

Effect of Ferrule Placement on the Fracture Strength of Cyclically Loaded Bovine Teeth Restored with Cemented Cast Post-Cores and Crowns.¹

Abdul Aziz Al-Amro* and Peter Robert Wilson†

Abstract - This experiment investigated the effect of a ferrule on the strength and fracture resistance of bovine teeth restored with cemented cast post-cores and crowns, compared to crowns alone or to crowns over non-ferrule cores. Thirty restored bovine teeth were subjected to 4×10^5 cycles from 20 N to 120 N at 10 Hz, followed by fracture testing. Crowns alone were weaker than post restored teeth. There was no difference in fracture strength between ferrule and non ferrule teeth restored with crowns. All of the fractured teeth were subsequently unrestorable. **Conclusions:** Fracture resistance was not enhanced by 2 mm ferrule height.

KEY WORDS: Ferrule, Casting, Fracture, Crowns, Teeth, Posts

INTRODUCTION

Endodontic therapy is reported to have a high success rate¹, but the final prognosis also depends on the quality of the coronal restoration². Weine³ claimed that more endodontically treated teeth are lost due to poor restoration than subsequent endodontic treatment failure.

Endodontically treated teeth tend to have an increased likelihood of fracture⁴ and the most likely cause of this is the loss of structural integrity caused by access cavity preparation, making the tooth less able to withstand normal occlusal loading^{5,6}. There is no scientific evidence to support the widespread belief that endodontically treated teeth are more brittle than vital teeth or dehydrate following loss of vitality⁷⁻¹⁰.

Fracture of restored, endodontically treated teeth is a serious complication¹¹⁻¹³. In 1955, Frank¹⁴ recommended a metal collar as a part of a coping and dowel to increase fracture resistance. Eissman¹⁵ later called this collar the 'ferrule effect'. Recently, Sorensen¹⁶ modified the definition of "ferrule effect" to describe a more internal feature of crown preparations, away from the margins. It is in the form of a column or ring of dentine surrounding the post space; the parallel-sided walls of the dentine preparation are subsequently enclosed by the fitting surface of the crown after cementation.

There have been conflicting studies that have investigated the benefit of the "ferrule effect". Some of these studies found that the "ferrule effect" was effective¹⁷⁻²¹ while others did not^{16, 22-26}. This variation may be due to differences in methodology. Many studies did not use extracoronal

restorations, and loads were applied directly to the post and cores^{18, 23, 24, 27}. In some investigations, there was no change in crown height, or crown-to-root ratio of ferrule samples, compared to other groups^{16,21,28} which meant that the ferrule samples effectively had more remaining tooth structure. Other studies are more realistic and simulated a crown lengthening procedure before preparation of a ferrule effect.^{19, 25, 26}

Several authors^{15, 17, 18, 29} have recommended a 2 mm high ferrule. Libman and Nicholls¹⁹ used a strain gauge to indicate cement failure and found that a minimum height of 1.5 mm ferrule was required to be effective.

Cyclic loading (fatigue testing) has been advocated by many authors^{19, 21, 30-35} and is considered more clinically relevant than static loading.

Bovine teeth have been widely used in laboratory studies as a substitute for human teeth^{21, 36, 37}. Isidor^{21, 30, 31} used bovine teeth in fatigue testing of post and core systems and found that bovine teeth were a valuable substitute for human teeth.

The working hypothesis is that a ferrule increases the fatigue strength and fracture resistance of bovine teeth restored with cemented, cast post-cores and crowns, compared to teeth restored with just PFM crowns or PFM crowns over a non-ferrule core.

MATERIALS AND METHODS

Incisor teeth were harvested from the mandibles of freshly killed dairy cows. All residual soft tissue was cleaned off the teeth before they were stored in Phosphate buffered saline solution with 0.05% Sodium Azide. Radiographs were taken of all the collected teeth to exclude those with large pulps. Teeth with visible cracks were also excluded. Thirty teeth of similar size and length were selected for the study.

