Effective Factors Including Periodontal Ligament on Vertical Root Fractures

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The purpose of the present study was to analyze effective factors including periodontal ligament on vertical root fractures (VRFs). Eighty maxillary central incisors were assigned to eight groups, depending on master apical file (MAF) size, loading point and existence of a simulated periodontal ligament (PDL). The gutta-percha in the root canal was vertically pressed with a Co-Cr rod using a universal testing machine. An ordinal logistic analysis was employed to determine significant factors. VRFs were observed in 88.8% of the specimens but no horizontal fractures were found. There were three types of VRFs: partial fracture not involving the apex (PF, 41.3%), partial fracture involving the apex (AF, 40.0%), and complete fracture (CF, 7.5%). MAF size significantly affected VRFs ($p < 0.05$); large MAF size exhibited more partial fractures involving the apex. Loading point and existence of PDL did not affect VRFs.

Key words: Root fracture, Root canal preparation, Endodontic treatment

INTRODUCTION

Endodontically treated teeth often require functional restoration for final prosthetics¹⁾ and are known to have a higher risk of root fracture and coronal leakage²⁻⁵⁾. The diagnosis of root fracture usually results in eventual extraction⁶⁾. Several causes of root fracture have been proposed: root canal preparation^{7,8)}, excessive use of force during root canal obturation^{9,10)}, wedging effect of spreader¹¹⁾, post space preparation¹²⁾, and post placement¹³⁾. These causes are considered to have applied a load on root canal.

Root fractures are classified into horizontal root fractures and vertical root fractures. Horizontal fracture is correlated with trauma¹⁰⁾, whereas vertical root fracture is correlated with endodontical treatment and restoration⁶⁻¹³⁾. The most common fracture pattern in many experimental fracture studies is the horizontal fracture¹⁴⁻¹⁶⁾, whereas only a few experimental studies show vertical root fractures during lateral condensation^{17,18)}.

A new experimental set-up has been suggested for analyzing factors on vertical root fracture¹⁹⁾. This set-up could induce vertical root fractures in 88.8% of the specimens. For simulating actual clinical situation of teeth, the periodontal ligament permitted the root mobility. A silicone layer simulating periodontal ligament was allowed the root to move in a limited space^{20,21)}. However, the role of periodontal ligament on vertical root fracture has not been clearly confirmed.

The purpose of the present study was to analyze effective factors including periodontal ligament on

vertical root fractures.

MATERIALS AND METHODS

Tooth specimens preparation

Maxillary central incisors were used in the present study. Reasons for extraction and the ages of patients when they were extracted were unknown. The roots of the incisors were dyed with an India ink (Salis International Ink, Hollywood, FL) to examine the presence of radicular cracks or craze lines under a CCD camera ($\times 25$) (VH-8000, Keyence, Osaka, Japan).

Tooth crown was removed with a diamond disc, and the length adjusted to 12 mm followed by coronal third flaring with Gates-Glidden burs (#1-4, Mani, Tochigi, Japan). The specimens were then assigned to eight groups of 10 teeth each. Groups 1-8 were categorized according to three factors: master apical file (MAF) size (Small or Large), loading point (Coronal or Apical), and existence (Present or Absent) of a simulated periodontal ligament (PDL) (Table 1). Regarding Groups 5-8, their results were referred from a previous report¹⁹⁾.

Root canal preparation and addition of simulated periodontal ligament

In Groups 1, 2, 5, and 6 (Small MAF), root canals were prepared in step-back manner with a #35 K-file (Zipperer Munich, Germany) as the MAF. In Groups 3, 4, 7, and 8 (Large MAF), root canals were prepared in crown-down manner with a #9 (diameter of file tip: 0.78 mm) Series 29 rotary ProFile (Dentsply Tulsa Dental, Tulsa, OK) driven by a

