Original Article

Evaluation of the Effect of Different Ferrule Designs on Fracture Resistance of Maxillary Incisors Restored with Bonded Posts and Cores

Z. Mahdavi Izadi[1], E. Jalalian[2], A. Eyvaz Ziaee[3], L. Zamani[3], B. Javanshir[4]

[1]Assistant Professor -Dept of Prosthodontics, Faculty of Dentistry, Azad University of Medical Sciences, Tehran, Iran
[2]Associate Professor -Dept of Prosthodontics, Faculty of Dentistry, Azad University of Medical Sciences, Tehran, Iran
[3]Resident of Prosthodontics. Faculty of Dentistry.Azad University of Medical Sciences, Tehran, Iran
[4]Dentist

Abstract:

Introduction: In cases of severe hard tissue loss, 2 mm circumferential ferrule is difficult to achieve. So in these cases we should use different ferrule designs.
This in vitro study investigated the effect of different ferrule designs on the fracture resistance of teeth restored with bonded post and cores.

Materials and Methods: Forty freshly-extracted central incisors were endodontically treated. The teeth were randomly divided into four groups; group 1 were teeth with 2 mm circumferential ferrule above the CEJ, group 2 were teeth with 2 mm ferrule only on the palatal side of the teeth, group 3 consisted of teeth with 2 mm ferrule only on the facial side and group 4 were teeth with 2 mm ferrule on the palatal and facial side of teeth with interproximal concavities.
All teeth were restored with fiber posts and composite cores. The specimen was mounted on a universal testing machine and compressive load was applied to the long axis of the specimen until failure occurred.

Results: The fracture resistance was 533.79 ± 232.28 in group 1, 634.75± 133.35 in group 2, 828.90 ±118.27 in group 3 and 678.78± 160.20 in group 4. The post hoc analysis showed statistically significant difference between groups 1 and 3 .

Conclusions: The results of this in vitro study showed that facial ferrule increases the fracture resistance of endodontically treated teeth restored with bonded post and cores.

Key Words: Ferrule; Fracture Resistance; Bonded Post and Core

Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2010; Vol: 7, No.3)

Corresponding author:
E. Jalalian, Department of Prosthodontics, Faculty of Dentistry, Azad University of Medical Sciences, Tehran, Iran.
dr_e_Jalalian@yahoo.com

Received: 25 February 2010
Accepted: 18 June 2010

INTRODUCTION

The fracture resistance of endodontically treated teeth is less than healthy ones due to their hard tissue loss because of caries, restorative and endodontic procedures [1]. These teeth also have a higher chance for fracture because of their severe loss of vital pulp moisture [2]. In cases of severe hard tissue loss of endodontically treated teeth, using a post as the retentive factor for core build up is helpful. The post transfers the occlusal force to the root and the result is vital root fracture [3]. Usage of ferrule effect is one of the approaches for strengthening the tooth having post. The ferrule consists of the shoulder finish line with parallel walls. It lessens the forces from tapered posts or bonding during seating of the post [1]. The maxillary incisors are usually damaged centrally or laterally [1]. Traumatic accidents cause cracks in the crown at the facial side in 90% of the cases which extend to the cervical

