

Effect of different partial ferrule locations on the fracture resistance of endodontically treated teeth restored with fiber posts and complete crowns

Haider Hasan Jasim. ⁽¹⁾

Key words

fracture resistance, ferrule, posts, ferrule locations

Abstract

Purpose. The purpose of this in vitro study was to evaluate the effect of partial ferrule locations on the fracture resistance of endodontically treated maxillary canines restored with complete crowns. **Material and Methods.** Fifty extracted maxillary canines were sectioned 18 mm from their apices, endodontically treated, and divided into 5 groups of 10 teeth each. All groups were prepared with full shoulder crown preparations. the first group having axial wall heights of 2 mm around the preparation circumferences, the axial walls were circumferential, 360 degrees around the preparations (Complete group), the second, third, and forth groups the axial walls were continuous for 180 degrees (one half of the axial tooth structure) of Palatal, Labial, and Proximal groups, and the fifth group all axial tooth structure was sectioned to the level of the preparation shoulder (Level group). All prepared teeth were then restored with quartz fiber posts (RTD), composite resin (Multicore) cores, and complete metal crowns. The fracture resistance was measured in a universal testing machine at 135 degrees to the long axis of the tooth until failure. Data were analyzed by ANOVA and then by Least Significance Difference test (LSD). The mode of failure was determined by visual inspection of all specimens. **Results.** Significant differences ($P < 0.05$) were found among the mean fracture loads of the test groups, and was 803.7 N, 747.7N, 347.3 N, 386.6 N, and 186.7N for the Complete, Palatal, Labial, Proximal, and Level groups, respectively. When the mode of failure was evaluated, all failure was an oblique palatal to facial root fracture for the groups with remaining coronal tooth structure. In the Level group, post debonding was the predominant mode of failure. **Conclusion.** The palatal axial wall was more effective than the labial or proximal axial wall in providing fracture resistance to force applied to the palatal aspect in endodontically treated teeth.

Introduction

The restoration of endodontically treated teeth has been a concern for prosthodontists for more than 100 years ⁽¹⁾.

Endodontically treated teeth are more susceptible to fracture than teeth with vital pulps ⁽²⁾. This susceptibility has been attributed to degradation in structural integrity following the substantial loss of tooth structure, which occurs during

(1) Lec., Tikrit University, College of dentistry, Basic Science/ Microbiology Department.

endodontic therapy and cavity preparation^(3,4).

When a tooth has more than 50% of its coronal structure missing, the use of a post-and-core foundation is recommended prior to prosthetic restoration⁽⁵⁾. Posts can either be prefabricated or custom made. Custom cast posts and cores allow for a close adaptation of posts to the post space preparations, and should fit optimally⁽⁶⁾.

The most common cause of failure for cast posts and cores is post dislodgment, followed by root or post fractures⁽⁷⁾. Prefabricated posts have an advantage in that the post space can be prepared and the post directly bonded in a single appointment⁽⁸⁾.

An important issue, in terms of failure load, is the amount of residual dentin⁽⁹⁾. The dentin height, but not its buccal thickness, appeared to significantly influence failure load. Similarly, the height of the residual dentin was reported to be more important than that of the post system used, in terms of failure load⁽¹⁰⁾.

Other in vivo⁽¹¹⁾ and in vitro studies have shown the importance of height⁽¹²⁻¹⁴⁾ and location^(8,15,16) of the remaining tooth structure for the mechanical properties of restored teeth.

To ensure functional longevity, endodontically treated teeth must have at least 5 mm of tooth structure coronal to the crestal bone. Three millimeters are needed to maintain a healthy soft tissue complex, and 2 mm of coronal tooth structure incisal to the preparation finish line are necessary to ensure structural integrity⁽¹⁷⁾.

The longevity of a restored tooth thus depends on the Amount of remaining tooth structure and on the efficiency of the restorative procedure used to replace lost structural integrity^(18,19).

The availability of 2.0 mm of coronal tooth structure between the crown preparation shoulder and the tooth/core junction was found to enhance fracture resistance⁽²⁰⁾. It appears that this extension of coronal tooth structure provides the greatest influence in terms of resistance and retention form for a crown⁽¹⁰⁾.

