©*Operative Dentistry, 2007,* **32-6**, 595-601

# Effect of a Ferrule and Increased Clinical Crown Length on the *In Vitro* Fracture Resistance of Premolars Restored Using Two Dowel-and-Core Systems

Q-F Meng • Y-M Chen • H-B Guang
KH-K Yip • RJ Smales



### Clinical Relevance

Crown lengthening with a 2.0 mm apical extended ferrule preparation may result in reduced root fracture strengths for endodontically-treated teeth. A carbon fiber-reinforced dowel-resin core system may reduce the severity of the root fractures.

## SUMMARY

**This study investigated the effect of a crown-lengthening ferrule on the fracture resistance of endodontically-treated teeth restored with two dowel-core systems.**

**Thirty-two extracted mandibular first premolars were sectioned perpendicular to the long axis at a point 1.0 mm occlusal to the buccal cementoenamel junction. Following endodontic treatment, the teeth were randomly assigned to four groups: cast Ni-Cr alloy dowel-core with no ferrule (Group A1), cast Ni-Cr alloy dowel-core with 2.0 mm ferrule (Group A2), prefabricated carbon fiber-reinforced dowel-resin core with no ferrule (Group B1) and carbon fiber-reinforced dowel-resin core with 2.0 mm ferrule (Group B2). Each specimen was embedded in a self-cured acrylic resin block from 2.0 mm apical to the margins of a cast Ni-Cr alloy crown, then loaded at 150° from the long axis in a universal testing machine at a crosshead speed of 1.0 mm/minute until fracture. The data were recorded and analyzed using ANOVA and Fisher's exact tests, with $\alpha$=0.05.**

**Mean failure loads (kN) for the A1, A2, B1 and B2 Groups were: 1.46 (S.D. 0.45), 1.07 (0.21), 1.13 (0.30) and 1.02 (0.27). The teeth restored with cast Ni-Cr dowel-cores and 2.0 mm ferrules demonstrated significantly lower fracture strengths, *p*=0.04. There were significant differences in the root fracture patterns between the two dowel**

Qing-Fei Meng, Dental Research Institute of Nanjing Medical University, Nanjing, PR China

*Ya-Ming Chen, Dental Research Institute of Nanjing Medical University, Nanjing, PR China

Han-Bing Guang, Dental Research Institute of Nanjing Medical University, Nanjing, PR China

Kevin H-K Yip, Faculty of Dentistry, The University of Hong Kong, Hong Kong SAR, PR China

Roger J Smales, Dental School, The University of Adelaide, Adelaide, South Australia, Australia and honorary professor, Dental Research Institute of Nanjing Medical University, Nanjing, PR China

*Reprint request: 140 Hanzhong Road, Nanjing, Jiangsu Province, 210029, PR China; e-mail: yaming_chen@yahoo.com

DOI: 10.2341/06-169

**systems, with the carbon fiber-reinforced dowel-resin core system, being the less severe *p*<0.05.**

**Crown lengthening with a 2.0 mm apical extended ferrule resulted in reduced fracture strengths for endodontically-treated teeth restored using two dowel-core systems and cast metal crowns. The carbon fiber-reinforced dowel-resin core system reduced the severity of the root fractures.**

## INTRODUCTION

Substantial coronal tooth destruction will usually require a dowel-core for intracanal retention of the restoration and distributing loading stresses to the remaining tooth structure. However, placement of the dowels in the root canals will not improve the strength of the remaining tooth structure.[1-2]

In one study, teeth with a metal dowel length equal to or greater than the clinical crown height had a success rate of 97%.[3] However, there also are reports of cast metal alloy dowel-cores having an inordinately high failure rate,[4] which is twice the frequency of prefabricated metal dowels.[5] Though short cast metal dowel lengths may be a significant factor in causing the high failure rates, in order to achieve an adequate apical seal, at least 4.0-5.0 mm of apical gutta percha should remain after canal preparation.[6]

Metal-free carbon, quartz and glass fiber-reinforced dowels have gained extensive use in recent years, following very promising initial clinical success rates.[7] Resin-bonded fiber-reinforced dowels offer several advantages over cemented cast and prefabricated metal dowels, including improved esthetics and a modulus of elasticity closer to dentin, preventing root fractures.[8] Fiber-reinforced dowel-resin cores were significantly better in preventing premolar root fractures than conventional dowel-amalgam cores in a five-year controlled clinical trial.[9]