and palatal sides, just opposite to the mandibular incisors in which the crack extends lingually [1]. The proximal cavities result from excavating caries in the maxillary incisors, because just facial and palatal sides of the tooth remain [1]. In these cases, 2 mm circumferential ferrule is difficult to achieve. Therefore, in the cases of severe hard tissue damages, using different ferrule designs is beneficial [1]. Several studies have been performed about ferrule effects, many of them suggested that the ferrule strengthens the teeth against functional, wedging and lateral forces during post insertion. In the study performed by Al-Amro and Wilson in 2009, regarding the effect of ferrule placement on fracture resistance of cyclically loaded bovine teeth restored with cemented cast post-cores and crowns, there was no difference in fracture resistance between ferrule and non ferrule teeth restored with crowns [4]. Lima et al conducted a study in 2010 about the influence of ferrule preparation with or without glass fiber posts on fracture resistance of endodontically treated teeth. They reported that there was no significant interaction between the ferrule preparation and post factors. The ferrule preparation increased the fracture resistance of endodontically treated teeth [5]. Several studies have been carried out about ferrule length, showing that maintenance of about 2 mm of the tooth structure above the shoulder finish line or gingival margin as ferrule is effective [6,7], but a few studied the effect of different ferrule designs on fracture resistance. In a study carried out by Cho et al in 2009, on the impact of interproximal groove placement and remaining coronal tooth structure on the fracture resistance of endodontically treated maxillary anterior teeth, it was reported that inclusion of interproximal grooves on the cast dowel and cores of endodontically treated anterior teeth with 1-2 mm of remaining coronal tooth structure does not significantly lower the failure threshold [8]. In another in vitro study conducted by Naumann et al in 2006 on 40 maxillary incisors, hey demonstrated that fracture resistance of endodonticlly treated teeth with post and core depends on the preservation of tooth structure, and incomplete crown ferrule has more varieties in the bearing resistance [1]. In the study conducted by Ng et al in 2006, the effect of remaining hard tissue site on fracture resistance of 50 endodontically treated maxillary anterior teeth was evaluated. It suggested that for root canal therapied (RCT) teeth that have no complete crown, the site of remaining hard tissue has an impact on fracture resistance [9]. Finally in 2007, the study by Dikbasi was performed on the evaluation of different ferrule designs on fracture resistance of endodontically maxillary central incisors with fiber post, composite cone and crowns. It showed that the different ferrule designs have no effect on fracture resistance of teeth having fiber posts [2].

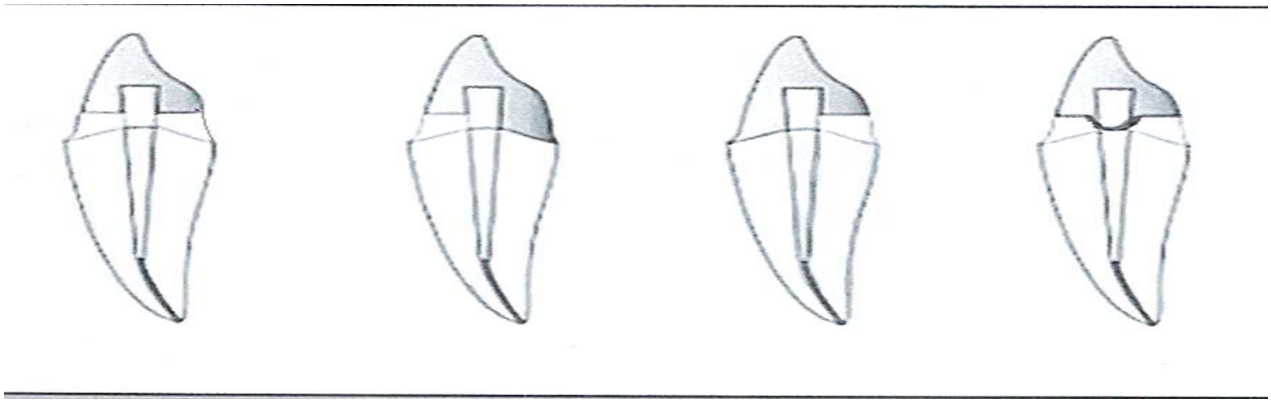
In attention to contradictories in studies and lack of enough investigations in this field, the aim of this study was to investigate the effect of different ferrule designs on the fracture resistance of teeth restored with bonded post and cores.

MATERIALS AND METHODS

This in vitro experimental study was performed on maxillary central incisors that were stored in 37 human serum immediately after extraction. Radiographs were taken and 40 samples with the same dimensions and entrance criteria (without any cracks, caries, fractures and internal and external resorptions) were chosen [1].