* BDS MDSc

† MDS MDSc PhD Grad Dip Hlth Admn

¹ Based on a thesis submitted to The University of Melbourne, being a partial fulfillment of the requirements for the Degree of Master of Dental Science.

Ten teeth were randomly selected to form the control group; for PFM crowns but no post and cores. They were held with wet gauze and prepared with a diamond bur D112G314 in a high-speed handpiece under copious water irrigation. The apical third of each root was notched for retention and mounted vertically in auto-polymerizing acrylic resin inside a short length of PVC pipe (20 mm diameter electrical conduit, 20 mm long). A centralising jig was used to keep each tooth vertically aligned until the acrylic resin set.

The control group tooth preparations were finalized using a high-speed handpiece attached to a dental surveyor by a specially fabricated, brass lockable elbow joint. The lingual reduction was completed with a medium grit D277314 diamond bur. The axial walls of the root were reduced with a fine D167C314 bur to leave a 1 mm shoulder margin. The finished, prepared tooth measurements were 6 mm high, 5 mm mesio-distally, 6 mm labio-lingually and a 1 mm shoulder margin located 3 mm above the margin of the acrylic mounting.

The remaining 20 teeth were sectioned at the level of the CEJ, using a slow-speed handpiece with copious water irrigation and a diamond disc (number D355C104 Super Diaflec "C" Double sided disc). Pulp tissue was removed with barbed broaches. The teeth were then mounted as for the control group. The gingival margin of the root was placed 3 mm above the acrylic mounting. A 10 mm long and 1.5 mm diameter posthole was prepared using twist drills in a slow-speed handpiece with copious water irrigation. The gingival third was flared labio-lingually to produce an anti-rotational feature. Each post and core was fabricated using a matching burn out post and inlay wax to adapt it to the post hole.

To standardize the core size, a custom mould was made of one of the prepared sound teeth with vinylpolysiloxane impression material in a custom made acrylic tray. A mix of pattern resin was then poured into the mould to make the cores. The cores were joined to the posts by drilling a small hole in each core and filling it with fresh pattern resin. The cores were then placed onto the posts while the latter were located in their post holes, to facilitate correct alignment and centralization of the cores. The excess resin around each core was removed. The post and core patterns were then sprued at their incisal edges using 3 mm diameter of wax for sprues and attached to a crucible former, five patterns per former. They were then coated with debubbler and dried with a gentle air stream.

A phosphate-bonded investment material was mixed, using 8ml Starvest's liquid, 6.5ml of distilled water and 60g powder under vacuum. This mixture was then poured into each casting ring and placed under 6 bars of pressure for 12 min. The plastic casting ring and sprue former were then removed (ringless technique). The invested patterns were placed in a burn out furnace at room temperature and raised to 260°C at a rate of 5°C min⁻¹, held for 30 minutes, then raised to 450°C at a rate of 5°C min⁻¹ and held for 40 minutes. The final temperature of 620°C was reached at a rate of 7°C min⁻¹ and held for 60 minutes. Casting with type IV gold alloy was performed, using an electric casting machine and a graphite crucible. The casting was divested and cleaned with 50 µm diameter aluminum oxide in a sandblasting machine. Each post was examined under 10x

magnification for any casting defect. The post and cores were adjusted to seat passively into their respective roots and then sand blasted.

Each post hole was irrigated with saline and dried with absorbent paper points before cementation. All post and cores were cemented with encapsulated Zinc Phosphate cement. The cement was mixed for five seconds in an amalgamator. A lentulospiral in a slow-speed handpiece was used to introduce the cement into the post space. The post was also coated with cement and slowly seated by finger force. During cementation, hydraulic backpressure was released by slight withdrawal and the post gently reseated; finger force was maintained, until the cement had set. Excess cement was removed and the axial walls adjusted to ensure a 1 mm wide shoulder margin.

From the group of post and core restored teeth (twenty in number), ten teeth were randomly selected to be the "ferrule effect" group. While the post and core was held in its respective root, the finish margin was relocated 2 mm apically using a medium grit diamond bur D112314 bur in a high-speed handpiece attached to the dental surveyor as before.

