean values (standard deviation) for the section with the greatest surface depression: a, W, L, S, and b = 0.42 (0.09), 2.68 (0.48), 3.4 (0.36), 0.74 (0.11), and 0.19 (0.08) mm, and φ = 43° (4.6°). Except for canal radius a, these values were conclusively used in the finite element analysis.

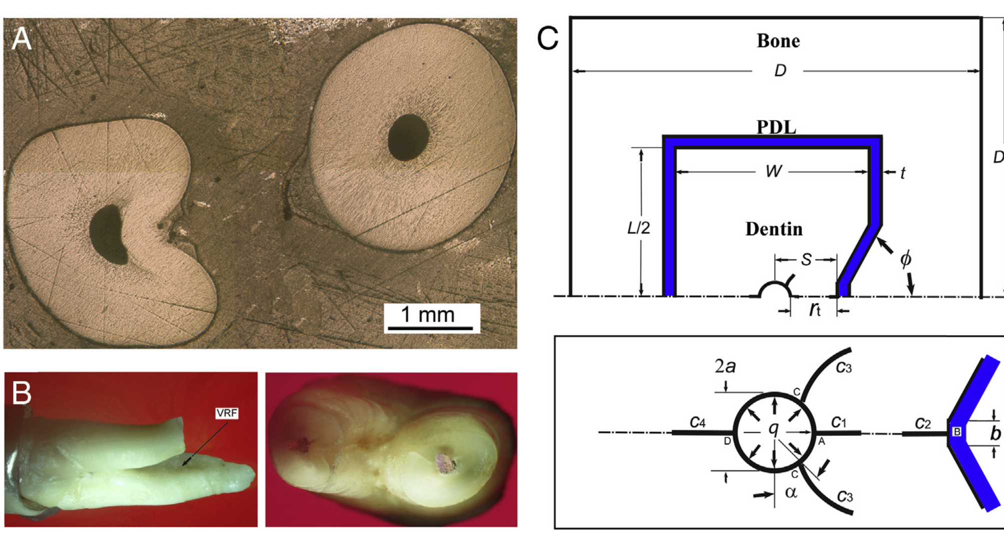

Figure 1. (*A*) A transverse section 4.9 mm above the root apex for an untreated bifurcated maxillary premolar. The buccal root (*left*) is distinguished by the kidney-shaped surface depression; the size and severity vary along the root axis. (*B*) Clinical VRF in a bifurcated maxillary premolar; the fracture initiates in the midsection of the buccal root where the surface depression is the greatest. (*C*) The 2D slice model used to predict VRF in the buccal root. By symmetry, only half of the structure is considered. The lower part is a magnified view of the canal region. The root section is rectangular except for a depression characterized by angle ϕ. The root, attached to bone via a 0.2-mm-thick PDL, contains a circular canal of radius a under uniform pressure (q). Four cracks (c_1–c_4, all of initial length c_F = 0.07 (18)) are placed on the canal surface as shown. The growth of these cracks because of pressure q is determined in accordance with linear fracture mechanics theory. VRF occurs when a given crack traverses the dentin wall.