Surface debries were taken by ultrasonic cavitron (Woodpick, China) [2,10]. Teeth were maintained in normal saline in the room temperature [6,10,11]. The working length of each canal was established radiographically (Futur-Italy), and all of them were instrumented to size 35 (Mani 25 mm) and

Fig 1. Four groups with different ferrule designs



were irrigated intermittently with 5.25% sodium hypochlorite. The MAF (master apical file) was 35 for all. Then they were flared using step back technique to file size 60 [1,2,10]. Canals were dried with paperpoints. Chosen MAC (master apical cone) was 35 for all. Size 15 lateral cones were packed into the canal by using lateral compaction technique with AH26 sealer (Dentsply Maillfer) using size 25 finger sprider (Denstply Maillfer) while the stopper was adjusted 1 mm behind the working length [1,2,10].Then samples were maintained in 37 wet incubator (Behdad Iran) for 1 week [2]. After finishing the procedures, the samples were randomly divided into four groups of ten teeth.Group (1): A circumferential ferrule 2 mm in height and at least 1 mm width according to CEJ was prepared by a flat-ended tapered diamond bur with 1.2 mm diameter (SS White USA). Group width according to CEJ was prepared just on the the palatal side.Group (3): A ferrule 2 mm in height and at least 1 mm width according to CEJ was prepared just on the facial side.

Group (4): A ferrule 2 mm in height and at least 1 mm width was prepared on both facial and palatal sides with proximal cavities (likewise the caries treatment by round bur 1.2 mm in diameter) [1] (Fig 1).

Post space was prepared in these samples using pizo reamer 1, 2 (Mani). Then using fiber post specific drill (RTD) we prepared 9 mm of canal length from the level of CEJ on palatal sides causing at least 3-5 mm gutta percha to remain apically (using a rubber stop on the drill's handle as a guide for canal preparation) [11-13]. Posts were tried in the canal, confirming that they were loosely placed there [14-16]. Using a 008 diamond fissure bur and water coolant, the head of the posts were cut to reach the equal length of 15 mm [13]. Post space was dried with paper point. Then we etched the canal with 38% phosphoric acid (pulp dent-etch rite) for 15 seconds, then we rinsed and dried the excess water, meaning that dentin was not dehydrated. Root canal walls were lubricated with bonding using a clean micro brush (Kerr Optibond Solo Plus light cured) and extra bonding was cleaned with another clean micro brush. At last, we cured them for 20 seconds using LED (litex 695). Base and catalyst of resin cement (RTD- Seal Bond Ultima-dual cure) were mixed and root canal walls were lubricated with it.Subsequently, fiber match posts of RTD in 1.2 mm diameter were lubricated with this cement and were inserted into the canal. They were under pressure for 5-10 seconds, then the excess cement was cleaned with brush and they were cured for 40

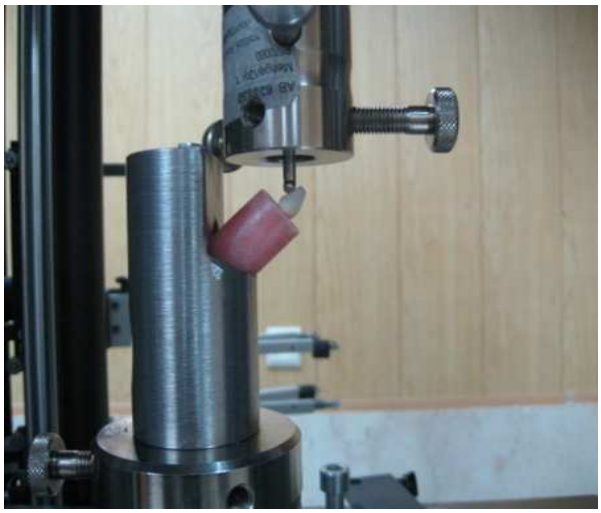


Fig 2

Fig 3

seconds [1,2,90].