The three test groups were designated as:

1. Control group (C): teeth with PFM crown but no post and core.
2. Non-ferrule group (NF): teeth with a PFM crown and a post and core but no ferrule effect.
3. Ferrule group (F): teeth with a PFM crown and post and core with a ferrule effect.

Each prepared tooth was relieved with 4 layers of die-spacer. A wax pattern for a crown coping was constructed on the prepared tooth using a margin wax for the margins and hard inlay wax for other areas. The copings were sprued, invested and burned out in exactly the same way as the post and cores, except the final temperature in coping reached 890°C. Casting was performed using an open gas flame (Gas and Oxygen) and a 65% nickel, 22.5% chromium and 9.5% molybdenum alloy in a graphite crucible. The castings were divested and cleaned as before.

The copings were oxidized at 950° C for 5 minutes without vacuum then sand blasted with 50 µm diameter aluminum oxide to control the thickness of the oxide layer thickness and ultrasonically cleaned in distilled water for 5 minutes.

Opaque layers were applied to the copings and were fired at 960°C in a Vacumat 100 furnace. Three layers of opaque were applied.

The dentin build up mix was made from Duceram dentine porcelain fired at 920°C. All the crowns were finished using a bur to make them as similar in size as possible i.e. 8mm mesiodistal, 10mm inciso-gingival for groups C and NF, and 12mm incisogingival height for group F.

Finally, the crowns were glazed at 900°C, the fitting surface sand blasted and any uncovered metal margins polished.

Each crown was cemented with encapsulated zinc phosphate cement 24 hours before testing. The cement was mixed for five seconds in an amalgamator. A brush was used to distribute the cement. The crown was seated

gently with finger pressure and held in place until the cement had set.

The samples were placed in a specially constructed apparatus attached to a closed loop servo-hydraulic testing machine (Material Testing System 810) at 45 degrees to the axis of load application. The load was applied via a 10mm diameter stainless steel ball to the mid-palatal area.

Each sample was maintained at 37°C +/- 1°C by a jacket of water fed to it via PVC tubing attached to a heated water reservoir.

The samples were subjected to a cyclic loading of 4×10^5 cycles before fracture testing. The loads applied during cycles were between a minimum load of 20 N and maximum load of 120 N with the force profile in the form of a half sine wave curve at 10 Hz.

The 20 N minimum preload was used to keep the load device in continuous contact with the specimen.

After cyclic loading, fracture testing was conducted with a static load applied with a crosshead speed of 3 mm per min. The output from the test machine was monitored with Labview software.

RESULTS

No failures occurred during cyclic loading so all samples proceeded to fracture with static loading.

This data is plotted in Figure 2. The mean fracture load for the control (C) group was 1400 N with a standard deviation of 320. The mean fracture loads for the non-ferrule (NF) and ferrule (F) groups were 2010 N and 2000 N respectively, and the standard deviations were 460 and 270, respectively.

Analysis of Variance followed by pairwise comparisons and Tukey's Test revealed that the mean load to fracture of the control group (C) was significantly less than the other two groups ($p < 0.003$).

The Ferrule (F) and Non-Ferrule (NF) groups mean loads to fracture were not significantly different from each other ($p = 0.997$).

The fracture mode was constant within each group. The control group demonstrated an oblique fracture mode extending from the lingual area of the root down to the labial area. The ferrule group had the same mode of fracture, whereas the non-ferrule group had a vertical root fracture mode.

DISCUSSION

In this study, samples that simulated vital tooth preparations fractured at lower loads than those with a post and core ($p < 0.003$). There was no difference in fracture load between post and core preparations, with or without a ferrule ($p = 0.997$).

'Vital' preparations and those with a ferrule failed with oblique fractures, initiated on the same side as the load, whereas post and core preparations without a ferrule had a more vertical fracture pattern (Figure 3).



Figure 1. Photograph of mounted teeth, all dentine preparation, core plus ferrule, core without ferrule (L to R). Horizontal line indicates height above cemento-enamel junction.

