Brazilian Dental Science
Ciência Odontológica Brasileira
unesp
UNIVERSIDADE ESTADUAL PAULISTA "JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE
Doi: 10.14295/bds.2019.v22i4.1720

Effects of ferrule and diameter of parallel cast post and core on fracture resistance

Efeitos da férula e diâmetro de núcleos metálicos paralelos na resistência a fratura

Ahmad MAALHAGH-FARD[1], Rafael Rocha PACHECO[1], Karanjot GILL[2], Warren Charles WAGNER[1]

1 – Department of Restorative Dentistry – University of Detroit Mercy – School of Dentistry – Detroit – MI – USA.

2 – Private Practice.

ABSTRACT

Objective: The aim of this study was to evaluate the effects of using different diameters of parallel cast posts with, or without ferrule, on the overall fracture resistance of Cast Post and Core (CPC). **Material and Methods:** Forty (40) endodontically treated human maxillary central incisors were divided into four groups (n=10): [F1] 1.0 mm diameter post with ferrule; [NF1] 1.0 mm diameter cast post without ferrule; [F1.5] 1.5 mm diameter cast post with ferrule; [NF1.5] 1.5 mm diameter post without ferrule. For all teeth, the post space (9.0 mm, in depth) was prepared using ParaPost™ drill. CPC using base metal alloy were fabricated and were cemented using resin modified glass ionomer (RMGI) cement along with the Porcelain Fused to Metal (PFM) crowns. A universal testing machine (Instron) was used to apply horizontal force perpendicular to the long axis of the tooth at the center of lingual surface, until catastrophic failure. Data was submitted to two-way ANOVA and Scheffé tests ($P<0.05$). **Results:** Both post diameter and ferrule statistically affected the maximum load at fracture ($P=0.004$ and $P=0.013$, respectively). The highest mean values were observed for samples with ferrule and wider post size (490N), while the lowest were observed for samples without ferrule and narrower post size (254N). There was no relationship between the presence of a ferrule and post size ($P=0.937$). **Conclusion:** For endodontically treated teeth with no ferrule, a wider-diameter cast post increased fracture resistance of a CPC and PFM crown procedure.

KEYWORDS

Ferrule; Fracture resistance; Metal Post; Intraradicular Retention.

RESUMO

Objetivo: O objetivo do presente estudo foi avaliar os efeitos de diferentes diâmetros de núcleos metálicos paralelos (com ou sem férula) na resistência a fratura do procedimento restaurador. **Material e Métodos:** Quarenta (40) incisivos centrais superiores humanos foram tratados endodonticamente e divididos em quarto grupos (n=10): [F1] Diâmetro de 1.0 mm, com férula; [NF1] Diâmetro de 1.0 mm, sem férula; [F1.5] Diâmetro de 1.5 mm, com férula; [NF1.5] Diâmetro de 1.5 mm, sem férula. Para todos os dentes, o espaço foi preparado para o núcleo (9.0 mm, em comprimento) utilizando brocas do ParaPost™. Os núcleos metálicos e as coroas metalocerâmicas fabricadas foram cimentados utilizando-se cimento de ionômero de vidro modificado por resina. Uma máquina de ensaios universal (Instron) foi utilizada para aplicar uma força horizontal perpendicular ao longo eixo do dente, no centro da face lingual, até falha catastrófica. Os dados foram analisados através de análise de variância de dois fatores e teste de Scheffé ($p<0.05$). **Resultados:** O diâmetro do núcleo e a presença (ou ausência) de férula afteram estatiscamente a resistência máxima a fratura do procedimento ($P=0.004$ e $P=0.013$, respectivamente). Os maiores valores foram observados para amostras com férula e de maior diâmetro (490N), enquanto os menores valores foram observados para amostras sem férula e de menor diâmetro (254N). **Conclusão:** Para dentes tratados endodondicamente, com férula, um núcleo de maior diâmetro aumentou a resistência a fratura de procedimentos restauradores envolvendo coroas metalocerâmicas cimentadas sobre núcleos metálicos fundidos.