After that, the crown was rebuilt with core build-up composites (Lumiglass-RTD) and celluloid crowns. The composite cores were cured 40 seconds from four sides of M-D-B-L. The height of each core was considered 8 mm [10]. For building artificial PDL just like the natural periodontium, all the teeth's root surfaces were root planned and were marked by a copy pencil 1-2 mm under the CEJ. Then an aluminum foil with 0.2 mm thickness was cut in root form and was adapted to the root dimensions from the marked line to the apex. Samples were merged vertically into the auto polymerized acrylic resin (Acropars-Iran) by a 10cc syringe using surviyor (Dentaurum). After the initiation of polymerization, samples were taken out of the acryl in the straight route with a circular movement and the foils were taken from the root surfaces. Polyether elastic material (Impergam 3m-ESPE) in appropriate consistency was injected into the acrylic space. Roots that had no more foils were inserted 1 mm below the CEJ level at the palatal side into the acrylic space, with the same angle mentioned previously. The excess material was cut by using a scalpel around the CEJ. This approach for building an artificial PDL is recommended for single-rooted teeth with a direct technique and for multi- rooted teeth with an indirect technique [17,18,20].

Finally, the samples were placed under the Zwick/Roell Z050 machine to be under pressure.

The compression force was inserted in 135 degree with the tooth line angle on the pit which was prepared on the lingual side of the tooth with 1 mm/min speed at 3 mm below the incisal edge. The machine was connected to the tracer. By decreasing the pressure, the machine stopped and the fracture force was recorded [1,2,9-11].

Fig 2 shows the 40 final samples and Fig 3 shows the sample under compressive loading.

At last, after gathering data, the mean and standard deviation was determined for each group. As the Kolmogorov-Smirnov test showed that the data were distributed normally, for analytic survey we used the ANOVA test showing significant differences between groups (p=.006).

As a complementary test we used Tukey HSD. The tests showed significant difference between groups 1 and 3 (p=.076).

RESULTS

The mean of fracture resistance in the four groups with different ferrule patterns have been shown in Table 1 which are as follows: Group (1) = 533.79 ±232.28 Newton, group

