Fracture resistance after simulated crown lengthening and forced tooth eruption of endodontically-treated teeth restored with a fiber post-and-core system

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ABSTRACT: Purpose: To evaluate the effect of ferrule preparation length on the fracture resistance after simulated surgical crown lengthening and after forced tooth eruption of endodontically-treated teeth restored with a carbon fiber-reinforced post-and-core system. **Methods:** 40 extracted endodontically-treated mandibular first premolars were decoronated 1.0 mm coronal to the buccal cemento-enamel junction. The teeth were divided randomly into five equal groups. The control group had no ferrule preparation (Group A). Simulated crown lengthening provided ferrule preparations of 1.0 mm (Group B) and 2.0 mm (Group C). Simulated forced tooth eruption provided ferrule preparations of 1.0 mm (Group D) and 2.0 mm (Group E). After restoration with a carbon fiber post-and-core system, each root was embedded in an acrylic resin block from 2.0 mm apical to the margins of a cast Ni-Cr alloy crown, and loaded at 150° from the long axis in a universal testing machine at a crosshead speed of 1.0 mm/minute until fracture. Data were analyzed using ANOVA with Tukey HSD tests, and Fisher's exact test, with $\alpha = 0.05$. **Results:** Mean failure loads (kN) for Groups A, B, C, D and E were: 1.13 (SD= 0.15), 1.27 (0.18), 1.02 (0.11), 1.63 (0.14) and 1.92 (0.19), respectively. Significant differences were shown for the effects of treatment method and ferrule length, with significant interaction between these two sources of variation ($P < 0.0001$). Increased apical ferrule preparation lengths resulted in significantly increased fracture resistance for simulated forced tooth eruption ($P < 0.0001$), but not for simulated crown lengthening ($P \geq 0.24$). (*Am J Dent* 2009;22:147-150).

CLINICAL SIGNIFICANCE: Simulated crown lengthening with 2.0 mm apical extended ferrule preparations resulted in significantly reduced fracture resistance for endodontically-treated roots restored with a carbon fiber post-and-core system. However, the combination of simulated forced tooth eruption and apical crown margin ferrule placement resulted in significantly increased fracture resistance.

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Introduction

Placement of post-cores or dowel-cores is a conventional method for restoring endodontically-treated teeth when inadequate tooth structure remains. The main function of the post in the root canal is to provide retention for the core, not to improve the fracture resistance of the endodontically-treated tooth.[1-3] However, many factors affect root fracture resistance, such as canal configuration and post adaptability,[4] post width,[5] post material[6,7] and ferrule design.[2,6-10] When compared to metal alloy posts, carbon fiber-reinforced posts have mechanical properties that more closely match those of dentin,[11,12] and are also significantly better in preventing catastrophic root fracture.[13,14] Ferrules effectively improve the fracture resistance of endodontically-treated teeth when adequate coronal tooth structure remains.[2,6-10] At least 1.5 mm ferrule preparation lengths for cast alloy post-cores,[15] and 2.0 mm ferrule preparation lengths for prefabricated non-metallic post-and-cores[9] have been recommended.

Broken down teeth with extensive tissue loss in the cervical third of the root are a challenge for clinicians to provide an adequate post-core retained artificial crown. Few studies have evaluated ferrule preparations for this situation.[16] The apical extended ferrule preparations must maintain the 'biological width' of the periodontal tissues. Surgical crown lengthening aims to increase the length of coronal tooth structure by removing the supporting periodontal structures to expose subgingival root surfaces.[17,18] A normal biological width can be re-established by this procedure.[19] If the tooth has reduced bone support or the osseous surgical procedure would create either a poor crown-to-root ratio, or an esthetic problem, then crown lengthening is contraindicated.[18,20]

An alternative method used to increase the length of coronal tooth structure is by orthodontic forced tooth eruption,[21,22] which employs slow passive or active extruding forces to achieve approximately 2.0 mm of extrusion per month.[23] This method preserves the supporting alveolar bone and provides a better crown-to-root ratio when compared to surgical crown lengthening.[16,19,22] Which of these two methods is best for increasing the fracture strength of endodontically-treated roots restored with fiber-reinforced post-and-core restorations, and the optimal length required for the ferrule preparations, remains unresolved.