A ferrule comprises a 360° metal crown collar encircling parallel walls of dentin and extending coronal to the margin or shoulder of the preparation. The preservation of at least 1.0 mm of coronal tooth structure above the artificial crown margin or shoulder substantially increased the *in vitro* fracture resistance of endodontically-treated teeth restored with cast dowel-cores and crowns.[1,3] Subsequent studies recommended a coronal ferrule length equal to or greater than 1.5 mm for cast dowel-cores[10] and 2.0 mm for prefabricated fiber-reinforced dowel-resin cores.[11]

Dowel material and ferrule design have been shown by many research workers to be significant factors affecting the *in vitro* fracture resistance of restored endodontically-treated teeth.[1-2,12-15] However, few *in vitro* studies have examined the combined effects of dowel material and ferrule design with clinical crown lengthening on the fracture resistance of restored endodontically-treated teeth or simulated tooth analogs.[11,16-18]

Therefore, this *in vitro* study evaluated the combined effect of two dowel systems and a crown-lengthening ferrule on the fracture resistance of restored teeth. The null hypothesis proposed was that, for endodontically-treated first premolars restored with cast metal alloy crowns, the fracture resistance of the teeth to a static loading force is independent of the dowel system used, whether or not placement of an apical extended ferrule is done.

## METHODS AND MATERIALS

### Specimen Preparation

Thirty-two sound mandibular first premolars were extracted for orthodontic reasons. The teeth were obtained with the consent of healthy Chinese adults 20 to 30 years of age, living in the same locality, without water fluoridation. After cleaning, the teeth were examined stereoscopically at 10x magnification to verify the absence of cracks and before being stored in 0.9% saline solution at 4°C for no longer than two weeks. The natural crowns were sectioned perpendicular to their long axes 1.0 mm coronal to the buccal cementoenamel junction using water-cooled diamond disks.

Standardized root canal preparations were completed using size 4 drills (Gates-Glidden, Dentsply Maillefer SA, Ballaigues, Switzerland) before placing laterally-condensed gutta percha points (Dentsply International Inc, York, PA, USA) to obturate the canals. Post-hole preparation channels, 10 mm deep, for tapered carbon fiber-reinforced dowels or posts (#2 C-POST, BISCO, Inc, Schaumburg, IL, USA) were made using the matching drills provided in a slow-speed contra-angle handpiece. The 32 prepared roots were randomly assigned to four equal groups (A1, A2, B1, B2) according to a table of random numbers. The root lengths and the mesiodistal and buccolingual diameters of the roots at the root face and the cross-sectional width of the canal walls at the mesial, buccal, distal and lingual root face sites were measured to 0.02 mm with a vernier caliper (Vernier Caliper Model 93218-0654, Harbin Measuring & Cutting Tool Group Co Ltd, Harbin, PR China). There were no statistically significant differences in these dimensions among the four groups, as shown in Table 1.

For Groups A1 and B1, the root face was left unprepared, with a 5.0 mm high tapered core being fabricated, leaving an 0.8 mm wide encircling shoulder of dentin (Figure 1a). For Groups A2 and B2, a 2.0 mm long ferrule with an 0.8 mm wide shoulder was prepared to extend apical from the root face to encircle the root, and a 5.0 mm high tapered core was fabricated

Table 1: *Mean Dimensions (mm) of Randomly Assigned Mandibular First Premolar Roots in Each Group*

| Group | Root | Width of Canal Wall Sites, and Roots, at Root Face* | | | | | |
|---|---|---|---|---|---|---|---|
| (N=32) | Length* | Mesial | Buccal | Distal | Lingual | M-D | B-L |
| A1 | 13.82 (0.54) | 1.89 (0.21) | 2.29 (0.22) | 1.84 (0.16) | 2.34 (0.12) | 4.97 (0.32) | 7.16 (0.42) |
| A2 | 14.23 (0.73) | 1.90 (0.14) | 2.06 (0.34) | 1.86 (0.13) | 2.14 (0.25) | 4.98 (0.26) | 7.31 (0.41) |
| B1 | 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) |
| B2 | 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) |
| 1-way ANOVA | F=0.916 $p$=0.45 | F=0.250 $p$=0.86 | F=1.381 $p$=0.27 | F=0.218 $p$=0.88 | F=1.155 $p$=0.34 | F=0.149 $p$=0.93 | F=0.807 $p$=0.50 |