Several authors⁽²¹⁻²³⁾ have suggested that a tooth should have a minimum of 2 mm of coronal structure above the

cemento-enamel junction (CEJ) to ensure proper resistance form for a tooth. This 2 mm of tooth structure will provide a ferrule effect with the artificial crown that should prevent fracture of the root, fracture of the post, and dislodgement of the post⁽²⁴⁾.

Materials and Methods

Fifty newly extracted maxillary canines free of cracks, caries, fractures, and restorations were collected for the study. All hard and soft tissue deposits were removed using ultrasonic scaler (EMS Piezon Systems, Nyon, Switzerland). Teeth were selected to conform as close as possible to the following dimensions: root lengths of 15-16 mm from the cemento-enamel junction (CEJ) to the apex on the facial surface, and faciolingual and mesiodistal widths of 7 and 5 mm, respectively at the cervical, measured with a digital caliper accurate to within 0.01 mm (Mitutoyo America Corp, Aurora, Ill; 0.01-mm accuracy). The teeth were stored in normal saline at room temperature during the study⁽²⁵⁾.

Radiographs of each tooth were made to ensure that there were no cracks, internal root resorption, or obstructions within the canal. The coronal aspects of teeth were sectioned with a diamond rotary cutting instrument (4180, TPS2-5; komet, Germany) used in a high-speed air turbine handpiece (Alegra led; W&H, Austria) with water spray, leaving 18 mm of sound tooth structure from the root apex to the sectioned surface. Wet 600-grit silicon carbide abrasive paper (3M ESPE, St. Paul, Minn) was used to refine and create a planar sectioned surface perpendicular to the long axis of the tooth.

Then the teeth were randomly assigned into 5 groups of 10 each. The specimens were then endodontically prepared with a step-back technique with a size 55 file (Densply-maillefer), each canal was prepared to within 1mm of the radiographic apex. After intermittent rinsing with 3 % sodium hypochlorite (Parcan, Septodont, France), the endodontic treatment was completed with lateral condensation of gutta-percha (DiaDent, Korea) and eugenol-free sealer (AH 26; Dentsply Maillefer).

Post space was created by removing the gutta-percha within the root canals, using an endodontic heat carrier (Plugger ; Dentsply-Maillefer) to a depth of 10mm from the coronal surface of the preparation.

Post space was prepared by fiber post specific drill (RTD; Macro-lock illusion post x-pro, France), leaving at least a 5-mm gutta-percha seal apically.

All specimens were embedded in autopolymerizing acrylic resin (Pattern Resin; GC Corp, Tokyo, Japan) poured in metal cylinder (30mm high and 22mm in diameter) to a level 5mm apical to the sectioned surface (figure I), with the long axis of each tooth parallel to the long axis of the cylinder using dental surveyor (Ney, Bloomfield, CT). Wet towels were placed around the cylinders during acrylic polymerization to help dissipate heat⁽²⁶⁾.

Each tooth was mounted on a surveyor (Paraskop; BEGO, Bremen, Germany) and prepared using a diamond rotary cutting instrument (Tooth Preparation Set; komet, Germany), in an air turbine handpiece under a water spray to receive a complete coverage crown. A square-end tapered diamond bur (TPS2-10) and a large-diameter diamond bur (TPS2-14) were used to prepare the labial and lingual surface with a uniform 1.0-mm width shoulder finish line with rounded internal angle and a 6-degree taper on opposing surfaces of the preparation. The finish lines for all specimens were placed at the level of the CEJ, all teeth were prepared by the same prosthodontist.

Four groups were prepared with full shoulder crown preparations having axial wall heights of 2 mm around the preparation circumferences.

For the fifth group, all axial tooth structure was removed to the level of the preparation shoulder. In the second, third, and fourth groups with axial tooth structure, one half of the axial tooth structure was removed labially, palatally, or proximally, and groups were identified according to the site of coronal axial tooth structure (fig. II). Thus, in first group the axial walls were circumferential, 360 degrees around the preparations (Complete group), in second, third and fourth groups the axial walls were continuous for 180 degrees

(Palatal, Labial, and Proximal groups), and the last group had no retained coronal tooth structure incisal to the finish line (Level group). For the 3 groups with 180 degrees of axial wall, the configuration of the transition zone between shoulder levels of the core foundation and axial wall heights was abrupt (a 90-degree angle), as illustrated in Figure II.