The present *in vitro* study evaluated the effect of ferrule preparation length on the fracture resistance of endodontically-treated teeth restored with a prefabricated carbon fiber-reinforced post-and-core system and cast metal alloy crowns, using either simulated surgical crown lengthening or simulated orthodontic forced tooth eruption. The null hypothesis proposed was that the root fracture resistance was independent of the ferrule preparation length and of the simulated treatment method.

Table 1. Mean dimensions (mm) of randomly assigned mandibular first premolar roots in each group.

		Width of canal wall sites, and roots, at root face*					
Group (N-40)	Root length*	Mesial	Buccal	Distal	Lingual	M-D	B-L
A	14.11 (0.55)	1.94 (0.09)	2.24 (0.19)	1.84 (0.13)	2.27 (0.30)	5.05 (0.33)	7.42 (0.39)
B	14.48 (0.77)	1.96 (0.15)	2.37 (0.15)	1.97 (0.15)	2.28 (0.18)	5.22 (0.23)	7.71 (0.35)
C	14.24 (0.46)	1.94 (0.13)	2.23 (0.18)	1.89 (0.15)	2.17 (0.26)	5.04 (0.28)	7.43 (0.36)
D	14.26 (0.30)	1.95 (0.16)	2.32 (0.14)	1.93 (0.11)	2.31 (0.18)	5.19 (0.34)	7.49 (0.65)
E	14.39 (0.50)	2.07 (0.20)	2.29 (0.11)	1.94 (0.11)	2.35 (0.14)	5.21 (0.22)	7.48 (0.30)
1-way ANOVA	F=0.563 P=0.69	F=1.002 P=0.42	F=1.150 P=0.35	F=1.289 P=0.29	F=0.790 P=0.54	F=0.768 P=0.55	F=0.595 P=0.67

Group A: carbon fiber post-core with no ferrule, as control; Group B: carbon fiber post-core with simulated crown lengthening and 1.0 mm ferrule; Group C: carbon fiber post-core with simulated crown lengthening and 2.0 mm ferrule; Group D: carbon fiber post-core with simulated forced tooth eruption and 1.0 mm ferrule; Group E: carbon fiber post-core with simulated forced tooth eruption and 2.0 mm ferrule.
*Mean (Standard deviation). M-D: Mesiodistal root width; B-L: Buccolingual root width.

Materials and Methods

Specimen preparation - Forty sound mandibular first premolars extracted for orthodontic reasons were obtained with the consent of healthy Chinese adults aged 20-30 years. The study was approved by the Medical Ethics Organization of Jiangsu province, PR China. After cleaning and the removal of attached soft tissues, the teeth were examined stereoscopically at x10 magnification to verify the absence of cracks, before being stored in 0.9% saline solution at 4°C. The teeth were used within 4 weeks after extraction. The natural crowns were decoronated perpendicular to their long axes 1.0 mm coronal to the buccal cemento-enamel junction, using water-cooled diamond disks.

Standardized root canal preparations using the step-back technique were completed with size 4 drills (Gates-Glidden[a]), before placing laterally-condensed gutta percha points[b] to obturate the canals. The root canal lengths were measured to 14.0 mm. Post-hole channels, 10.0 mm deep, for tapered carbon fiber-reinforced posts (#2 C-POST[c]) were prepared using the matching drills provided in a slow-speed handpiece with water coolant. The 40 prepared roots were assigned to five equal groups (A, B, C, D, E), according to a table of random numbers. The roots had very similar dimensions (Table 1), which were measured to 0.02 mm (Vernier Caliper Model 93218-0654[d]).

The prepared post-hole walls were etched with 32% phosphoric acid gel (Uni-Etch[c]) for 15 seconds, then rinsed thoroughly with an air-water spray and dried lightly with paper points. A resin-based adhesive (One-Step Plus[c]), was applied twice as a thin layer over the walls of the post-hole and once over the surfaces of a prefabricated carbon fiber-reinforced post (#2 C-Post[c]). After thinning lightly with dry oil-free air, the adhesive was light-cured (Variable Intensity Polymerizer Junior[c]) from a coronal direction for 10 seconds at 600 mW/cm^2. The post-hole was filled completely by injecting resin luting cement (Post Cement Hi-X[c]), before inserting the carbon fiber-reinforced post. A resin composite core (Light-Core[c]) was built up around the post and light-cured for 40 seconds.