*A1: cast dowel-core with no ferrule; A2: cast dowel-core with 2.0 mm ferrule; B1: carbon fiber dowel-core with no ferrule; B2: carbon fiber dowel-core with 2.0 mm ferrule.*
*M-D: Mesiodistal root width, B-L: Buccolingual root width.*
**Mean (Standard Deviation).*

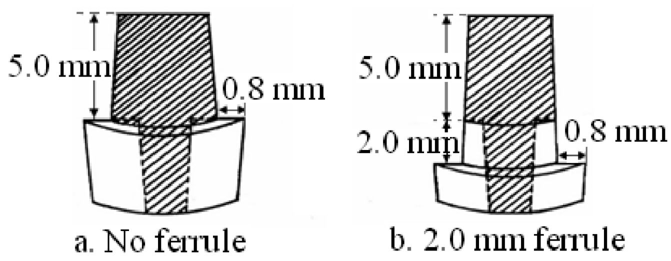


Figure 1: *Preparation designs: a. No ferrule and b. 2.0 mm ferrule.*

(Figure 1b). All cores were prepared with a 12° convergence angle using a milling machine (F3/Ergo, Dusseldorf, Germany).

Group A1: After taking a vinyl polysiloxane impression (Aquasil, Dentsply International) of the prepared post-hole, a tapered dowel-core was fabricated in a cast nickel-chromium (Ni-Cr) alloy (Chang Ping Shi Ye Inc, Shanghai, PR China) and sandblasted. The post-hole walls were conditioned with 10% polyacrylic acid (Dentsply International) for 15 seconds, then rinsed thoroughly and dried lightly with paper points. Before milling, the Ni-Cr alloy dowel-core was placed using glass-ionomer cement (GIC) (Glasionomer, Shofu Inc, Kyoto, Japan) according to the manufacturer's instructions.

Group A2: The root was prepared with an apical extended 2.0 mm long ferrule. A Ni-Cr alloy dowel-core was fabricated and cemented, as in Group A1.

Group B1: The prepared post-hole walls were etched with 32% phosphoric acid gel (UNI-ETCH, BISCO, Inc) for 15 seconds, then rinsed thoroughly and dried lightly with paper points. A resin-based adhesive (ONE-STEP PLUS, BISCO, Inc) 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 dowel (#2 C-POST, BISCO, Inc). After thinning lightly with dry, oil-free air, the adhesive was light-cured (Variable Intensity Polymerizer Junior, BISCO, Inc) from a coronal direction for 10 seconds at 600 mW/cm$^2$. The post hole was completely filled by injecting resin luting cement (POST CEMENT HI-X, BISCO, Inc) before inserting the carbon fiber-reinforced dowel. A resin composite core (LIGHT-CORE, BISCO, Inc) was built-up around the dowel and light cured for 40 seconds before milling.

Group B2: The root was prepared with an apical extended 2.0 mm long ferrule. A carbon fiber-reinforced dowel and a resin composite core were placed, as in Group B1.

After 24 hours in the saline storage medium, a standardized Ni-Cr alloy crown was fabricated in the dental laboratory for each of the prepared teeth and cemented with GIC (Shofu Inc). The specimens were kept in the storage medium at all times except during the experimental testing.

**Fracture Strength Testing**

Each root was coated with a 0.1~0.2 mm thin layer of vinyl polysiloxane silicone (modulus of elasticity 0.3 MPa) (Aquasil, Dentsply International) 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 (modulus of elasticity 2~3 GPa) (Shanghai Dental Materials Manufacturing Co, Shanghai, PR China). A unidirectional static load was then applied to the buccal cusp of the Ni-Cr alloy crown at an angle 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, Changchun Tester Institute, Changchun, PR China) at a crosshead speed of 1.0 mm/minute (Figure 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 patterns noted.