The post spaces were cleaned for 20 seconds with water spray and then slightly dried with paper points. Dual and hydrophilic self-adhesive resin luting agent (Universal Resin Cement; Bioloren-Viavolta, 59 Saronno, Italy) was mixed according to manufacturer's instructions and placed into canals with a spiral file (Lentulo; Dentsply Maillefer) using a low-speed handpiece. A prefabricated quartz fiber post (RTD; Macro-lock illusion post x-pro, France) was introduced into the prepared canal space (fig. III), using a pumping motion to release hydraulic pressure created during the cementation process⁽²⁷⁾. Excess luting agent was removed, and a quartz-tungsten-halogen unit (Elipar S10, 3M ESPE; Germany) was placed directly over and in contact with the post for 20 seconds to ensure complete polymerization of the resin luting agent. The root surfaces and cervical dentin were etched with 37% phosphoric acid for 15 s, rinsed and air dried, then bonding agent (AdheSE, Ivoclar Vivadent; Liechtenstein) was placed and light polymerized. Cores were fabricated in a standardized form, using core-former (ParaForm; Coltene/Whaledent, Cuyahoga Falls, Ohio)⁽²⁸⁾. Multicore flow (Ivoclar vivadent;USA) was applied to the core former to complete the coronal core, 40 s of photo-activation was used to accelerate the setting. The core foundation was refined with a tapered flat-end diamond rotary cutting instrument (TPS2-9; Komet) with water irrigation and x 3 magnification to produce a preparation with a total convergence angle of approximately 6.0 degrees. Wax patterns for the crowns were formed directly on tooth specimens coated with a lubricant (Gator Die Lube; Whip Mix Corp, Louisville, Ky). Wax patterns were formed using a vinyl polysiloxane

impression material (Lab-Putty; Coltene/Whaledent) mold made with a polycarbonate resin central incisor crown form (101; 3M ESPE). This mold was used in fabricating all wax crown patterns. A standardized notch was demarcated on the palatal surface of the crown where the load was to be applied 3 mm from the incisal edge⁽²⁾ (fig. IV). The wax patterns were invested in high expansion phosphate-bonded investment material (GC Fujivest II; GC America Inc, Alsip, Ill) and cast using a high-palladium alloy (Ultima Lite; Dentsply Ceramco, Burlington, NJ). The cast crowns were cemented (SpeedCEM, Ivoclar Vivadent; Liechtenstein) under a static 20-N load⁽²⁸⁾.

Specimens were tested with a universal testing machine (Model 1445; Zwick USA, Atlanta, Ga) was used to apply a compressive load to specimens with a crosshead speed of 0.5 cm/min at an angle of 135 degrees to the long axis of teeth until failure occurred. The compressive load was applied to the notch on the palatal surface of the crowns (fig. V). Failure was defined as fracture of the core material with displacement from the post head, or when fracture affected the core or the tooth. The mode of failure was recorded after the test using a x4 binocular loupe (Pros kit, China). The load was measured in newtons (N).

The data were analyzed with a 1-way analysis of variance (ANOVA) to determine the overall differences among the mean values of the test groups and the overall variability within the test groups. The least significant difference (LSD) test was used to determine the significant differences between the test groups.

Results:

Table I summarizes the mean failure loads, standard deviations (SDs), and standard errors (SEs) for the 5 test groups. Table II; One-way ANOVA was performed, revealed that the coronal tooth structure location had a significant influence on the fracture resistance ($P < 0.05$). Table III Least significant difference (LSD) test was used to compare between the groups, the result of the analysis showed that the fracture

resistance of all groups with remaining coronal tooth structure incisal to the preparation finish line was significantly greater than the level group ($P < 0.05$). The fracture resistance of second group with tooth structure on the palatal aspect (Palatal group) was not significantly different from the Complete group, as demonstrated in bar chart in figure VI.

All specimens in 4 groups with axial tooth structure incisal to the preparation finish line displayed nearly the same fracture behavior mode, with an oblique fracture extending from the palatal surface of the root down to the labial surface just below the tooth's insertion into the acrylic resin. In all specimens in 4 groups, the cemented metal crown was fractured without evidence of debonding of either the crown or the cemented post. Post debonding was the initial mode of failure for the Level group, but when load application was continued beyond initial failure, failures occurred due to vertical root fracture. Here, the post-core-crown complex was observed to lift away from the root prior to root fracture.