Cores were prepared 5.0-7.0 mm high with a 12° convergence angle, leaving a 0.8 mm wide encircling shoulder in dentin, using a milling machine (F3/Ergo[e]) with flat-ended tapered tungsten carbide burs. The root face was left unprepared in the control group (Group A), which had a 5.0 mm high resin composite core. Simulated crown lengthening resulted in ferrule preparation lengths of 1.0 mm (Group B) and 2.0 mm (Group C), which increased the heights of the cores. Simulated forced tooth eruption resulted in ferrule preparation lengths of 1.0 mm (Group D) and 2.0 mm (Group E), while maintaining the 5.0 mm heights of the cores (Fig. 1).

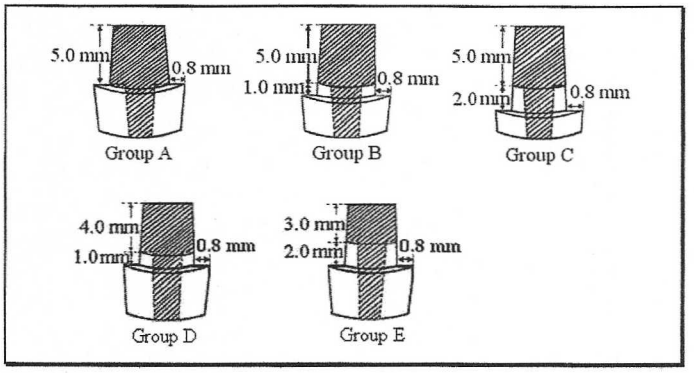

Fig. 1. Preparation designs. **A.** with no ferrule as control; **B.** with simulated crown lengthening and 1.0 mm ferrule; **C.** with simulated crown lengthening and 2.0 mm ferrule; **D.** with simulated forced tooth eruption and 1.0 mm ferrule; **E.** with simulated forced tooth eruption and 2.0 mm ferrule.

After 24 hours in the isotonic saline storage medium, a standardized nickel-chromium (Ni-Cr) alloy crown fabricated in the dental laboratory for each of the prepared teeth was cemented with glass-ionomer cement (Glasionomer[f]). The teeth were kept in the storage medium at all times except during the experimental testing.

Fracture resistance testing - Each root was coated with a 0.1~0.2 mm thin layer of a vinyl polysiloxane silicone (modulus of elasticity 0.3 MPa) (Aquasil[b]), to simulate the periodontal ligament before being embedded, from 2.0 mm apical to the crown preparation margins, in a block of self-cured acrylic resin[g] (modulus of elasticity ~2.5 GPa).

A unidirectional static load was then applied to the buccal cusp of the Ni-Cr alloy crown, at an angle of 150° from the long axis of the root, using a cylindrical Ni-Cr alloy rod (3.0 cm long x 0.8 cm diameter) in a universal load-testing machine (Model CSS-2202[h]) at a crosshead speed of 1.0 mm/minute (Fig. 2). The 150° angle simulated the application of an oblique occlusal force. The force (kN) for initial root fracture was recorded and the failure site pattern noted.

Statistical analysis - All analyses employed a commercial software package (SPSS v11.0[i]). One- and two-way ANOVAs with Tukey HSD tests, and Fisher's exact test were used to detect any significant differences between the groups. The probability level for statistical significance was set at $\alpha = 0.05$.