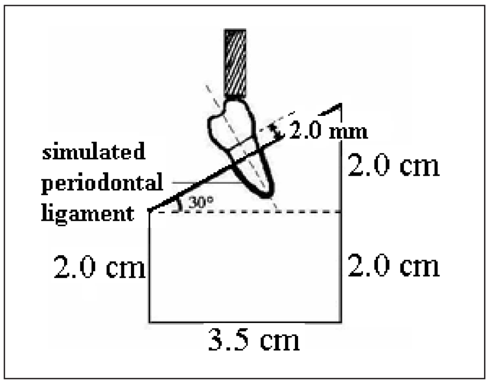


Figure 2: *Diagrammatic representation of tooth specimen embedding and loading.*

**Statistical Analysis**

All analyses were conducted using a commercial software package (SPSS v11.0, SPSS Inc, Chicago, IL, USA). One-way and two-way ANOVA with Tukey HSD tests, Student's *t*-test 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.

## RESULTS

The mean force (kN) required to fracture the roots of the teeth and the fracture sites in each group is shown in Table 2. For fracture resistance, two-way ANOVA revealed a significant difference in the effect of ferrule design (favoring the no ferrule design) ($p$=0.04) but no significant difference in the effect of the dowel system ($p$=0.10), with no significant interaction between these two sources of variation ($p$=0.24). For the cast Ni-Cr dowel-core system, the Group A1 (no ferrule) design fractured at a marginally significantly higher mean force than the Group A2 (2.0 mm ferrule) design (t=2.221, $p$=0.05). For the prefabricated carbon fiber dowel-core system, there was no statistically significant difference between the mean fracture forces for the Group B1 (no ferrule) and the Group B2 (2.0 mm ferrule) designs (t=0.771, $p$=0.43).

With respect to the cervical third of the root (Table 2), fracture patterns were classified according to the root fracture site. Fisher's exact tests (Table 3) demonstrated that the presence or absence of a ferrule did not influence the site of root fractures for each of the two dowel systems ($p$=1.00). However, the type of dowel system significantly influenced the site of root fractures for both the ferrule and no ferrule designs ($p$<0.05). Most of the root fractures associated with the Ni-Cr alloy dowels were severe and located below the cervical third, while most of the root fractures associated with the carbon fiber dowels were less severe and located at or above the cervical third.

Table 2: *Mean Force (kN) Required to Fracture the Tooth Roots, and the Fracture Sites, in Each Group*

| Group (N=32) | 2.0 mm Ferrule | Fracture Strength* (kN) | Root Fracture Site: At or Above Cervical Third | Root Fracture Site: Below Cervical Third |
|---|---|---|---|---|
| A1 | No | 1.46 (0.45) | 3 | 5 |
| A2 | Yes | 1.07 (0.21) | 2 | 6 |
| B1 | No | 1.13 (0.30) | 8 | 0 |
| B2 | Yes | 1.02 (0.27) | 7 | 1 |
| Two-way ANOVA | Ferrule effect: F=4.691, $p$=0.04**<br>Dowel-core effect: F=2.674, $p$=0.10 | | | |

*Mean (Standard Deviation).
**Statistically significant.

Table 3: *Fisher's Exact Test Results for the Two Root Fracture Sites in the Four Groups*

| **Ferrule** | Ni-Cr Dowel | Fiber Dowel | **Dowel Type** | No Ferrule | Ferrule |
|---|---|---|---|---|---|
| **No/Yes** | $p$=1.00 | $p$=1.00 | **Ni-Cr/Fiber** | $p$=0.03* | $p$=0.04* |

*Statistically significant.

## DISCUSSION

### Specimen Preparation and Fracture Strength Testing

Mandibular first premolars were selected for this study, because these teeth are vulnerable to vertical root fracture after endodontic treatment.[19] The teeth were obtained from young adults who lived in the same locality and had very similar root forms and dimensions (Table 1). Gross destruction of the coronal tissues was simulated using standardized flat root face preparations. Grossly broken down endodontically-treated teeth may also require surgical crown lengthening,[20] which facilitates placement of a long apical extended ferrule to potentially enhance the resistance of the remaining root to fracture.[21-22]