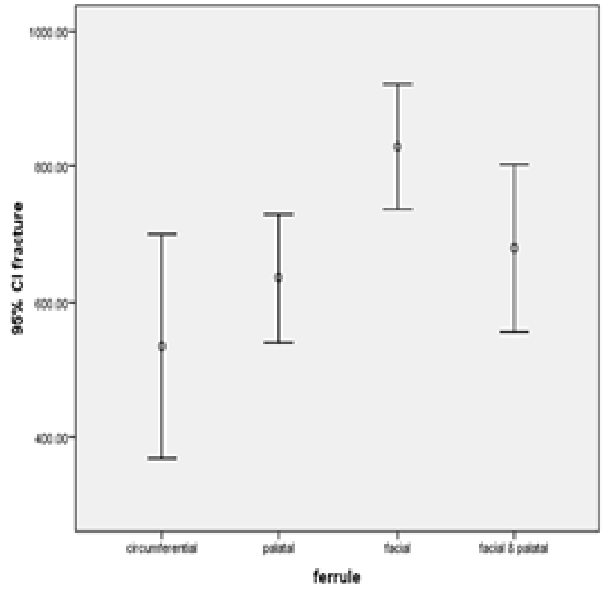


Chart 1. Mean and standard deviation of fracture resistance in each group

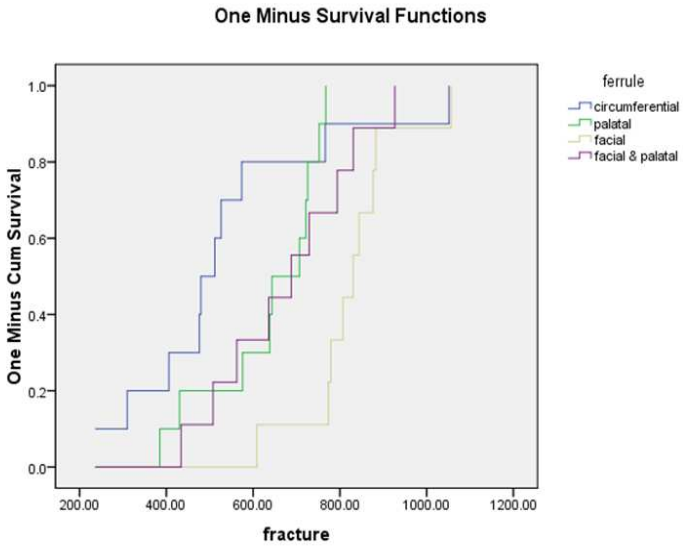


Chart 2. Cumulative chart showing accumulation of fracture by increasing force

(2) =634.75±133.35 Newton, group (3) =828.90 ±118.27 Newton, and group (4) 678.78 ±160.24 Newton. In the statistical analysis of the data using the ANOVA test, a significant difference has been observed between the groups 1 and 3 (p=.006).

Tukey HSD analysis for the detailed comparison among the test groups also showed that there was only a significant difference between groups 1 and 3 statistically meaning that the mean fracture resistance in group (1) was significantly lower than the one in group 3 (p=.076) (Chart 1 and 2).

Table 1: Mean of fracture resistance and standard deviation in each group

1	**533079**	10232.28
2	**634075**	10133.35
3	**828090**	9118.27
4	**678078**	9160.20

DISCUSSION

Endodontically treated teeth usually have little coronal tissue because of caries, placement of previous restorations and trauma or endodontic treatment. So in these cases effective restoration of a tooth which had received endodontic treatment could be difficult [2]. Fracture resistance of the roots is one of the most important factors in selecting the best method to restore these endodontically treated teeth which have lost a considerable amount of their crown tissue. Using post to distribute the torque along the roots against the forces in the mouth has always been considered important [19]. The teeth in which the roots have been treated are prone to fracture due to extensive damage to the tissue. In order to place the post in the root, it is necessary to prepare the post space, and the post space process will further weaken the dental tissue which in turn may result in micro fracture and perforation. The post itself transfers the occlusal load to the root and increases the risk of vertical fracture of the root [2].

Fracture in the anterior teeth follows a particular pattern [1,2]. Increasing the occlusal

load may result in damage in the facial and subgingival region and only the palatal area will remain intact, while the vertical forces on the facial surface of the tooth may cause a crack in the palatal and subgingival region which will leave only the facial part intact. Proximal cavities are also visible in these teeth after removing the dental caries [1]; therefore, various possibilities for the loss of dental tissue were studied in order to examine the different clinical conditions. Based on the data obtained from this study, group 3 which had ferrule on thefacial side unexpectedly had the highest mean fracture resistance while group 1 with the surrounding ferrule had the lowest mean fracture resistance. Groups 2 and 4 had lower means compared with group 3.

Due to the normal distribution of the data ANOVA and Tukey HSD statistical tests were used for analysis and based on their results a significant difference was only seen between the mean fracture resistances in groups 1 and 3, meaning that the mean fracture resistance in group 3 was considerably higher than that of group 1. There was no significant difference among other groups. The mean fracture resistance was more than 400 Newton in all four groups which was more than the force that causes fracture clinically [20,21].

In this study, fracture in the palatal core and an oblique root fracture up to 1/3 cervical were the most common types of fracture in all four groups so it was enough to have that amount of resin bond which could prevent fracture and debonding in the different components of these samples, while this type of fracture is the most common type of fracture in clinic [9].

In a similar study carried out by Naumann et al in 2006, the impact of four types of ferrule preparation was examined on the mean fracture resistance, in which similar results were obtained regarding the mean fracture resistance, meaning that the mean fracture resistance was greater in a group which had a facial ferrule compared to other groups. Group 4 had the lowest mean among the four groups and groups 1 and 2 had higher means compared with group 4; therefore, we can conclude that the lack of some coronal ferrule preparation in endodontically treated teeth with bonded cores or posts may result in greater variety in the amount of loading that can cause fracture, and this amount may be reduced to lower than the authorized limit in clinic.