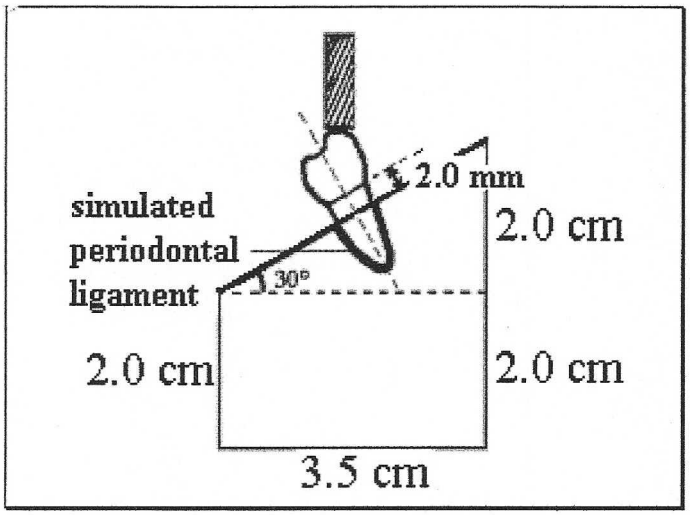

Fig. 2. Diagram of the embedding and loading of restored tooth specimen.

Table 2. Mean force (kN) required to fracture the tooth roots, and the fracture sites, in each group.

Group (N=40)	Ferrule length (mm)	Fracture strength (kN)*	Root fracture site: At or above cervical 1/3	Root fracture site: Below cervical 1/3
A	0.0	1.13 (0.15)	8	0
B	1.0	1.27 (0.18)	8	0
C	2.0	1.02 (0.11)	7	1
D	1.0	1.63 (0.14)	7	1
E	2.0	1.92 (0.19)	7	1

2-way ANOVA:
Treatment method effect: F=81.81, P<0.0001**
Ferrule effect: F=21.95, P<0.0001**
Interaction effect: F=31.81, P<0.0001**
Group codes are defined in Table 1.
*Mean (Standard deviation). **Statistically significant.

Results

The mean force (kN) required to fracture the restored teeth, and the root fracture sites, in each group are shown in Table 2. For fracture resistance, 2-way ANOVA revealed statistically significant differences in the effects of both the treatment method and the ferrule length, with significant interaction also between these two sources of variation (P< 0.0001).

For the simulated surgical crown lengthening method, Group B (1.0 mm ferrule) demonstrated significantly higher fracture resistance loads than Group C (2.0 mm ferrule), (P= 0.008), but both of these groups showed no significant differences when compared to the control Group A (no ferrule), (P= 0.24, 0.39). However, for the simulated forced tooth eruption method, there were significant differences among all three groups (P≤ 0.005), with increased ferrule preparation length being associated with higher fracture resistance loads. The findings are shown in Table 3 and illustrated in Fig. 3.

Almost all of the fractures were found at or above the cervical one-third of the roots (Table 2). No statistically significant differences among the three groups were found (P= 1.00).

Discussion

Specimen preparation and fracture resistance testing - Mandibular first premolars were selected for this study because

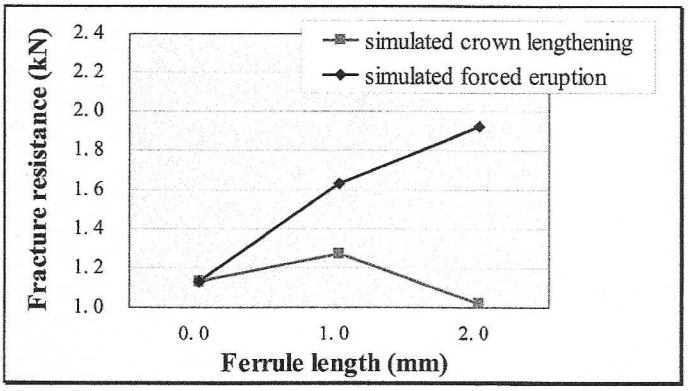

Fig. 3. Comparison of root fracture resistance for simulated crown lengthening and forced tooth eruption with different apical extended ferrule lengths.

Table 3. Statistical comparisons between groups using the Tukey HSD tests.

Ferrule length	Simulated crown lengthening	Simulated forced eruption
0.0-mm/ 1.0-mm	P= 0.24	P< 0.001*
0.0-mm/ 2.0-mm	P= 0.39	P< 0.001*
1.0-mm/ 2.0-mm	P= 0.008*	P= 0.005*

*Statistically significant.

these teeth are vulnerable to vertical root fracture following endodontic treatment.[24] The teeth were extracted from young adults who lived in the same locality, and had very similar root forms and dimensions (Table 1). Gross destruction of coronal tooth structure was simulated by using standardized flat root-face preparations. All the cores and ferrule preparations were machined by the same person (Q-FM) using the same milling device.