The roots of the restored teeth were coated with silicone rubber and embedded in acylic resin. The moduli of elasticity of these materials approximated those of the viscoelastic periodontal ligament and the alveolar bone, respectively.[23-24] To minimize the experimental variables, a unidirectional static loading force was used in this and many other studies of root fractures. However, further *in vitro* testing should more closely simulate the complex dynamic forces present during mastication and parafunction and the effects of single severe impacts. An oblique force applied at 150° from the long axis of the mandibular premolar was employed to simulate functional working-side buccal cusp loading. Similar *in vitro* studies of maxillary incisor fracture resistance have employed angles from 110°-150°.[21,25-27]

### Fracture Resistance of Restored Premolars

Endodontically-treated teeth requiring placement of deep subgingival preparation margins may need surgical crown lengthening or orthodontic extrusion to gain the retention and resistance forms necessary for successful coronal restorations. Crown lengthening surgery is considered an effective method for restoring endodontically-treated teeth with subgingival defects.[20] The alveolar bone level can be lowered surgically for apical extension of the preparation margins and to re-establish biological width, which is necessary for periodontal health.[28] Crown lengthening would facilitate the apical placement of a ferrule and, presumably, also increase fracture resistance of the root.

However, the static loading test results showed that the mean fracture strength for Groups A1 and B1 with no ferrules was 35.5% and 10.8%, higher than for Groups A2 and B2, which were prepared with 2.0 mm ferrules (Table 2). Other *in vitro* studies employing metal alloy dowels have found either no significant difference in fracture resistance[17] or a significant reduction in fracture resistance[16] for the crown lengthening and ferrule placement when compared to no crown lengthening and no ferrules. One *in vitro* study involving a quartz fiber-reinforced dowel-resin composite found that a 2.0 mm apical extended ferrule was significantly more effective in increasing fracture resistance than shorter ferrules.[11] A recent finite element analysis study of maxillary incisors found that, when subjected to a palatal load, the placement of either conventional coronal or apical extended ferrules produced high tensile stresses in dentin at the palatal cervical margins of the preparations.[18] These stresses approached the tensile strength of dentin and may possibly result in crack propagation.

The effective clinical crown length ($C_e$) in the apical extended ferrule groups was 11.0 mm, which is 2.0 mm more than that in the no ferrule groups, and the embedded root length ($R_b$) was 10.0 mm, which is 2.0 mm less than what is in the no-ferrule groups. Therefore, the clinical crown/root ratio ($C_e/R_b$) was 1.10 for the ferrule groups and 0.75 for the no-ferrule groups (Figure 3). In addition, the diameter of the root decreases towards the root apex, because of root taper. The placement of a 2.0 mm long ferrule, which increased the clinical crown/root ratio, reduced the fracture strength of the endodontically-treated teeth (Table 2). Thus, caution is needed when preparing a long, heavy ferrule in the clinical situation, as the reduced volume of the root dentin that remains may then compromise the fracture resistance of the root to heavy occlusal stresses.

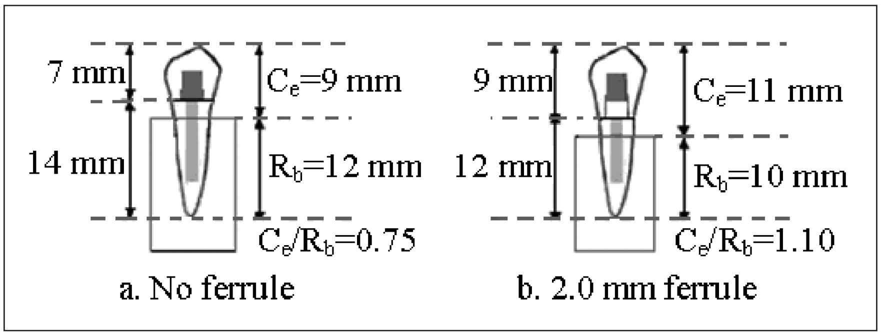


Figure 3: *Effective clinical crown length ($C_e$) to embedded root length ($R_b$) ratios ($C_e/R_b$) for restored teeth: a. No ferrule, and b. 2.0 mm ferrule.*

