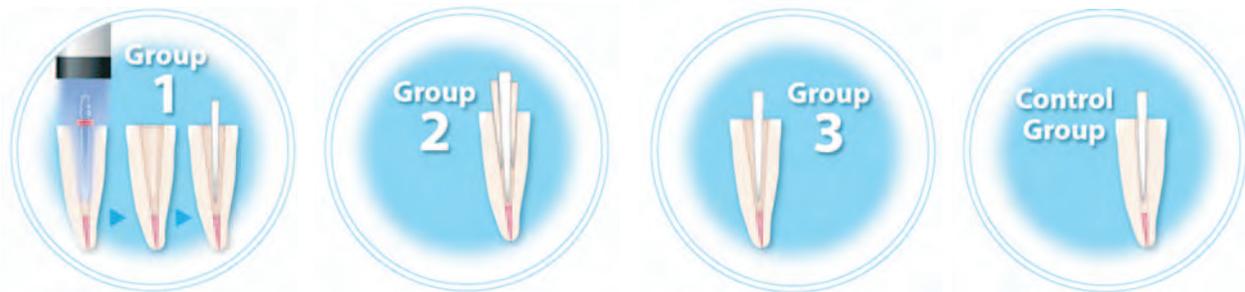# Fracture Resistance of Endodontically-treated Teeth Restored Using Three Root-reinforcement Methods

Horieh Moosavi, DDS, MS; Fathemeh Maleknejad, DDS, MS;
Soodabeh Kimyai, DDS, MS

Abstract

Aim: The aim of this *in vitro* study was to compare the fracture resistance of endodontically-treated anterior teeth with their roots reinforced using three different restorative methods.

Methods and Materials: Forty sound maxillary human central incisors were randomly assigned to four groups (n=10). The crowns of the teeth were removed at a level 2 mm incisal to the cementoenamel junction (CEJ). After root canal therapy, flared canals were simulated in three groups. In the first, second, and third groups the flared canals were reinforced with resin composite (RCO) (Clearfil DC Core Automix), two Reforpins (REF), and a resin cement (RCE) (Panavia F 2.0), respectively. In the fourth (DEN) group flared canals were not created. The same size fiber reinforced composite (FRC) posts were cemented with resin cement (Panavia F 2.0) in all groups. After post cementation and restoration of the teeth crown with a core build-up composite (Clearfil Photo Core), the roots of the teeth were embedded in acrylic resin blocks up to 1 mm below the CEJ. The samples were loaded in an Instron testing machine with a crosshead speed of 0.5 mm/min at a 45° angle to the long axis of the tooth on the palatal surfaces until failure occurred. Data were analyzed using the Kruskal-Wallis, Mann-Whitney, and Chi-square tests (p=0.05).

Results: Significant differences were found between fracture resistance in all of the groups (P<0.05) with the exception being among the RCO and REF groups. The least mean value 230 (130) N and the highest mean value 830 (220) N were shown in the fracture resistance of the RCE and DEN groups, respectively.

Conclusion: Reforpin can be used as an alternative to resin composite for internal reinforcement of weakened roots according to the results of this study. For reinforcement of flared canals, fiber posts along with Reforpin or

resin composite proved to have higher fracture resistance than resin cement. Non flared canals had the highest fracture resistance.

Keywords: Fiber post, resin cement, Reforpin, flared canals

Introduction

Restoration of endodontically treated anterior teeth with weakened roots requires special attention because the esthetics and functions of these teeth must be reconstructed. Factors such as trauma in immature teeth, gross caries, internal resorption, congenital disorders, previous restoration with large post diameters, or over instrumentation during root canal therapy can result in the creation of a large flared root canal. Flared canals are more susceptible to fracture because of remaining thin walls.[1]

Traditionally the custom cast post and core has been used in this situation. Today an alternative method of restoring a flared canal has been described.[2] An adhesively bonded fiber post for severely compromised roots may provide improved fracture resistance while creating better stress distribution and transfer when loaded which contributes to the reinforcement of the tooth.[3,4]