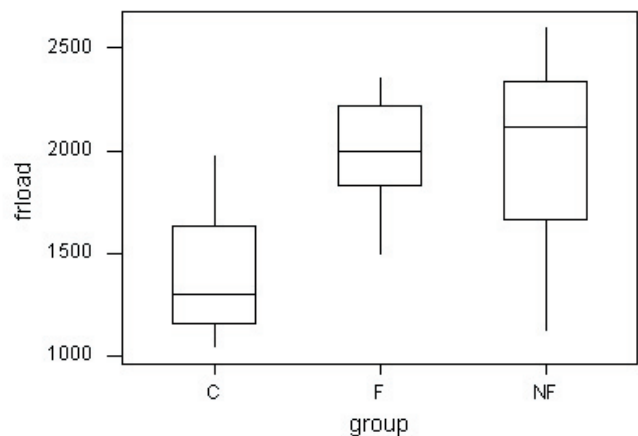


Figure 2. Plot of Fracture load in N (frload) against treatment group (Control, Ferrule, Non Ferrule)



Figure 3. Photograph of fractured teeth: all dentine preparation, core plus ferrule, core without ferrule (L to R)

These results can be explained by considering the differing stress distributions in the three test groups. For 'vital' preparations group (C) the hollow pulp chamber would not have a post transmitting load from post into root, and the tensile stress would therefore have concentrated in the dentine around the palatal cervical area. This would have been exacerbated by the margin functioning as a deep notch within the dentine. Combined together, these two effects produced an oblique fracture initiated from the palatal shoulder margin at relatively low loads. For

the ferrule (F) group, the palatal shoulder margin was also within dentine and oblique fractures were initiated from the palatal cervical area as in group (C). However, there was the potential for some of the applied load to be dissipated within the root dentine via the core and post. Loads at failure were therefore higher. This is in agreement with the findings from other laboratory studies^{38, 39}, where it was observed that the post actually increased the fracture resistance of endodontically treated teeth. A recent retrospective study by Aquilino *et al.*⁴⁰ found that endodontically treated teeth with posts demonstrated better survival than teeth without posts. On the other hand, the current study does not agree with other laboratory studies⁴¹, where it was found that there was no significant effect of post replacement on endodontically treated tooth fracture resistance. This controversy may be related to the amount of tooth structure around the post which may be the most important factor in fracture resistance.

In the non-ferrule group (NF), there was effectively no shoulder angle within the dentine to form a stress-concentrating notch. Most of the load would have been dissipated via the post and core to the radicular dentine and the pattern of fracture was therefore different to the other two groups (C and F).

Despite their differences in fracture sites, groups NF and F had similar fracture loads. It is therefore not possible to recommend one over the other, as both groups were unrestorable.

This raises an important issue with regard to the necessity of the ferrule effect. In most cases, either crown lengthening or orthodontic extrusion would be required to expose sufficient supragingival dentine to allow an adequate ferrule to be prepared^{15,16,19}. The biological and financial costs of obtaining a ferrule must be considered as both clinical procedures have potential adverse effects: exposure of furcation areas; reduced bone support for the root; insufficient remaining root length for an adequate post length; aesthetic problems with the reduced cervical dimension of tapered roots; an additional cost and discomfort for the patient^{25, 42}.

In the present study, the fracture occurred at a higher load, in all the groups, when compared to the Zhi-Yue²⁸ study. The mean fracture loads were: 'vital' preparation with PFM crown but no post and core 959 N [1400 N]; Non-ferrule group with a PFM crown and a cast post and core 993 N [2010 N]; and Ferrule group with a PFM crown and cast post and core 1793 N [2000 N]. This could be due to the bovine teeth that were used in the current study. Bovine teeth are larger than human teeth and they need a larger force to break them. However, the loads to failure in this study are comparable to that of the Al-Hazaimah study²⁶. He used a prefabricated post and composite core cemented with resin cement in human central incisors (1407 N) for ferrule group and (1218 N) for non ferrule group. Such high loads rarely occur in clinical situations, which could lead to alveolar fracture or tooth avulsion before tooth fracture. The supporting structures could be physically modelled to allow for a more realistic failure mode.