Discussion:

Based on the result of this study, the hypothesis that "the location of remaining dentin structure incisal to the finish line will not affect the fracture resistance" was rejected.

It should be clear that the term ferrule is often misinterpreted. It is often used as an expression of the amount of remaining sound dentine above the finish line. It is in fact not the remaining tooth structure that is the 'ferrule' but rather the actual bracing of the complete crown over the tooth structure that constitutes the ferrule effect⁽⁸⁾.

It is generally accepted that for a cast restoration extending at least 2 mm apical to the junction of the core and the remaining tooth structure, encirclement of the root with this ferrule will protect the endodontically treated tooth against fracture by counteracting and better distributing the stresses generated by the post⁽²⁹⁾. The strength of the remaining tooth has been directly related to the remaining bulk of dentin and fracture

resistance has diminished with a decrease in remaining dentin⁽²⁰⁾.

The fracture resistance of an endodontically treated tooth is a crucial factor for the long-term survival of the tooth⁽³⁰⁾ and is influenced by the restorative procedures^(31, 32). In particular, the amount of residual coronal dentin following endodontic treatment appears to be a crucial factor for the prognosis of the tooth⁽²⁾.

This study showed that ferrule location significantly increased the fracture resistance of endodontically treated teeth restored with prefabricated posts and cores. However, it is important to note that the forces responsible for failure in all ferrule groups in this study were considerably higher than the maximal physiologic forces acting on the teeth intraorally⁽³³⁾. Lyons and Baxendale⁽³³⁾ observed that the mean force applied on a maxillary canine was 215 N. In the presence of parafunctional loading, the authors noted that this force increased to 254.8 N, and the maximum forces were between 343 and 362.6 N.

This study showed that the palatal axial wall is as effective as a 360-degree circumferential axial wall in providing fracture resistance, under the conditions of this study. With specimens fabricated for this study, the palatal axial wall was more effective than the labial and proximal axial wall in providing fracture resistance to force applied to the palatal aspect of the specimen crowns. Rather, the important point may be the presence of axial wall in a location where opposing tooth contacts generate occlusal loads.

For the restoration to succeed, the length must be great enough to interfere with the arc of the casting pivoting about a point on the margin on the opposite side of the restoration. The shorter wall does not afford this resistance⁽³⁴⁾. The shorter the wall, the more important its inclination. Non axial forces tend to displace the restoration by causing rotation around the gingival margin. Rotation is prevented by any areas of the tooth preparation that are placed in compression, called resistance areas. Multiple resistance areas cumulatively make up the resistance form

of a tooth preparation⁽³⁴⁾ as illustrated in figure IV.

The fracture resistance of the restored endodontically treated tooth is directly related to the strength of the remaining tooth structure and the post and core, as well as the bond strength between them. When the remaining axial wall is at the location where the load is applied, the non-axial load from the palatal side in a maxillary anterior crown places the ferrule tooth structure and the gingival margin in the opposite side in compression, buttressed against the post-core. Thus, the strength of the root and remaining tooth structure and not the bond between the post-core and the root and remaining tooth structure is primarily challenged. In contrast, if the remaining axial wall is on the labial aspect, the non-axial load from the palatal side in a maxillary anterior crown would be firstly resisted by the bond between the post-core and the root challenging the post/core/root junction, and as the resistance of the post-core bond to the root and the strength of the remaining tooth structure is overcome, root fracture results at a lower force level than the former (Fig. 4). With no coronal tooth structure remaining, the resistance to displacement is mainly a function of the bond between the post-core and the root. These findings are believed to be related to the direction of occlusal forces and the location of the remaining coronal tooth structure.

In 2 groups (Palatal and Complete), the remaining axial tooth structure was located in sites that seemed to directly oppose labially directed dislodging forces. Specimens in these groups appeared to more effectively resist fracture compared to specimens in the other 3 groups.

In those 3 groups, tooth preparations completely lacked axial tooth structure (Level) or axial tooth structure was located labially or proximally, where it seems labially directed dislodging forces would not be directly opposed, and the non-axial load from the palatal side in a maxillary anterior crown challenges the post/core/root junction. In the absence of axial tooth structure in a location that could oppose dislodging forces, the

prognosis for a restored endodontically treated tooth may be unfavorable.