The most common type of fracture in this study was oblique fracture from palatal CEJ up to 1/3 epical and 1/3 middle border in the facial area [1].

In another study conducted by Dikbasi and colleagues in 2007 in order to assess the impact of the different types of ferrule on fracture resistance of the upper incisors, those teeth without post which had solely received endodontic treatment and had the crown showed the highest mean fracture resistance and the group lacking ferrule had the lowest mean among other groups. Statistically speaking, there was no significant difference among other groups with different types of ferrule. Vertical fracture of the root was not observed in any of the above-mentioned groups and the type of fracture in all groups was almost horizontal or oblique similar to the results of our study [2].

In contrast to the two researches mentioned above, in a study performed by Ng and colleagues in 2006, in which the impact of the incomplete crown ferrule on fracture resistance was assessed, the groups which contained surrounding and palatal ferrule had the highest mean fracture resistance and the lowest mean was related to the group with no tissue above the shoulder finish line so they drew the conclusion that the location of the remaining crown tissue may influence the mean fracture resistance, as in this study there was a significant statistical difference between the groups with the surrounding and palatal ferrule and the group with the facial ferrule

[9]. The amount of the remaining hard tissue above the finishing line is often considered to be vital to increase the mean fracture resistance and this will be useful for the surrounding ferrule [1].

In 2009, Cho H et al investigated the effect of grooves, the remaining tooth structure and their combination on tooth fracture resistance of endodontically treated anterior teeth with cast dowel and cores. Sixty extracted maxillary anterior teeth with similar dimensions were randomly divided into three groups of 20 teeth. It was shown that the inclusion of interproximal grooves on the cast dowel and cores of endodontically treated anterior teeth with 1-2 mm of remaining coronal tooth structure does not significantly lower the failure threshold [8].

There is more tissue above the finishing line in samples of group 1 with surrounding ferrule so they are expected to have greater mean fracture resistance compared with the other groups. Furthermore, there is less dental tissue in groups 2 and 3 compared with the two other groups, so they are expected to react similarly and have lower mean fracture resistance compared with the two other groups, but as the adhesive area for core build-up in group 1 is smaller than those of other groups; therefore, the low mean fracture resistance may be justified in this group [1].

In group 3, adhesive area for core build-up is wider than those of group 1 and 4, moreover, higher levels of adhesion between core build-up composite and the tooth may result in a higher mean fracture resistance in this group compared with other groups which finally leads to a significant difference with group 1.

Statistically speaking, there was no significant difference visible among groups 1, 2 and 4 and groups 2, 3 and 4 which in turn can indicate the fact that the different locations of ferrule will not have any impact on the mean fracture resistance similar to the results which have been achieved in other articles as well [2,22-24]. A palatal loading on maxillary anterior teeth may cause stress in the form of tension in the palatal margin and may also cause stress in the form of compression in the facial margin [25]. Based on a report by Torbjorner and colleagues, anterior teeth will sustain fracture as a result of tension and not compression [26]. The fracture will start from the weak bond between the tooth and restoration as in these areas the bond strength has been limited by the strength of the adhesive material and this fracture usually happens at the palatal area which tolerates the maximum amount of stress and loading; therefore, the first marginal and cervical opening will be visible in the palatal area [25] which can explain the different types of fracture in this study.

The various types of fracture observed in this study were almost favorable meaning that there was no need to extract the tooth in clinic. These findings correspond with the results of other studies.

Also based on the report by Naumann et al, post, core and the dentin have formed a unit called mono block which will distribute the loading along the root more effectively and this is an advantage of bonded posts [1,2,9].

This study was carried out with high precision to have homogeneity among the samples and the teeth were randomly classified into groups, despite all these efforts, it was impossible to have 100% homogeneous samples as there are lots of interfering factors involved such as the variety in humidity, the number of dentinal tubules, different extraction time and the root anatomy [2].