PALAVRAS-CHAVE

Férula; Resistência a fratura; Pinos metálicos; Retenção intradicular.

INTRODUCTION

Restorative procedures of endodontically treated teeth have been widely investigated in the Dental literature, and the importance of a ferrule in the preparation design for cast post is well reported.[1-4] When the crown preparation of sound coronal-tooth structure extends beyond the core in the apical direction, there is a ferrule effect. The height of axial wall significantly enhances the fracture resistance of endodontically treated teeth restored with cast posts and cores and complete crowns, and a minimum height of 1.5 mm [2] or 2.0 mm [4-7] have been reported. For some clinical situations, the inclusion of a ferrule is difficult (or impossible) due to lack of coronal tooth structure. Crown lengthening or forced eruption procedures might lead to increased area of tooth structure, but it is usually at the expense of decreasing the crown-to-root ratio, surgical procedures and additional cost to the patient. [8-9]

Even though for some clinical situations, a single-tooth implant provides a more favorable prognosis, these procedures may not be indicated in medically-compromised patients. [10-11] In addition, adolescent patients may not be able to receive a dental implant since their skeletal growth is incomplete. [12] Several retrospective and in vitro studies have shown that coronal coverage following endodontic treatment resulted in decreased tooth loss rates. [13-16] Core may improve retention and resistance to displacement for teeth that have lost significant tooth structure. A post is recommended to provide retention and to improve the distribution of functional loads along the root. [17-19] Posts can either be pre-fabricated or custom made. Cast post and cores are custom made casts from metal alloys. Pre-fabricated posts are either metallic (such as titanium alloy, stainless steel posts) or non-metallic (such as carbon fiber, ceramic or glass fiber reinforced resin composite). [20]

Traditionally, a custom cast post-and-core (CPC) is recommended for restoring the lost hard tissue (commonly, dentin) of an endodontically treated tooth before a crown is placed, [2,11,21] with teeth that lost less than 50% of sound tooth structure. [22] CPC procedures allow an intimate adaptation between post and prepared tooth surfaces, and should fit optimally, reducing the thickness of cement line and increasing mechanical retention. This type of procedure is still commonly performed by clinicians that want to increase the retention when using cast posts. The shape of the post also affects fracture resistance, however parallel-sided cast posts demonstrate higher retention when compared to the tapered ones. [17, 23-24] Furthermore, the use of a parallel post may reduce the thickness of the dentin at more apical areas of the root. Several studies have also reported that longer posts might lead to increased retention. [25-27] The diameter of the post is also important, with studies reporting that the post should be as narrow as possible to increase fracture resistance. [28] Dental literature lacks on studies that report the effects of parallel cast post diameter on fracture resistance of endodontically treated teeth, in situations where an implant procedure is not feasible for the moment.

The aim for this in vitro study was to evaluate the effects of using different diameters of parallel cast posts with, or without ferrule, on the fracture resistance of human maxillary central incisors. Hypothesis tested were that: [1] the absence of ferrule would reduce the fracture resistance of the restorative procedure and [2] a wider post diameter would also reduce the fracture resistance.