Ideally, dowels should have a similar modulus of elasticity to dentin in order to better distribute occlusal loads and prevent high stress concentrations in the remaining sound root substance.[14,29] Moduli of elasticity are approximately 21 GPa for carbon fiber-reinforced dowels (BISCO, Inc), 150-200 GPa for cast Ni-Cr alloys and 15 GPa for human dentin.[23] In a finite element study, irrespective of dowel length and diameter, when compared to more rigid cast gold and prefabricated stainless steel dowels, fiber-reinforced dowels reduced stress on root dentin around the apical dowel tips by 5-14%.[30] Moduli of elasticity are approximately 16-25 GPa for universal and posterior resin composites,[23] which may be used as core materials with fiber-reinforced dowels. When subjected to fatigue loading, the latter combination provided significantly stronger artificial crown retention than cast gold alloy dowel-cores and titanium alloy dowel-resin composite cores.[13] The use of a resin-based luting cement with a low modulus of elasticity would also reduce the transfer of mechanical stresses from a rigid metal dowel to the remaining root dentin,[29,31] as would the use of a resin composite to reinforce thin-walled root canals.[27]

The root fracture sites were significantly different for Ni-Cr alloy dowels and carbon fiber-reinforced dowels (Table 2). Most failures for the Ni-Cr alloy dowel-core system were catastrophic fractures, such as vertical root fractures and oblique root fractures located below the cervical third of the roots; whereas, most failures for the fiber-reinforced dowel-core system were less severe oblique fractures located at or above the cervical third of the roots and were potentially repairable.

## CONCLUSIONS

This *in vitro* study found that mandibular premolars restored without a ferrule fractured at significantly higher loads than teeth restored with an apical extended 2.0 mm long ferrule ($p$=0.04). The provision of a long, heavy ferrule decreased the volume of sound root dentin and increased the clinical crown length relative to the embedded root length. Root fractures were more severe and were located further apical for the cast Ni-Cr alloy dowel-core system than for the prefabricated carbon fiber-reinforced dowel-resin core system ($p$<0.05). Therefore, the null hypothesis that tooth fracture resistance was independent of placement of an apical extended ferrule was not accepted.

**Acknowledgements**

This study was financially supported (Nanjing Medical University A/c 1347) and undertaken by the Dental Materials Research Laboratory of Dr Ya-Ming Chen, Department of Prosthodontics, School of Stomatology, Nanjing Medical University, PR China. The unrestricted use of a financial donation received from BISCO, Inc and financial assistance received from The China Travel Grant, The University of Hong Kong in support of Dr KH-K Yip, are gratefully acknowledged. The authors appreciate the statistical advice received from Prof Feng Chen, Department of Statistics, School of Public Health, Nanjing Medical University.

*(Received 5 December 2006)*

## References

1. Sorensen JA & Engelman MJ (1990) Ferrule design and fracture resistance of endodontically-treated teeth *Journal of Prosthetic Dentistry* **63(5)** 529-536.

2. Tan PLB, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT & Dawson D (2005) *In vitro* fracture resistance of endodontically-treated central incisors with varying ferrule heights and configurations *Journal of Prosthetic Dentistry* **93(4)** 331-336.

3. Sorensen JA & Martinoff JT (1984) Clinically significant factors in dowel design *Journal of Prosthetic Dentistry* **52(1)** 28-35.

4. Morgano SM & Milot P (1993) Clinical success of cast metal posts and cores *Journal of Prosthetic Dentistry* **70(1)** 11-16.

5. Torbjörner A, Karlsson S & Odman PA (1995) Survival rate and failure characteristics for two post designs *Journal of Prosthetic Dentistry* **73(5)** 439-444.

6. Mattison GD, Delivanis PD, Thacker RW Jr & Hassell KJ (1984) Effect of post preparation on the apical seal *Journal of Prosthetic Dentistry* **51(6)** 785-789.

7. Fredriksson M, Astback J, Pamenius M & Arvidson K (1998) A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts *Journal of Prosthetic Dentistry* **80(2)** 151-157.

8. Freedman GA (2001) Esthetic post-and-core treatment *Dental Clinics of North America* **45(1)** 103-116.

9. Mannocci F, Qualtrough AJ, Worthington HV, Watson TF & Pitt Ford TR (2005) Randomized clinical comparison of endodontically-treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results *Operative Dentistry* **30(1)** 9-15.

10. Libman WJ & Nicholls JI (1995) Load fatigue of teeth restored with cast posts and cores and complete crowns *International Journal of Prosthodontics* **8(2)** 155-161.