In this study, maxillary canines were used with the force applied from the palatal direction. The mean failure load of teeth with only the palatal portion of axial tooth structure remaining (Palatal group) was not significantly different than that of teeth in the complete group, and the mean failure loads of both groups were significantly higher than those of labial and proximal ferrule groups. The failure loads of level group were significantly lower compared to all other groups, the failure load of all specimens having tooth preparations with axial walls (Complete, Palatal, Labial, and Proximal groups) was significantly greater than specimens without axial walls incisal to the finish line (Level group).

The findings of the present study are in agreement with Ng et al ⁽⁸⁾. Their results showed that having good palatal ferrule only is as effective as having a complete 'all around' ferrule, as this tooth structure will resist the forces applied in function to the palatal surface of the maxillary incisor. The findings of the present study are also in agreement with WU Feng-Meng et al ⁽¹⁶⁾, who compared the fracture resistance of one-wall ferrule in different locations in mandibular first premolars, they concluded that the fracture strength was higher when the dentin wall of ferrule was closer to the loading force.

Our study, disagree with Arunpraditkul et al ⁽¹⁵⁾, who evaluate the fracture resistance of endodontically treated teeth between those with four walls and those with three walls of remaining coronal tooth structure and the effect of the site of the missing coronal wall in mandibular second premolars, they found that the site of the missing coronal wall did not affect the fracture resistance of endodontically treated teeth, the explanation for difference in results could be attributed to the differences in the extent of missing axial wall, in their study the missing axial wall is limited to that wall only and the other three walls were retained, while in our study the missing axial wall was

continuous 180 degrees (half crown preparation).

This study demonstrated that if complete ferrule is not available, the location of remaining coronal tooth structure and the direction of occlusal forces need to be determined.

The primary mode of failure for Complete, Palatal, Labial, and Proximal groups was root fracture. The resin bond between the different restorative components in these 4 groups appears to have been sufficient to resist fracture of the post or debonding from the root, which is the most common mechanism of clinical failure for endodontically treated teeth ^(7,17). Even though root fracture is a catastrophic event, it occurred at a much higher load compared to the Level group in which debonding of the post was the initial mode of failure.

There were some limitations in the design of this study, for more meaningful results, further studies should incorporate thermocycling and fatigue load instead of a static single

load, and the specimens should adjoin the neighboring teeth. In addition, the preparation design of a lengthened crown to provide an ideal ferrule should be considered and compared.

Conclusion:

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The mean fracture strengths of endodontically treated maxillary canines restored with a crown with different ferrule locations were significantly higher compared to the level group.
2. The palatal axial wall was more effective than the labial or proximal axial wall in providing fracture resistance to force applied to the palatal aspect
3. The primary mode of failure for ferrule groups was root fracture, while for the Level group post debonding was the initial mode of failure.

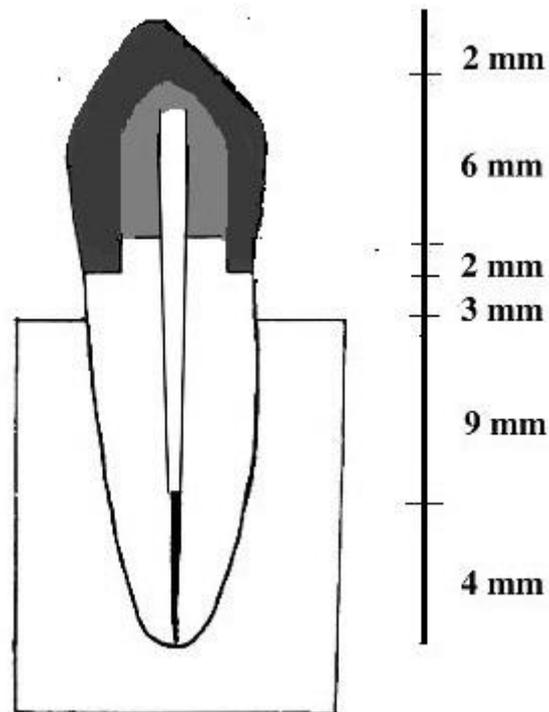


Fig. I. Measurements of tooth specimen.