The advent of more advanced composites and ceramics has led to the development of a wide variety of esthetic posts.[4] Many dentists prefer to use prefabricated post systems because they are more practical, less expensive, and, in some situations, less invasive than customized post and core systems.[1] Practitioners have root canal posts available to them that are made of translucent, white, or tooth colored materials. These posts increase the transmission of light within the root and overlying gingival tissues, thereby, eliminating or reducing the dark appearance often associated with non-vital abutments and metal posts and cores. Up to now tooth-colored posts have been made from carbon, glass or quartz fiber-reinforced resin, or zirconia ceramic which is a much stiffer material.[5] The modulus of elasticity and diametral tensile strength of fiber posts are sufficiently low and close to these properties in dentin, thus, minimizing the risk of root fracture in the restored tooth.[4,5]

Reforpin is a glass fiber accessory post for crown support in endodontically treated teeth. Reforpin diameters and anatomic shapes allow its use in any situation from very narrow canals to wider or oval ones and eliminates the need for a thick cement layer inside enlarged canals.[6] However, these fiber-reinforced composite posts have been advertised and used by dentists with little scientific evidence supporting their use.

The null-hypothesis of this research was there would be no differences in the fracture resistance of root reinforced anterior teeth with three different methods using tooth-colored restorative materials. The mode of failure of compromised endodontically treated teeth was also assumed to be similar.

Methods and Materials

Forty intact human maxillary central incisors were selected for this *in vitro* study. After cleaning, each tooth was examined under a fiber optic light to ensure the absence of carious lesions, cracks, and micro fractures. Teeth with similar root sizes and lengths were used. Radiographs were taken from buccolingual and mesiodistal orientations to ensure an adequate similarity in the shape of canals and internal diameter of roots. To ensure an even size distribution within groups, the overall mean root dimensions of all the teeth measured from the cementoenamel junction (CEJ) were 6.5 (0.5) mm mesiodistally, 6.8 (0.5) mm buccolingually, and 16.0 (1.3) mm in root length.

Selected teeth were stored at room temperature in a 0.1% thymol solution. The anatomical crowns of the teeth were cut off 2 mm coronal to the CEJ of the buccal surfaces with carborundum disks and a water coolant. Then roots of the teeth were instrumented with a conventional step-back technique to the International Standardization Organization (ISO) file size of #60 (Mani Inc, Tochigi-ken, Japan) at the apex. After irrigation

Groups 1, 2, 3 — Flared Canals Drilled
Group 4 — Dentin Left Intact
Gutta-percha
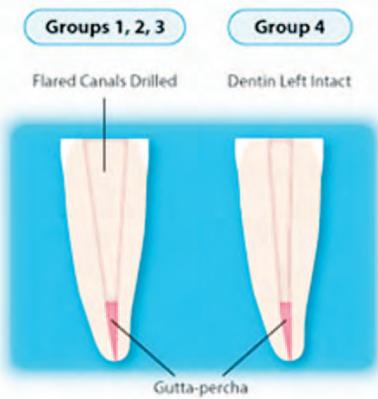
and drying, the root canals were filled using lateral condensation with gutta-percha (Lot 011199; Dentsply Asia, Hong Kong, China) and a sealer (AH plus Root Canal Sealer, Dentsply Maillefer, Tulsa, OK, USA). Then coronal gutta-percha was removed using Gates-Glidden burs leaving at least 4 mm of material at the apical end of the root.

In the first three groups the flared canal spaces were enlarged by removing the internal dentin to a depth of 5 mm. Therefore, thin-walled canals were simulated by creating these flared canals which measured 3.5 mm wide at the occlusal surface, 1.5 mm at the apex, and 8 mm deep. A tapered drill 1.4 mm maximum in diameter (Fiberpoints Root Pins post kit, Schuetz-Dental, Rosbach, Germany) was used for this purpose.

The FRC post length remained standard for all groups. The radicular portion of the posts was considered to be 8 mm in length while the coronal portion was considered to be 6 mm from the buccal aspect of the CEJ. The root canals and tooth surfaces were cleaned with an air-borne particle abrasion system (DentoPrep, Aluminium Oxide Microblaster, Ronvig, Danmark and Cojet, 3M ESPE, Seefeld, Germany). The root canals were conditioned with a self-etching primer (ED-primer II adhesive, Kuraray America, Inc., New York, NY, USA) for 30 seconds while gently air-drying the primer for three seconds to promote solvent evaporation. Excess primer was removed with paper points, and the remainder was irradiated with a light curing unit (Optilux 500, Demetron-Kerr, Orange, CA, USA) at 500 mW/cm^2.