Many authors^{21, 36, 37} have advocated bovine teeth to overcome the problems associated with human teeth: difficulty to obtain due to the improvement of the dental awareness and health; exhibiting relatively large variations in mor-

phology, age and mechanical flaws^{25, 43} and age and/or post-extraction time are usually not specified⁴⁴. Also, the mechanical properties of human and bovine teeth were comparable⁴⁵. On the other hand, the fatigue strength of bovine teeth is influenced by their age⁴⁶. The same age group and tooth size were used in the current study. Isidor^{21, 30, 31} found that bovine teeth were a valuable substitute for human teeth in fatigue testing of post and core systems.

Libman and Nicholls¹⁹ found that when more than 1.5mm of ferrule height was used, the number of loading cycles to failure was significantly increased. However, comparison with this study is difficult, because the failure in Libman and Nicholls' study was in the cement between the crown and core, as determined by strain gauges and not gross tooth fracture. A 2 mm ferrule height was used in this study, as recommended by many authors^{15, 17, 18, 47}.

In the work of Sorensen¹⁶, Isidor²¹ and Zhi-Yue²⁸ the crown heights were the same inciso-gingivally in all the samples, which meant that the ferrule samples had more remaining tooth structure. This would have affected the results, as preservation of dentine is a major factor in improving the fracture resistance of endodontically treated teeth^{39, 40}.

In the present study, the artificial crown length of the ferrule samples was longer than in the other groups to simulate the additional placement of ferrule. This approach has been used in other studies^{19, 25, 26} because it is more relevant to the clinical situation in which a ferrule is to be prepared on non-vital teeth, that is, teeth which are extensively damaged and have little coronal structure remaining.

CONCLUSIONS

Within the limitations of this laboratory study, the following conclusions can be made.

1. No failure occurred during fatigue loading (4×10^5) with a 120 N load.
2. The mean load to fracture of "vital tooth preparation" in the control group (C) was significantly less than the other two groups.
3. The mean load to fracture of post and cores group with the Ferrule (F) and without Ferrule (NF) were not significantly different from each other.
4. Preparation for ferrule did not improve the fracture resistance of roots compared to non-ferrule.
5. None of the teeth restored with post and cores were restorable after fracture.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Joseph Palamara and Mr Karl Rahaus for their technical assistance. They also thank Professor Ian Gordon from the Statistical Consulting Centre, Department of Mathematics and Statistics, The University of Melbourne for statistical assistance. This work was based on material presented for the Degree of Master of Dental Science.

MANUFACTURERS' DETAILS

- Burs: Diamond-Horico, Germany.
- Mounting Resin: Vertex Dentamex BV, The Netherlands.
- Dental surveyor: Krupp Dentograp, Fried-Krupp GmbH, Germany.
- Twist drills: Parapost W-P426, Whaledent, USA.
- Burn out post: Parapost XP, WP7516, Whaledent, USA.
- Paste opaque, Duceram Plus, Dental GmbH and CO. KG, Ducera Germany .
- Die spacer: Tru-Fit, Geo Taub, Jersey City, NJ, USA.
- Cement: PhospaCEM IC, Vivadent, Liechtenstein.
- Margin wax: Delar Margin Wax, USA.
- Inlay wax: Kerr Green inlay wax, USA.
- Pattern resin: GC America, USA.
- Debubbler: Waxit, Degussa, Germany.
- Tray material: GC Ostron 100, GC Dental Products Corp, Tokyo, Japan.
- Impression material: Extrude, Kerr, USA.
- Casting Alloy [post and core]: Argenco 5, Argibond, Australia.
- Casting Alloy: Wiron 99 [crown], BEG, Bremen, Germany.
- Porcelain furnace: VITA, Germany.
- Material testing System: MTS System Corp, Eden Prairie, Minn, USA.
- Labview software: National Instruments Corp, Austin, USA.
- Investment material: Starvest/Hi-therm, micro-fine C&B high heat casting investment, Emdin International Corp, USA.