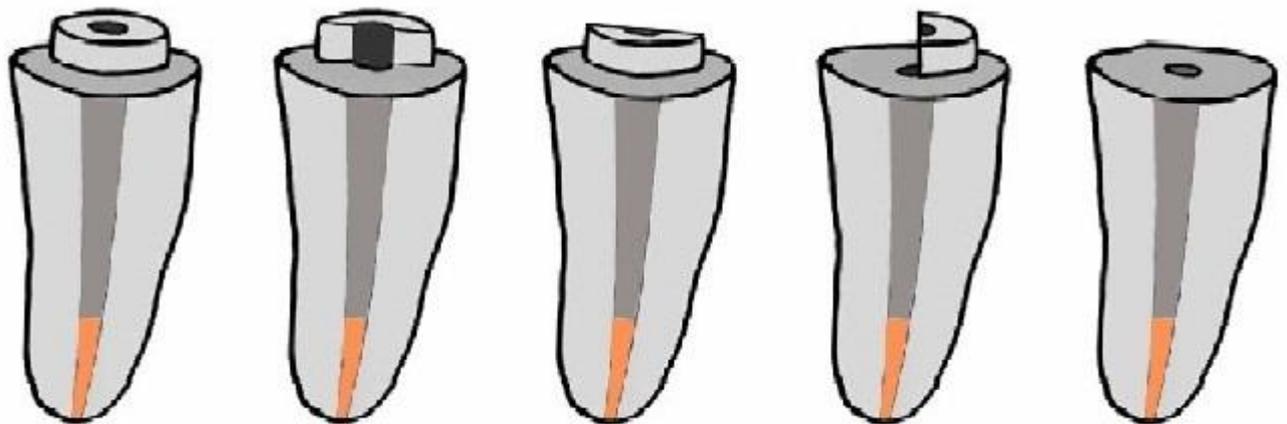


Fig. II. Specimen design. Location of remaining tooth structure and root canal.

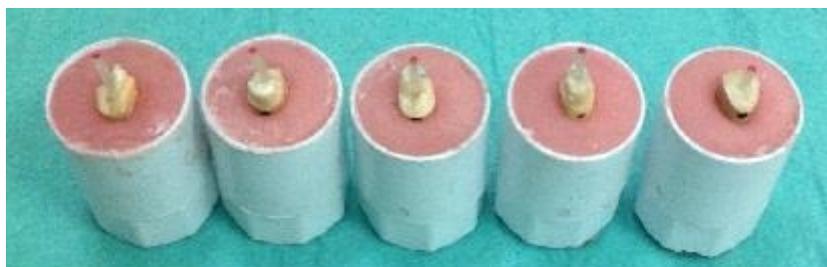


Fig. III. Teeth specimen mounted in acrylic block and quartz fiber post in place.



Fig. IV. Notch in the palatal surface of complete metal crowns.

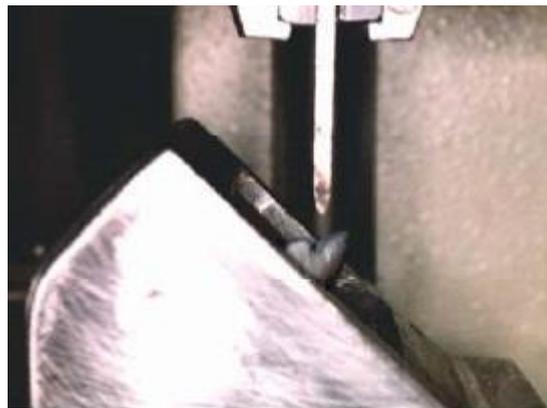


Fig. V. Applying load on the teeth specimen.