The samples were divided into four groups (n=10) according to the reinforcing material involved in

the test as follows:
- Resin composite (RCO)
- Reforpin (REF)
- Resin cement (RCE)
- Dentin (DEN)

In the RCO group Clearfil DC Core Automix resin composite (Kuraray America, Inc., New York, NY, USA) was injected to fill the root canal spaces. A No. 4 transparent Lumenix plastic post (Lumenix, Dentatus USA, Ltd., New York, NY, USA) was inserted into the center of the canal. This post was used to direct and condense the composite to the canal walls for root reinforcement. With the transparent post in place, the tip of the light curing unit was placed on the end of the post and the composite was cured for 60 seconds. The plastic post was then carefully removed and a #3 D.T. light-post R.T.D FRC post (Bisco Inc., St Egreve, France) was cemented into the newly created canal space with Panavia F 2.0 resin cement (Kuraray America, Inc., New York, NY, USA) according to the manufacturer's instructions.

Group 1 – RCO
Luminex plastic post in composite resin
Plastic post removed
Light-post cemented in space
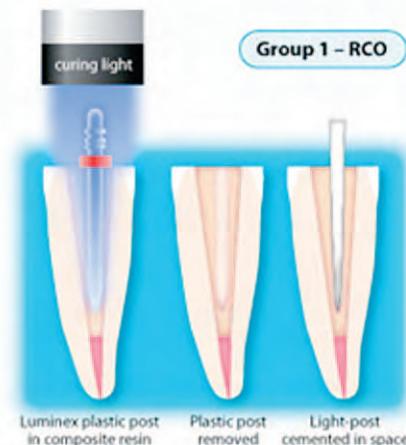
In the REF group the Panavia F 2.0 A and B pastes were mixed together and placed on one #3 FRC post and two accessory Reforpin posts (Angelus, Londrina, PR, Brazil) in order to replace the missing internal root structure then seated using finger pressure.

In the RCE group the Panavia F 2.0 A and B pastes were mixed together and applied to a #3 D.T. light-post for cementation and filling the remaining space around the seated post. Radiographs were taken after root filling to facilitate the exclusion of specimens showing voids or filling defects. The DEN group was similar

Table 1. Material classification used for sample preparation.

Group	n	Reinforced Material	Post	Luting Material	Build-up
RCO	10	Resin Composite	Quartz FRC	Panavia	Resin Composite
REF	10	Reforpin	Quartz FRC	Panavia	Resin Composite
RCE	10	Resin Cement	Quartz FRC	Panavia	Resin Composite
DEN	10	Dentin	Quartz FRC	Panavia	Resin Composite

FRC=Fiber Reinforced Composite

Table 2. Detailed description of root reinforcement in the experimental groups.

Group	Post Systems and Mode of Intraradicular Reinforcement	Components
RCO	Clearfil DC Core Automix and D.T. light-post (#3) luted with Panavia F 2.0	Base & Catalyst Pastes Quartz fiber 60% volume Epoxy resin 40% volume ED Primer II, A&B Panavia pastes
REF	Two Reforpins And D.T. light-post (#3) luted with Panavia F 2.0	Glass fiber 70% volume Epoxy resin 30% volumeQuartz fiber 60% volume Epoxy resin 40% volume ED Primer II, A&B Panavia pastes
RCE	D.T. light-post (#3)luted with Panavia F 2.0 into flared canal	Quartz fiber 60% volume Epoxy resin 40% volume ED primer II, A&B Panavia pastes
DEN	D.T. light-post (#3) was luted with Panavia F 2.0 into non flared canal	Quartz fiber 60% volume Epoxy resin 40% volume ED primer II, A&B Panavia pastes