ADDRESS FOR CORRESPONDENCE

Peter Wilson, School of Dentistry and Oral Health, La Trobe University, PO Box 199, Bendigo, Victoria 3552, Australia.
E-mail: prwilson@latrobe.edu.au

REFERENCES

1. Pekruhn, R.B. The incidence of failure following single-visit endodontic therapy. *J. Endod.*, 1986; **12**:68-72.
2. Ray, H.A., and Trope, M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. *Int. Endod. J.*, 1995; **28**:12-8.
3. Weine, F.S. *Endodontic therapy*. Franklin S. Weine. 4th edn. St. Louis: Mosby; 1989.
4. Baraban, D.J. The restoration of pulpless teeth. *Dent. Clin. North Am.*, 1967:633-53.
5. Hood, J.A. Biomechanics of the intact, prepared and restored tooth: some clinical implications. *Int. Dent. J.*, 1991; **41**:25-32.
6. Reeh, E.S., Douglas, W.H., and Messer, H.H. Stiffness of endodontically-treated teeth related to restoration technique. *J. Dent. Res.*, 1989; **68**:1540-4.
7. Fusayama, T., and Maeda, T. Effect of pulpectomy on dentin hardness. *J. Dent. Res.*, 1969; **48**:452-60.
8. Huang, T.J., Schilder, H., and Nathanson, D. Effects of moisture content and endodontic treatment on some mechanical properties of human dentin. *J. Endod.* 1992; **18**:209-15.
9. Sedgley, C.M., and Messer, H.H. Are endodontically treated teeth more brittle? *J. Endod.*, 1992; **18**:332-5.
10. Papa, J., Cain, C., and Messer, H.H. Moisture content of vital vs endodontically treated teeth. *Endod. Dent. Traumatol.*, 1994; **10**:91-3.
11. Sjogren, U., Hagglund, B., Sundqvist, G., and Wing, K. Factors affecting the long-term results of endodontic treatment. *J. Endod.*, 1990; **16**:498-504.
12. Vire, D.E. Failure of endodontically treated teeth: classification and evaluation. *J. Endod.*, 1991; **17**:338-42.
13. Caplan, D.J., and Weintraub, J.A. Factors related to loss of root canal filled teeth. *J. Public Health Dent.*, 1997; **57**:31-9.
14. Frank, A.L. Protective coverage of pulpless teeth. *J. Am. Dent. Assoc.*, 1959; **59**:895-900.
15. Eissman, H., and Radke, R.A. *Pathways of the pulp*. edited by Cohen, S., and Burns, R.C.; with 36 contributors; principal illustrator, Richard C. Burns. 5th edn. St. Louis: Mosby Year Book; 1991.
16. Sorensen, J.A., and Engelman, M.J. Ferrule design and fracture resistance of endodontically treated teeth. *J. Prosthet. Dent.*, 1990; **63**:529-36.
17. Rosen, H., Partida-Rivera, M. Iatrogenic fracture of roots reinforced with a cervical collar. *Oper. Dent.*, 1986; **11**:46-50.
18. Barkhordar, R.A., Radke, R., and Abbasi, J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. *J. Prosthet. Dent.*, 1989; **61**:676-8.
19. Libman, W.J., and Nicholls, J.I. Load fatigue of teeth restored with cast posts and cores and complete crowns. *Int. J. Prosthodont.*, 1995; **8**:155-61.
20. Milot, P., Stein, R.S. Root fracture in endodontically treated teeth related to post selection and crown design. *J. Prosthet. Dent.*, 1992; **68**:428-35.
21. Isidor, F., Brondum, K., and Ravnholt, G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. *Int. J. Prosthodont.*, 1999; **12**:78-82.
22. Tjan, A.H., and Whang, S.B. Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls. *J. Prosthet. Dent.*, 1985; **53**:496-500.
23. Saupe, W.A., Gluskin, A.H., and Radke, R.A., Jr. A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots. *Quintessence Int.*, 1996; **27**:483-91.
24. Loney, R.W., Kotowicz, W.E., and McDowell, G.C. Three-dimensional photoelastic stress analysis of the ferrule effect in cast post and cores. *J. Prosthet. Dent.*, 1990; **63**:506-12.
25. Gegauff, A.G. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. *J. Prosthet. Dent.*, 2000; **84**:169-79.
26. Al-Hazaimeh, N., and Gutteridge, D.L. 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. *Int. Endod. J.*, 2001; **34**:40-6.
27. Patel, A., and Gutteridge, D.L. An in vitro investigation of cast post and partial core design. *J. Dent.*, 1996; **24**:281-7.
28. Zhi-Yue, L., and Yu-Xing, Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. *J. Prosthet. Dent.*, 2003; **89**:368-73.
29. Trabert, K.C., Cooney, J.P., Caputo, A., Standlee, J., Teel, S., and Ingle, J.I. *Endodontics*. Ingle, J.I., and Taintor, J.F.; 41 contributors. 3rd edn. Philadelphia: Lea & Febiger; 1985.
30. Isidor, F., Odman, P., and Brondum, K. Intermittent loading of teeth restored using prefabricated carbon fiber posts. *Int. J. Prosthodont.*, 1996; **9**:131-6.
31. Isidor, F., and Brondum, K. Intermittent loading of teeth with tapered, individually cast or prefabricated, parallel-sided posts. *Int. J. Prosthodont.*, 1992; **5**:257-61.
32. Huysmans, M.C., Peters, M.C., Van der Varst, P.G., and Plasschaert, A.J. Failure behaviour of fatigue-tested post and cores. *Int. Endod. J.*, 1993; **26**:294-300.
33. Huysmans, M.C., and Van der Varst, P.G. Mechanical longevity estimation model for post-and-core restoration. *Dent. Mater.*, 1995; **11**:252-57.
34. Fan, P., Nicholls, J.I., and Kois, J.C. Load fatigue of five restoration modalities in structurally compromised premolars. *Int. J. Prosthodont.*, 1995; **8**:213-20.
35. Heydecke, G., and Peters, M.C. The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review. *J. Prosthet. Dent.*, 2002; **87**:380-6.