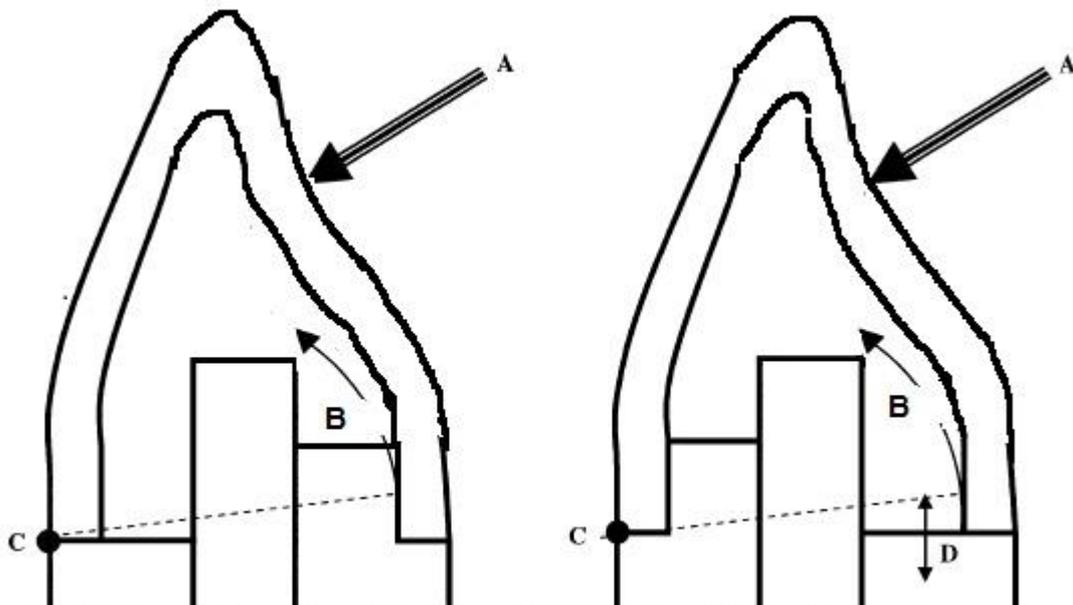


Figure VII. Resistance form of complete crown. (A) Direction of force; (B) Arc of crown displacement; (C) Fulcrum; (D) Bond strength of post-core to root.

Table 1. Descriptive statistics showed Resistance to failure of test specimens: mean values and standard deviations of test groups and standard errors.

Group	Mean (N)	SD	SE
Complete	803.7	170.63	53.99
Palatal	747.7	149.20	47.21
Facial	347.3	137.22	43.42
Proximal	386.6	128.55	40.68
Level	186.7	125.54	39.73

Table 2. ANOVA test for all groups.

Anova	F-test	P-value	Significance
among groups	0.35.09	P<0.05	HS
HS: highly significant at level P<0.05			

Table 3. Least Significant Difference (LSD) comparisons between groups

LSD	P-value	Sig
1 st and 2 nd	0.386	NS
1 st and 3 rd	P<0.01	HS
1 st and 4 th	P<0.01	HS
1 st and 5 th	P<0.01	HS
2 nd and 3 rd	P<0.01	HS
2 nd and 4 th	P<0.01	HS
2 nd and 5 th	P<0.01	HS
3 rd and 4 th	0.542	NS
3 rd and 5 th	0.016	S
4 th and 5 th	P<0.01	HS

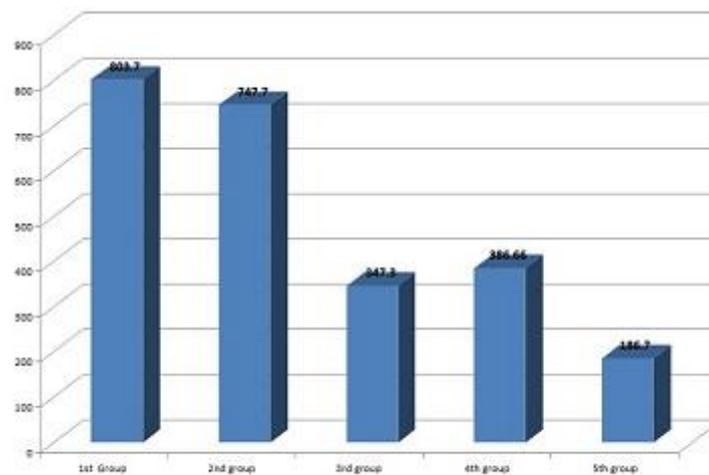


Fig. VI. Diagram displayed the fracture resistance of each group versus load (Newton).