to the RCE group with the exception flaring was not done to preserve natural dentin (Tables 1 and 2).
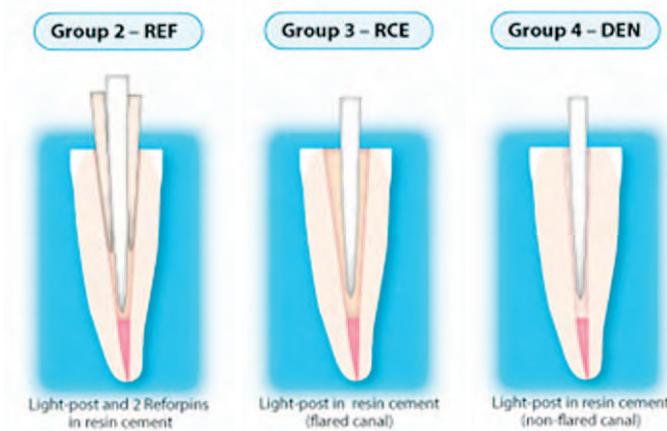
In all four groups the coronal surfaces of the specimens were etched for 15 seconds with 35% phosphoric acid (Panavia etching agent, Kuraray Europe, Duesseldorf, Germany) and rinsed. The resin composite cores were standardized and constructed using a core-forming matrix (TDV Dental, Ltd, Pomerode, SC, Brazil) and a composite core (Clearfil photo core, Kuraray America, Inc., New York, NY, USA). Materials used for restoration and reinforcement in the four groups are shown in Tables 1 and 2.

All specimens were stored in distilled water at 37ºC for 24 hours before loading. To mount the teeth for testing, each root was coated with a rubberized film (Plastic-dip, PDI Inc., Circle Pines, MN, USA) on the external root surface to within 1 mm of the CEJ to simulate the periodontal

Table 3. Mean forces in Newton required for specimen fracture and failure mode observations.

Group	n	Mean SD in Newtons	Restorable Failure	Non-restorable Failure
RCO	10	390 (120)	6	4
REF	10	500 (140)	10	0
RCE	10	230 (130)	4	6
DEN	10	830 (220)	8	2

Group 2 – REF — Light-post and 2 Reforpins in resin cement

Group 3 – RCE — Light-post in resin cement (flared canal)

Group 4 – DEN — Light-post in resin cement (non-flared canal)

ligament. Roots were mounted in acrylic resin blocks (Formatray, Kerr Manufacturing, Orange, CA, USA) with plastic rings 2.5 cm in diameter to the level of the rubberized film. The teeth were submerged in water for five minutes during resin polymerization to prevent over heating.

Using a special mounting jig, each specimen was allowed to be positioned at 45º to the long axis of the tooth. A Model 1122 Instron testing machine (Instron, Canton, MA, USA) was used to apply a constant load at a crosshead speed of 0.5 mm/min at 45º to the middle third of the palatal surface of the crowns until failure occurred. The maximum force applied at the moment the specimens fractured was recorded in Newtons and was reported as the fracture resistance of the specimens. In all groups fracture load value and mode-to-fracture were recorded.

The different modes of failures were defined as restorable or non-restorable failures. They were observed with a microscope using X20 magnification. Fracture lines extending over 1 mm below the CEJ were deemed non-restorable fractures.

Then data were evaluated statistically using a non-parametric Kruskal-Wallis test followed by the Mann-Whitney test as a post-hoc test. To determine differences in fracture mode between groups, the Chi-square test was utilized. The level of significance was set at 95%.

Results
The mean values, standard deviation of fracture resistance, and the mode of failure in the test groups are listed in Table 3.

The Kruskual-Wallis test revealed significant differences (P<0.05) between all of the groups. The flared canal teeth with roots reinforced with resin cement showed the lowest of mean load value. Specimens with unaffected residual dentin wall thickness (DEN group) achieved the highest mean value of fracture resistance.
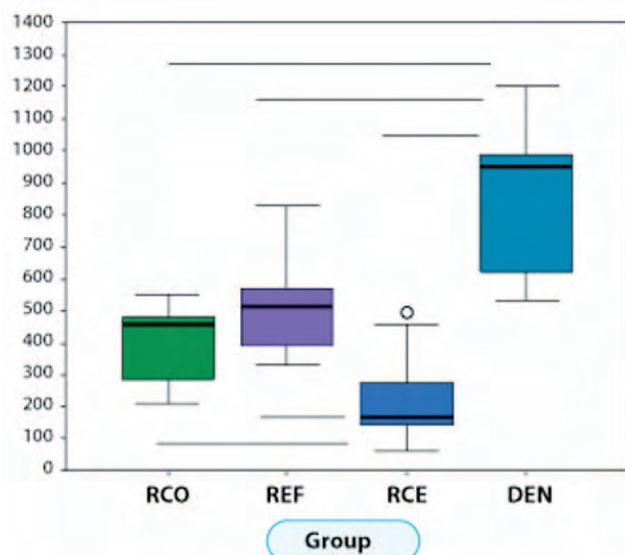
Figure 1. Box plots of fracture resistance testing continues line mark statistical differences between the groups (P<0.05).