36. Nakamichi, I., Iwaku, M., and Fusayama, T. Bovine teeth as possible substitutes in the adhesion test. *J. Dent. Res.*, 1983; **62**:1076-81.
37. Cottis, S.M. Effect of preparation design and cyclic loading on the strength of bonded heat-pressed all-ceramic crowns. Cottis, S.M.; 2000.
38. Trabert, K.C., Caput, A.A., and Abou-Rass, M. Tooth fracture-a comparison of endodontic and restorative treatments. *J. Endod.*, 1978; **4**:341-5.
39. Kantor, M.E., and Pines, M.S. A comparative study of restorative techniques for pulpless teeth. *J. Prosthet. Dent.*, 1977; **38**:405-12.
40. Aquilino, S.A., and Caplan, D.J. Relationship between crown placement and the survival of endodontically treated teeth. *J. Prosthet. Dent.*, 2002; **87**:256-63.
41. Guzy, G.E., and Nicholls, J.I. In vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. *J Prosthet Dent.* ,1979; **42**:39-44.
42. Stankiewicz, N.R., and Wilson, P.R. The ferrule effect: a literature review. *Int. Endod. J.*, 2002; **35**:575-81.
43. Morgano, S.M. and Milot, P. Clinical success of cast metal posts and cores. *J. Prosthet. Dent.* 1993; **70**:11-16.
44. Saunders, W.P. The shear impact retentive strengths of four dentine bonding agents to human and bovine dentine. *J. Dent.*, 1988; **16**:233-8.
45. Sano, H., Ciucchi, B., Matthews, W.G., and Pashley, D.H. Tensile properties of mineralized and demineralized human and bovine dentin. *J. Dent. Res.*, 1994; **73**:1205-11.
46. Tonami, K., and Takahashi, H. Effects of aging on tensile fatigue strength of bovine dentin. *Dent. Mater. J.*, 1997; **16**:156-69.
47. Trabert, K.C., and Cooney, J.P. The endodontically treated tooth. Restorative concepts and techniques. *Dent. Clin. North Am.*, 1984; **28**:923-51.