The roots of the restored teeth were coated with silicone rubber and embedded in acrylic resin. The moduli of elasticity of these materials approximated those of the viscoelastic periodontal ligament and the alveolar bone, respectively.[25,26] An oblique force, applied at 150° from the long axis of the mandibular premolar tooth, was employed to simulate functional working-side buccal cusp loading.[16]

Fracture resistance of restored premolars - The effective clinical crown length (Ce) to embedded root length (Rb) ratio (Ce/Rb) is defined as "the physical relationship between the portion of the tooth within the alveolar bone compared with the portion not within the alveolar bone, as determined radiographically".[27] The tooth with its root embedded in the alveolar bone could be considered as a Class I lever, with the fulcrum in the cervical portion.[28] Surgical crown lengthening increases the crown portion of the fulcrum (effort arm), with the root portion (resistance arm) decreased and the center of rotation moved apically. However, forced tooth eruption only decreases the root portion of the tooth. Thus, the Ce/Rb for Groups B and C were 0.91 and 1.10 (21.3% and 46.7% greater than the control Group A, respectively), but the Ce/Rb for Groups D and E were 0.82 and 0.90 (9.3% and 20.0% greater than the control Group A, respectively), (Fig. 4). The mean fracture resistance for Groups B and C were 28.3% and 88.2% lower than those for Groups D and E, respectively (Table 2, Fig. 2). The forced tooth eruption method reduced the crown-to-root ratio less and increased the root facture resistance more than the surgical crown lengthening method, the results being supported by anecdotal clinical reports.[19,22,29]

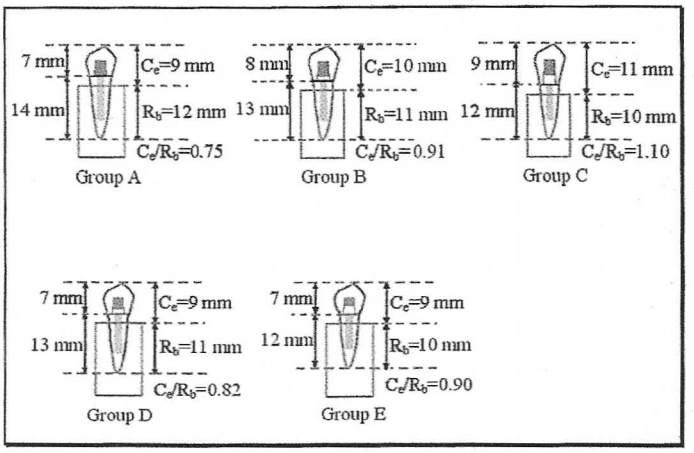

Fig. 4. Effective clinical crown length (Ce) to embedded root length (Rb) ratios (Ce/Rb) for the restored teeth: Group codes are defined in Fig. 1.

A minimum 1:1 crown-to-root ratio has been suggested for a prospective abutment tooth under normal circumstances.[30] The diameter and dentin bulk of the root also decreases towards the root apex because of root taper. Therefore, clinical attention should be paid to the potential reduction in root fracture resistance when preparing a long ferrule in the cervical portion of an extensively broken-down endodontically-treated single-rooted tooth. For Groups D and E, which simulated forced tooth eruption, the Ce/Rb ratios were both less than the minimum suggested.[30] The combination of forced tooth eruption and a ferrule preparation increased significantly the fracture resistance of the endodontically-treated teeth (Table 2, Fig. 3).

In this *in vitro* study, the null hypothesis was not accepted for either the apical extended ferrule preparation length or the simulated treatment method employed.

a. Dentsply Maillefer SA, Ballaigues, Switzerland.
b. Dentsply International Inc., York, PA, USA.
c. Bisco, Inc., Schaumburg, IL, USA.
d. Harbin Measuring and Cutting Tool Group Co. Ltd, Harbin, PR China.
e. Degussa AG, Düsseldorf, Germany
f. Shofu Inc., Kyoto, Japan.
g. Shanghai Dental Materials Manufacturing Co., Shanghai, PR China.
h. Changchun Tester Institute, Changchun, PR China.
i. SPSS Inc., Chicago, IL, USA.

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