Figure 1 shows the results of the Mann-Whitney test as a post-hoc analysis. The RCO, REF, and RCE groups had significant differences with the DEN group (P<0.001). Specimens with flared canals and reinforced with Reforpin had a higher mean load value than resin composite reinforcement but there was no significant difference (P>0.05). The RCO and REF groups showed significant differences with the RCE group.

The Chi-square analysis, in terms of the failure mode, revealed statistical differences between experimental groups (P=0.019). The number of restorable failures in the REF, DEN, and RCO groups were 10, 8, and 6, respectively. The RCE group had the majority of non-restorable failures (Table 3).

Discussion

This study evaluated the effect of different methods for intraradicular reinforcement of endodontically treated teeth using resin composite, resin cement, and tooth-colored posts on the fracture resistance and mode of failure of anterior teeth. Previous studies have reported the selection of intact natural central incisors appears to be an acceptable way to study post systems.

It is believed the use of a rigid material (acrylic resin) to embed extracted teeth may lead to distorted load values and possibly affect the mode of failure of the specimens.[3] Therefore, an attempt was made to simulate the periodontal ligament for surrounding anatomical structures by coating the roots with polyvinylsiloxane and embedding the roots in acrylic resin.[2,7]

Crown fabrication using prefabricated posts and resin composite is a viable technique for weakened and endodontically treated roots, especially in anterior teeth of teenagers in which a post-core-crown is contraindicated.[8] Because adhesive cementation results in lower microleakage and higher retention, it is even preferred for metal posts.[9] The resin cement provides a micromechanical and chemical bond to post and dentin not observed in other cements.[2] Panavia F was used for luting the FRC posts in all samples because previous studies reported the use of Panavia F resin cement dramatically increased the load capability in this situation.[10,11]

Light penetration into the root is limited even with translucent posts.[12] Therefore, to be certain of adequate curing within the root dual cure types of resin composite or cement were used. Bonded resin cements are recommended for use in roots with thin walls such as immature teeth or those with extensive caries in children because of its potential to increase the fracture resistance of teeth.[13]

Statistical analysis revealed significant differences between all of the test groups. The RCE group showed a lower fracture resistance than the RCO, REF, and DEN groups. This poor result could be expected because the space between the post and canal wall was large and could overstress the luting system in terms of high polymerization stresses. Despite the low cost of the materials used in the RCE group this method for restoration of the flared canals is not recommended.

The DEN group showed the highest fracture resistance. This group had no canal flaring which resulted in more remaining dentin. Speculation has existed for some time about the role of a well fitting post in the coronal portion of canals being of paramount importance in minimizing clinical failures. The amount of hard tissue surrounding the post as a principle factor in this regard has been reported.[14] A significant difference was observed between the mean values of fracture resistance in the RCO and REF groups with the DEN group. The load mean value for the REF group was greater than the RCO

group, but the difference between them was not significant. Therefore, the effect of reinforcement with resin composite and Reforpin was similar.

Consistent with existing literature, an increasing compressive load at a fixed angle of 135º to the long axis of the specimen was used to test specimens for failure.[15,16] Biting forces decrease from the molar region to the incisors. The maximum force on a central incisor is 200 N and 100 N for a lateral incisor. In the presence of parafunctional loading, Lyons and Baxendale noted this force increased.[17] In some studies static compressive loading might imply a different conclusion than would a chewing simulation because such a simulation was not actually performed.[18,19]

Fatigue stress, thermocycling, mechanical loading, and humidity aging were not introduced in the test specimens. However, it is important to remember the mean values of forces responsible for failures in the present study and other studies were considerably higher than the maximum physiologic forces acting on the teeth.[17] However, fatigue stresses may be responsible for fracture with lower forces in the oral cavity. On the other hand, repeated loading could lead to fatigue failure in the oral cavity so interpretation of the results should be done with caution.