Table 1 Examined conditions and results of fracture patterns and loads

Group	MAF size	Loading point	Periodontal ligament	Fracture pattern				Average Fracture load (kgf)
				NF	PF	AF	CF	
1	S	C	+	0	8	1	1	34.8
2	S	A	+	1	6	3	0	33.8
3	L	C	+	0	3	4	3	27.6
4	L	A	+	0	1	9	0	19.2
5*	S	C	—	1	6	1	2	37.2
6*	S	A	—	1	5	4	0	36.5
7*	L	C	—	6	2	1	1	30.3
8*	L	A	—	0	2	8	0	25.0
Total				9	33	31	7	

Master apical file (MAF) size: Small (S) or Large (L)

Loading point: Coronal (C) or Apical (A)

(n=80)

Existence of a simulated periodontal ligament: Present (+) or Absent (—)

Fracture patterns: no fracture (NF), partial fracture not involving the root apex (PF), partial fracture involving the root apex (AF) and complete fracture (CF)

*Referred from Okitsu et al.¹⁹⁾

Triauto-ZX (Morita, Tokyo, Japan) as the MAF. The final working length was determined when the tip of MAF was visible at the apical foramen. The root canals were filled with 6% NaOCl during instrumentation.

Root canal preparation was followed by irrigation with 5 ml of 15% EDTA and 6% NaOCl, then drying with paper points. After which, the root canal was filled with warmed gutta-percha in two steps: down-pack and back-pack. A gutta-percha master cone (GC, Tokyo, Japan), the tip of which was covered with Sealapex (Kerr, Romulus, MI), was inserted into the prepared canal to down-pack using a System B Fine plugger (Analytic Endodontics, Orange, CA) with 200°C and Power 10 settings. The coronal portion of the canal was back-packed using an Obtura II (Obtura Spartan, Fenton, MO) with a 23 gauge applicator needle at a setting of 200°C. The obturated gutta-percha length of Groups 1, 3, 5, and 7 was 9 mm from the apex, while that of Groups 2, 4, 6, and 8 was 6 mm from the apex. The former and latter groups were defined as coronal loading point and apical loading point, respectively.

The roots of Groups 5-8 were directly embedded into an acrylic tube (20-mm height $\times$ 10-mm diameter) with autopolymerizing resin. On the other hand, the roots of Groups 1-4 were embedded into an acrylic tube (18-mm height $\times$ 10-mm diameter) with a layer of vinyl polysiloxane (Exahiflex, GC) as a simulated periodontal ligament 200 to 500 μ m in thickness. The roots were then embedded in an autopolymerizing resin at a depth of 8 mm from the top edge of an acrylic tube. The roots were controlled its position at the center of the acrylic tube by a special jig. Simulated periodontal ligament spaces were fabricated by wrapping the root with a

single layer of aluminum foil. The roots together with foil were removed from the tube. The surface of the root and root space in the tube were coated with an impression adhesive (Adhesive Exahiflex, GC). Immediately after the injection of vinyl polysiloxane, the root was repositioned in the tube using the jig. Thus the space of the foil was replaced by polysiloxane. Another acrylic tube (2-mm height $\times$ 10-mm in diameter) was bonded onto the acrylic tube by adhesive. It was also filled with autopolymerizing resin so that the root would not move downward during the fracture test.

Fracture test

The top surface of gutta-percha in the root canal was loaded by the flat head of a 1.0-mm diameter Co-Cr rod (Sun-platinum orthodontic wires, Dentsply Sankin, Tokyo, Japan). The load was continuously applied using a special jig equipped in a universal testing machine (1123, Instron, Canton, MA) at a cross-head speed of 1.0 mm/min until the Co-Cr rod was apically inserted to a depth of 2 mm (Fig. 1).

Immediately after the fracture test, the acrylic tube was removed with a diamond disc. The root surface was thoroughly examined with a CCD camera ($\times 25$), and fracture patterns were classified into four categories as follows: no fracture (NF), partial fracture not involving the root apex (PF), partial fracture involving the root apex (AF), and complete fracture (CF) (Fig. 2).

Ordinal logistic regression was used to analyze the fracture patterns and one-way ANOVA was used to evaluate fracture loads at a significant level of 5% (JMP 5.1, SAS, Cary, NC).