In another study, Heideck et al pointed out that the biggest problem in using natural teeth is the variety in size and mechanical parameters which may cause a high standard deviation [27], however using human teeth is still the most reliable method to assess fracture resistance [1,2,7,9,27-30].

In this study, we did not use the crown on the samples to exert the compressive loading

directly on the palatal surface of the teeth at an angle of 135 degrees in relation to the long axis to omit the interfering factors like the material structure, length, shape and thickness of the crown and precisely measure the structural strength and fracture resistance [19,31]. The crown will transfer a part of this loading to the root while all the loading will be transferred to the root without the crown [19,32-34]. The loading was exerted at an angel of 135 degrees to simulate occlusion type 1 [1,2,9,7,35]. It is worth knowing that the single loading test which was used in this research can not create all the oral conditions as in the mouth. The teeth are in a wet surrounding influenced by thermal and chemical changes and cyclic forces will be exerted on them while chewing the food [6]. In addition, this study was carried out on the central teeth of the maxilla so the results can only be attributed to them. Since the single loading test was solely used in this study to assess the mean fracture resistance, it is recommended to perform similar studies with more samples in the future using fatigue and thermo cycling loadings. As these studies were in vitro, it is suggested to carry out similar researches in vivo conditions to obtain more precise results.

We also suggest comparison between casting and prefabricated posts to recognize their differences under clinical conditions.

CONCLUSION

Under the limits of this in vitro study, we conclude that the group with the facial ferrule had the highest mean fracture resistance and it may increase the fracture resistance of endodontically treated teeth restored with bonded post and core.

ACKNOWLEDGMEN

Authors would like to thank the Dental Research Center, Tehran University of Medical Sciences and also Dr M. Kharazi for statistical analyzing and valuable comments on the manuscript.

REFERENCES

1- Naumann M, Preuss A, Rosentritt M. Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: an in vitro evaluation after chewing simulation. Acta Odontol Scand 2006 Feb;64(1):31-6.

2- Dikbas I, Tanalp J, Ozel E, Koksal T, Ersoy M. Evaluation of the effect of different crown ferrule designs on the fracture resistance of endodontically treated maxillary central incisors in corporating fiber posts, composite cores and crown restorations. J Contemp Dent Pract 2007 Nov 1;8(7):62-9.

3-Stankiewicz NR, Wilson PR. The ferrule effect: a literature review. Int Endod J 2002 Jul;35(7):575-81.

4-AL-Amro AA, Wilson PR. Effect of ferrule placement on the fracture resistance of cyclically loaded bovine teeth restored with cemented cast post-cores and crowns. Eur J Prosthodont Restor Dent 2009 Sep;17(3):105-10.

5- Lima AF, Spazzin AO, Galafassi D, Correr-Sabrinho L, Carlini-Junior B. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. J Appl Oral Sci 2010 Jul-Aug:18(4):360-30.

6- Ng CC, al-Bayat MI, Dumbrigue HB, Griggs JA, Wakefield CW. Effect of no ferrule on failure of teeth restored with bonded post and cores. G Dent 2004 Mar-Apr;52(2):143-60.

7- 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 Apr;93(4):331-60.

8- Cho H, Michalakis KX, Kim Y, Hiryama H. Impact of interproximal groove placement and remaining coronal tooth structure on the fracture resistance of endodontically treated maxillary anterior teeth. J Prosthodont 2009 Jan;18(1):43-8.