References

1. S. Sirimai, D. N Riis, and S. M. Morgano, An in vitro study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-and-coresystems. *J Prosthet Dent* 1999;81:262-269.
2. Jens T. Mangold, and Matthias Kern. Influence of glass-fiber posts on the fracture resistance and failure pattern of endodontically treated premolars with varying substance loss: an in vitro study. *J Prosthet Dent* 2011;105:387-393.
3. Da Silva, Raposo, Versluis, Fernandes-Neto, and Soares. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. *J Prosthet Dent* 2010;104:306-317.
4. Watanabe MU, Anchieta RB, Rocha EP, Sidney Kina, Almeida EO, et al Influence of Crown Ferrule Heights and Dowel Material Selection on the Mechanical Behavior of Root-Filled Teeth: A Finite Element Analysis. *Journal of Prosthodontics* 2012; 1-8
5. Christensen GJ. When to use fillers, build-ups or posts and cores. *J Am Dent Assoc* 1996;127:1397-8.
6. Qualtrough AJ, Mannocci F. Tooth-colored post systems: a review. *Oper Dent* 2003;28:86-91.
7. Sorensen JA, Martinoff JT. Endodontically treated teeth as abutments. *J Prosthet Dent* 1985;53:631-6.
8. Ng CC, Dumbrigue HB, Al-Bayat MI, Griggs JA, Wakefield CW. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. *J Prosthet Dent* 2006;95:290-6.
9. Stankiewicz NR, Wilson PR. The ferrule effect: a literature review *Int Endod J* 2002;35:575-81.
10. Isidor F, Brondum K, 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.
11. Creugers NH, Mentink AG, Fokkinga WA, Kreulen CM. 5-year follow-up of a prospective clinical study on various types of core restorations. *Int J Prosthodont* 2005;18:34-39.
12. Akkayan B. An in vitro study evaluating the effect of ferrule length on fracture of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. *J Prosthet Dent* 2004;92:155-62.
13. Tan PL, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *J Prosthet Dent* 2005;93:331-6.
14. Barkhordar RA, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. *J Prosthet Dent* 1989;61:676-8.
15. Arunpraditkul S, Saengsanon S, Pakviwat W. Fracture resistance of endodontically treated teeth: three walls versus four walls of remaining coronal tooth structure. *J Prosthodont* 2009; 18: 49-53.
16. XingMing-EN, WU Feng-Ming. The effect of one wall ferrule with different location and height on fracture resistance of endodontically treated teeth restored with fiber posts, composite cores, and full-metal crowns. *Stomatology*, 2013, 33(5): 303-306.
17. Spear F. When to restore, when to remove: the single debilitated tooth. *Compend Contin Educ Dent* 1999;20:316-28.
18. Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. *Int J Prosthodont* 2001;14:355-63.
19. Buttel L, Krastl G, Lorch H, Naumann M, Zitzmann NU, Weiger R. Influence of post fit and post length

- on fracture resistance. *Int Endod J* 2009;42:47-53.
20. Zhi-Yue L, 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.
 21. Trabert KC, Cooney JP. The endodontically treated tooth: restorative concepts and techniques. *Dent Clin North Am* 1984;28:923-51.
 22. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. *J Prosthet Dent* 1990;63:529-36.
 23. Wagnild GW, Mueller KI. Restoration of the endodontically treated tooth. In: Cohen S, Burns RC, editors. *Pathways of the pulp*. 8th ed. St. Louis: Elsevier; 2001. p. 765-95.
 24. Pierrisnard L, Bohin F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: a mechanical study using finite element analysis. *J Prosthet Dent* 2002;88:442-8.
 25. Aykent F, Kalkan M, Yucel MT, Ozyesil AG. Effect of dentin bonding and ferrule preparation on the fracture strength of crowned teeth restored with dowels and amalgam cores. *J Prosthet Dent*. 2006;95:297-301.
 26. Loney RW, Moulding MB, Ritsco RG. The effect of load angulation on fracture resistance of teeth restored with cast post and cores and crowns. *Int J Prosthodont* 1995;8:247-51.
 27. Cooney JP, Caputo AA, Trabert KC. Retention and stress distribution of tapered-end endodontic posts. *J Prosthet Dent* 1986;55:540-6.
 28. 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.
 29. Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. *J Prosthet Dent* 1993;69:36-40.
 30. Vire DE. Failure of endodontically treated teeth: Classification and evaluation. *J Endod* 1991;17:338-42.
 31. Gutmann JL. The dentin-root complex: anatomic and biologic considerations in restoring endodontically treated teeth. *J Prosthet Dent* 1992;67:458-67.
 32. Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores. A review. *Quintessence Int* 2005;36:737-46.
 33. Lyons MF, Baxendale RH. A preliminary electromyographic study of bite force and jaw-closing muscle fatigue in human subjects with advanced tooth wear. *J Oral Rehabil* 1990;17:311-8.
 34. Rosenstiel S F, Land MF, Fujimoto J. *Contemporary Fixed Prosthodontics*. Mosby Elsevier, fourth edition, 2006.