Fiber posts tested by [in vitro] studies show a great variability in fracture resistance. These differences might be due to the selection of samples, different sizes of the selected posts, and different testing procedures. Cormier et al.[20] identified fiber posts as having the lowest fracture resistance when compared to metal or ceramic posts, whereas Akkayan and Gulmez[21] found comparable fracture resistance values between zirconium oxide and fiber posts. In this project fractures occurred at similar loads found by Pereira et al.[16] and Peroz et al.[9] Conservation of tooth structure guarantees tooth resistance to fracture.[22]

The results of this study revealed the highest mode of fracture was restorable. A complete dislocation of post-crown complex was frequently observed. The highest number of non-restorable failures was found in the RCE group. To some extent this phenomenon was related to the structure and the innate properties of the resin cement. Resin cement has an even lower modulus of elasticity than resin composite; therefore, the load capability is higher for resin composite than for resin cement.[23] In other words, resin composite has physical properties similar to those of dentin which is the main factor for root fracture resistance.[24] Previous studies have shown the most common cause of failure when using the prefabricated post and resin composite is the fracture of the restorative material itself which confirms the findings of the present study.[2,22,23] Hu et al.[15] demonstrated the failure modes of specimens restored with carbon-fiber posts to be less than with resin composite cores predominantly involved root fracture, which is inconsistent with the present study.

Milot and Stein stated the main variable to determine an increase in fracture resistance was the amount of preserved dental tissue apical to the core-dentin interface and not the type of post.[24] In the present study, the remaining 2 mm of teeth crown may have played an important role in the mode of fracture. The results of this study are in agreement with other studies in concluding resin composite fracture could occur at a lower force than required to cause root fracture.[25]

Cement debonding and post dislodgement was observed more in the RCO and DEN groups. This might be due to innate disadvantages of the resin composite and failure in composite adhesion to canal walls or of the resin cement to posts. Clinically, when the cement begins to break, the retention of the post is greatly compromised. If the post is not entirely dislodged, the root is at greater risk of fracture. Fracture in the attachment of the resin composite core to fiber posts was most commonly found in the REF group. This is probably due to the adhesive and frictional forces between multiple posts. Most of the fractures in the RCE group were non-restorable and involved root canal walls.

Long-term clinical evaluation of Reforpin, other FRC posts, and adhesive systems is essential to fully understand their clinical performance.

Conclusion

Within the limits of the current study, the following conclusions can be stated:

1. There were statistically significant differences in fracture resistance and mode of failure between different restorative techniques and materials used.
2. Reforpin could also be used as an alternative to the resin composite for reinforcement.
3. In the REC group, the resin cement does not reinforce wide canals in a manner similar to unflared canals.
4. The greatest number of restorable and non-restorable failures occurred in REF and RCE groups, respectively.