Fig. 1 Schema of loading apparatus. a: cross-head of universal testing machine, b: Co-Cr rod, c: simulated periodontal ligament, d: autopolymerizing resin, e: acrylic tube.

Fig. 2 Typical fracture patterns. PF: partial fracture not involving the root apex, AF: partial fracture involving the root apex, CF: complete fracture.

RESULTS

Fracture patterns and fracture loads of the specimens are summarized in Table 1. Ordinal logistic regression revealed the significant effect of MAF size on vertical root fracture pattern ($p < 0.05$). However, other factors such as loading point, existence of PDL and their interactions were not significant. The ratio of AF in large MAF groups (Groups 3, 4, 7, and 8; 57.5%) was greater than that in small MAF groups (Groups 1, 2, 5, and 6; 22.5%). The ratio of PF in small MAF groups (62.5%) was greater than that in large MAF groups (17.5%).

The MAF size significantly affected fracture load. The fracture load of small MAF groups (35.5 kgf) was greater than that of large MAF groups

(25.5 kgf, $p < 0.05$). Loading point and existence of PDL did not significantly influence fracture load.

DISCUSSION

A silicone layer was used to simulate periodontal ligament, thereby allowing the root to move within limited space^{17,20,21}. It is important to examine effective factors including periodontal ligament on vertical root fractures. Moreover, the silicone layer of simulated periodontal ligament will relax and/or proportionate stress²², and might stress concentration apically.

In this study, no horizontal fractures were observed and 88.8% of the specimens showed vertical root fractures. In previous reports on root fractures, the tooth was usually embedded in resin and a load applied at 130-135° inclination from the horizontal plane using a universal testing machine¹⁴⁻¹⁶. Horizontal root fractures were the most frequent fracture pattern shown in these previous studies, and only a few studies reported on vertical fractures¹⁶⁻¹⁸. When a load was applied toward the apex to simulate lateral condensation with a spreader *in vitro*, a vertical root fracture involving the apex occurred^{17,18}. The wedge effect of the spreader was thus thought to be a cause of vertical root fractures.

The fracture patterns in the present study were classified into four categories: NF, PF, AF, and CF. The location of cracks on the root surface corresponded to the level of the head of Co-Cr rod that pressed the gutta-percha in the root canal. The vertical load induced gutta-percha deformation to stress the root dentin laterally. A crack then originated at the highest stress concentration area and could possibly propagate radially. The mechanical properties of dentin were reported to be anisotropic^{23,24}. In particular, the tensile strength of root dentin parallel to the long axis of the root is greater than that perpendicular to the long axis. Therefore, a crack easily propagates coronally or apically rather than horizontally.

For analyzing vertical root fractures, our previous report suggested that the interaction between MAF size and loading point significantly influenced vertical root fracture patterns. Large MAF size with apical loading point led to a more severe fracture pattern¹⁹. Otherwise in the present study, the experimental set-up including periodontal ligament, only MAF size factor was significant: larger MAF size showed more severe fracture patterns. When the load was applied to gutta-percha, the root canal wall could be laterally expanded because of the existence of PDL. Therefore, the existence of PDL might cause root fractures more easily. The number of non-fractured teeth in groups with and without PDL was 1 and 8, respectively; the average fracture loads were 28.9 kgf and 32.2 kgf, respectively. However,

these differences were not statistically significant. This phenomenon was probably responsible for neglecting the interaction between MAF size and loading point in this study.

In particular, large MAF size led to a greater number of vertical root fractures involving the apex (AF). The larger size of the apical foramen and thinner thickness of root dentin could reduce fracture resistance, which would enable AF to occur more frequently.

The fracture load of the present study ranged from 11.5 to 45.5 kgf. The vertical load during lateral condensation was reported to range from 1 to 3 kgf^{8,18)}. Therefore, the load applied during the lateral condensation procedure alone to the long axis of the root would not directly cause a vertical root fracture.

Taking into account the limitations of this *in vitro* experiment, we concluded that the size of master apical file might be a more effective factor than loading point or existence of a simulated periodontal ligament on vertical root fractures. This suggested that clinicians should pay more attention in preserving root dentin to avoid vertical root fractures.

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