9- 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 Apr;95(4):290-6.
10- Salari MH, Jalalian E, Soleimani S. Effect of ferrule on fracture resistance of endodontically treated teeth that were restored with bonded post and cores. Islam Dent Assoc Iran Dent J 2007 Sep;19(2):86-91.
11- Jalalian E, Nikooie S, Shams S, Jomhari S. Comparison of the effect of four nonmetal posts on fracture resistance of endodontically treated teeth restored with composite. Shiraz Uni Dent J;10(4):299-308.
12- Asmussen E, Peutzfeldt A, Heitmann T. Stiffeness, elastic limit and strength of newer types of endodontic posts. J Dent 1999 May;27(4):275-8.
13- Maccari PC, Conceicao EN, Nunes MF. Fracture resistance of endodontically treated teeth restored with three different prefabricated esthetic posts. J Esthet Restor Dent 2003;15(1):25-30.
14- Barjau-Escribano A, Sancho-Bru JL, Forner-Navarro L, Rodriguez–Cervantes PJ, Perez-Gonzales A, Sanchez-Marin FT. Influence of prefabricated post material on restored teeth: fracture strength and stress distribution. Oper Dent 2006 Jan-Feb;31(1):47-54.
15- Balbosh A, Kern M. Effect of surface treatment on retention of glass fiber endodontic posts. J Prosthet Dent 2006 Mar;95(3):218-23.
16- Hauman CH, Chandler NP, Purton DG. Factors influence the removal of posts. Int Endod J Oct;36(10):687-90.
17- Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002 Apr;87(4):431-7.
18- Cho I, Song H, Koak J, Heo S. Marginal accuracy and fracture strength of ceromer/fiber-reinforced composite crowns: effect of variation in preparation design. J Prosthet Dent 2002;88(4):388-95.
19- Dilmener FT, Sipani C, Dalkiz M. Resistance of three new estethic post-core systems to compressive loading. J Prosthet Dent 2006 Feb;95(2):130-60.
20- Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. J Prosthet Dent 2003 Jul;90(1):31-41.
21- Lundgren D, Laurell L. Occlusal force pattern during chewing and biting in dentitions restored with fixed bridges of cross-arch extention. I. Bilateral end abutments. J Oral Rehabil 1986 Jan;13(1):57-71.
22- Kutesa-Mutebi A, Osman YI. Effect of the ferrule on fracture resistance of teeth restored with prefabricated posts and composite cores. Afr Health Sci 2004 Aug;4(2):131-5.
23- al-Hazaimeh N, Gutteridge DL. An in vitro study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated posts and composite core restorations. Int Endod J 2001 Jan;34(1):40-6.
24- Saupe WA, Gluskin AH, Radke RA Jr. A comparative study of fracture resistance between morphologic dowel and cores and resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots. Quintessence Int 1996 Jul;27(7):483-91.
25- Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent 1994 Jun;71(6):565-7.
26- Torbjorner A, Franson B. Biomechanical aspects of prosthetic treatment of structurally compromised teeth. Int J Prosthodont 2004 Mar-Apr; 17(2):135-41.
27- Heydecke G, Butz F, Strub JR. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in vitro study. J Dent 2001 Aug;29(6):427-33.
28- Gegauff AG. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post and crowns. J Prosthet Dent 2000 Aug;84(2):169-79.
29- 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 Jan;95(1):50-4.
30- Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on resistance of endodontically treated maxillary central incisors. J Prosthet Dent 2003 Apr;89(4):368-73.
31- Sirimai S, Riis DN, Morgano SM. An in vitro study of fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-core systems. J Prosthet Dent 1999 Mar;81(3):262-9.
32- Graig RG, Powers JM. Restorative dental material. 11th edition. St. Louis:Mosby. 2002. chapter 4,9.
33- Reagan SE, Fruits TJ, Van Brunt CL, Ward CK. Effects of cyclic loading on selected post and core systems. Quintessence Int 1999 Jan;30(1):61-7.
34- Patel A, Gutteridge DL. An in vitro investigation of cast post and partial core design. J Dent 1996 Jul;24(4):281-7.
35- Ottl P, Hahn L, Lauer HCh, Fay M. Fracture characteristics of carbon fiber ,ceramic and non palladium endodontiv post systems at monotonously increasing loads. J Oral Rehabil 2002 Feb;29(2):175-83.