References

1. Saupe WA, Gluskin AH, Radke RA. A comparative study of fracture resistance between morphologic dowel and cores and a resin reinforced dowel system in the intrardicular restoration of structurally compromised roots. Quintessence Int 1996; 27:483-91.
2. Lui JL. Composite resin reinforcements of flared canals using light-transmitting plastic posts. Quintessence Int 1994; 25:313-9.
3. Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003; 89:360-7.
4. Farah JW, Powers JM. Non-metal posts. Dent Adv 2003; 20:523-6.
5. Purton DG, Chandler NP, Qualtrough AJE. Effect of thermocycling on the retention of glass-fiber root canal posts. Quintessence Int 2003; 34:366-9.
6. Angelus Dental Solutions, Reforpin 2003. Retrieved online 3, October, 2005 from: http://www.angelus.ind.br/ingles/dentistica_reforpin.asp.
7. Mendonza DB, Eackle WS, Kahl EA, Ho R. Root reinforcement with a resin–bonded preformed post. J Prosthet Dent 1997; 78:10-4.
8. Torbjorner A, Fransson B. A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont 2004; 17:369-76.
9. Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores: a review. Quintessence Int 2005; 36:737-46.
10. Naumann M, Preuss A, Frankenberger R. Load capability of excessively flared teeth restored with fiber-reinforced composite posts and all-ceramic crowns. Oper Dent 2006; 31:699-704.
11. De Munck J, Vargas M, Van landuyt K, Hikita K, Lambrechts P, Van Meerbeek B. Bonding of an auto adhesive luting material to enamel and dentin. Dent Mater 2004; 20:963-71.
12. Ferrari M, Vichib A, Grandinic S. Efficacy of different adhesive techniques on bonding to root walls: an SEM investigation. Dent Mater 2001; 17:422-9.
13. Katebzadeh N, Dalton BC, Trope M. Strengthening immature teeth during and after apexification. J Endodo 1998; 24:256-9.
14. Gutmann JL. The dentin-root complex: Anatomic and biologic considerations in restoring endodontically treated teeth. J Prosthet Dent 1992; 67:458-67.
15. Hu YH, Pang LC, Hsu CC, Lau YH. Fracture resistance of endodontically treated anterior teeth restored with four post-and-core systems. Quintessence Int 2003; 34:349-53.
16. Pereira JR, de Ornelas F, Conti PC, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 2006; 95:50-4.
17. Lyons MF, Baxendale RH. A preliminary electromyography study of bite force and jaw-closing muscle fatigue in human subjects with advanced tooth wear. J Oral Rehabil 1990; 17:311-8.
18. Kern M, Strub JR, Lu XY. Wear of composite resin veneering materials in a dual-axis chewing simulator. J Oral Rehabil 1999; 26:372-8.
19. Naumann M, Sterzenbach G, Proschel P. Evaluation of load testing of postendodontic restorations in vitro: Compressive loading, gradual cycling loading and chewing simulation. Part B: Applied Biomaterials. J Biomed Mater Res B Appl Biomater 2005; 74:829-34.
20. Cormier CJ, Burns DR, Moon P. In vitro comparison of the fracture resistance and failure mode of fiber, ceramic and conventional post systems at various stages of restoration. J Prosthet Dent 2001; 10:26-6.
21. Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002; 87:431-7.
22. Fraga RC, Chaves BT, Mello GS, Siqueira JF Jr. Fracture resistance of endodontically treated roots after restoration. J Oral Rehabil 1998; 25:809-13.

23. Mezzomo E, Massa F, Libera SD. Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: an in vitro study. Part 1. Quintessence Int 2003; 34:301-6.
24. Milot P, Stein R. Root fracture in endodontically treated teeth related to post selection and crown design. J Prosthet Dent 1992; 68:428-35.
25. Bex RT, Parker MW, Judkins JT, Pelleu GB Jr. Effect of dentinal bonded resin post-core preparations on resistance to vertical root fracture. J Prosthet Dent 1992; 67:768-72.

About the Authors

Horieh Moosavi, DDS, MS

Dr. Moosavi is an Assistant Professor in the Department of Operative Dentistry of the School of Dentistry, Dental Research Center at Mashhad University of Medical Sciences in Mashhad, Iran. Her research interests include microleakage, adhesive systems, tooth colored restorative materials, tooth regeneration and biomaterials. She is a member of the Iranian Academy of Cosmetic Restorative Dentistry.

e-mail: moosavih@mums.ac.ir

Fathemeh Maleknejad, DDS, MS

Dr. Maleknejad is an Associate Professor in the Department of Operative Dentistry of the School of Dentistry, Dental Research Center at Mashhad University of Medical Sciences in Mashhad, Iran. Her research interests include tooth bleaching, microleakage, and tooth-colored restorative materials. She is a member of the Iranian Academy of Cosmetic Restorative Dentistry.

e-mail: f-maleknejad@mums.ac.ir

Soodabeh Kimyai, DDS, MS

Dr. Kimyai is an Assistant Professor in the Department of Operative Dentistry of the School of Dentistry at the Tabriz University of Medical Sciences in Tabriz, Iran. Her research interests include tooth bleaching and tooth-colored restorative materials. She is a member of the Iranian Academy of Cosmetic Restorative Dentistry.

e-mail: kimyais@tbzmed.ac.ir