11. Akkayan B (2004) An *in vitro* study evaluating the effect of ferrule length on fracture resistance of endodontically-treated teeth restored with fiber-reinforced and zirconia dowel systems *Journal of Prosthetic Dentistry* **92(2)** 155-162.

12. Mezzomo E, Massa F & Libera SD (2003) Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: An *in vitro* study Part I *Quintessence International* **34(4)** 301-306.

13. Goto Y, Nicholls JI, Phillips KM & Junge T (2005) Fatigue resistance of endodontically-treated teeth restored with three dowel-and-core systems *Journal of Prosthetic Dentistry* **93(1)** 45-50.

14. Barjau-Escribano A, Sancho-Bru JL, Forner-Navarro L, Rodriquez-Cervantes PJ, Pérez-González A & Sánchez-Marín FT (2006) Influence of prefabricated post material on restored teeth: Fracture strength and stress distribution *Operative Dentistry* **31(1)** 47-54.

15. Pereira JR, de Ornelas F, Conti PC & do Valle AL (2006) Effect of a crown ferrule on the fracture resistance of endodontically-treated teeth restored with prefabricated posts *Journal of Prosthetic Dentistry* **95(1)** 50-54.

16. Gegauff AG (2000) Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns *Journal of Prosthetic Dentistry* **84(2)** 169-179.

17. Al-Hazaimeh N & Gutteridge DL (2001) An *in vitro* study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated post and composite core restorations *International Endodontic Journal* **34(1)** 40-46.

18. Ichim I, Kuzmanovic DV & Love RM (2006) A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root *International Endodontic Journal* **39(6)** 443-452.

19. Wu MK, van der Sluis LW & Wesselink PR (2004) Comparison of mandibular premolars and canines with respect to their resistance to vertical root fracture *Journal of Dentistry* **32(4)** 265-268.

20. Yeh S & Andreana S (2004) Crown lengthening: Basic principles, indications, techniques and clinical case reports *New York State Dental Journal* **70(8)** 30-36.

21. Manning KE, Yu DC, Yu HC & Kwan EW (1995) Factors to consider for predictable posts and core build- ups of endodontically-treated teeth. Part I: Basic theoretical concepts *Journal of the Canadian Dental Association* **61(8)** 685-695.

22. Morgano SM, Rodrigues AH & Sabrosa CE (2004) Restoration of endodontically-treated teeth *Dental Clinics of North America* **48(2)** 397-416.

23. O'Brien WJ (1996) Elastic modulus, E In: Biomaterials properties database Ann Arbor: University of Michigan; www.lib.umich.edu/dentlib/Dental_tables/Elasmod.html.

24. Bourauel C, Freudenreich D, Vollmer D, Kobe D, Drescher D & Jager A (1999) Simulation of orthodontic tooth movements. A comparison of numerical models *Journal of Orofacial Orthopaedics* **60(2)** 136-151.

25. Trabert KC & Cooney JP (1994) The endodontically treated tooth: Restorative concepts and techniques *Dental Clinics of North America* **28(4)** 923–951.
26. Duncan JP & Pameijer CH (1998) Retention of parallel-sided titanium posts cemented with six luting agents: An *in vitro* study *Journal of Prosthetic Dentistry* **80(4)** 423-428.
27. Wu X, Chan ATT, Chen YM, Yip KH & Smales RJ (2007) Effectiveness and dentin bond strengths of two materials for reinforcing thin-walled roots *Dental Materials* **23(4)** 479-485.
28. Lanning SK, Waldrop TC, Gunsolley JC & Maynard JG (2003) Surgical crown lengthening: Evaluation of the biological width *Journal Periodontology* **74(4)** 468-474.
29. Lanza A, Aversa R, Rengo S, Apicella D & Apicella A (2005) 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor *Dental Materials* **21(8)** 709-715.
30. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y, Takano N & Yatani H (2006) Stress analysis of endodontically-treated anterior teeth restored with different types of post material *Dental Materials Journal* **25(1)** 145-150.
31. de Santis R, Prisco D, Apicella A, Ambrosio L, Rengo S & Nicolais L (2000) Carbon fiber post adhesion to resin luting cement in the restoration of endodontically-treated teeth *Journal of Materials Science Materials in Medicine* **11(4)** 201-206.