MATERIALS AND METHODS

Forty (40) sound human maxillary central incisors teeth were selected from the Department of Oral and Maxillofacial Surgery at the University of Detroit Mercy, School of Dentistry. Selected teeth had a minimum root length of 13 mm, from the root apex to the buccal cementoenamel junction (CEJ). The teeth were stored in a solution of 0.2% sodium azide (Laboratory Grade Sodium Azide; Fisher Scientific, Fair Lawn, NJ) and then subjected to a standard endodontic treatment by an operator who was unaware of each tooth's group identity. Canal preparation was performed by using a rotary instrumentation using a ProFile GT (Dentsply Tulsa Dental Specialties; Tulsa, OK). The working length was set at 1.0 mm short of the apical foramen. Obturation was performed by warm vertical condensation continuous-wave technique using a size 40 master gutta-percha cone (Dentsply Tulsa Dental Specialties; Tulsa, OK) and an endodontic sealer (Roth Grossman Sealer; Pearson Dental; Sylmar, CA). The teeth were inspected for cracks using 3.5X magnification (Prism Loupes; Carl Zeiss Inc., Thornwood, NY) prior to embedding in dual-component model resin blocks (Polyurock; Gendres & Metaux; North Attleboro, MA). The long axis of each tooth was parallel to the long axis of the block and invested to the mid-facial extent of the CEJ. Then, the teeth were divided into four (4) groups of ten (n=10). Two independent variables were recorded: Presence (or absence) of ferrule, and the post diameter. Half of the teeth received a cast post with a 2.0 mm ferrule. The other half received a cast post without a ferrule. The average outer diameters of the Size 4.5 and 6 of ParaPost System (Coltène/Whaledent, Inc.; Cuyahoga Falls, OH) were 1.0 mm and 1.5 mm, respectively. To distribute the tooth sizes, the teeth were ranked from the largest to the smallest average diameter (the largest measured diameter plus the smallest diameter, divided by two).

Then, the ranked teeth were distributed from the largest to the smallest into the four treatment groups. Coronal tooth structure was removed to the CEJ level by using a coarse-chamfer, diamond bur (Brasseler USA; Savanna, GA) connected to a high-speed hand piece under water refrigeration. A new diamond bur was used for each tooth. The crown margin was designed to follow cemento-enamel junction, with the facial and lingual extents of the margin 1.5 mm more apical than the proximal margins. The buccal margins were 1.2 mm wide, with a shoulder configuration, and the lingual chamfer margins were 0.5 mm wide. The margin of each tooth was prepared with a diamond-rotary cutting instrument (6847KR-016; Brasseler USA; Savannah, GA) with a 16-degree total-occlusal convergence angle. Incisal reduction was of 2.0mm and facial reduction was of 1.5 mm. Then, 0.5 mm of lingual margin reduction was performed with a diamond-rotary cutting instrument (6379-023; Brasseler; USA). For the control group, teeth were further reduced in order to leave a 2.0 mm, uniform ferrule while the teeth in non-ferrule group were reduced in order to entirely eliminate the ferrule (Figure 1).

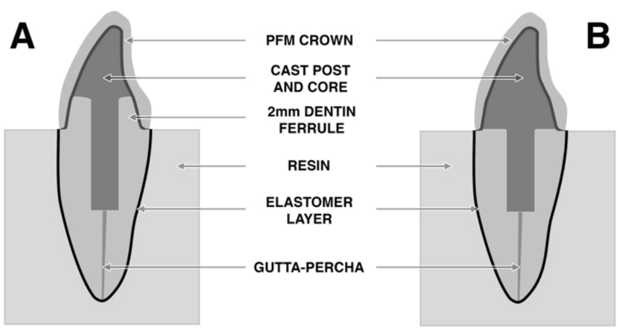

Figure 1 - Schematic figure of specimen preparation. A- Samples with ferrule; B- Samples with no ferrule.

Gutta-percha removal was, then, performed, preserving at least 4 mm of the apical material. For each tooth, the post space was prepared to 9.0 mm using drill sizes 4.5 and 6 (Coltène/Whaledent, Inc.; Cuyahoga Falls, OH). Direct CPC resin patterns were made with selfcuring acrylic resin (GC Pattern Resin; GC America; Chicago, IL) and corresponding plastic patterns (Coltène/Whaledent, Inc.; Cuyahoga Falls, OH). The patterns were invested in phosphate-bonded investment material (Fujivest; GC America; Chicago, IL) following manufacture's recommendations. Thirty (30) minutes after the start of mixing, the investment was placed in a preheated burnout oven (Temp Master A; Jelrus; Hicksville, NY) at a temperature of 1100°C for 45 min. The patterns were cast in base metal alloy (4ALL; Ivoclar Vivadent Inc.; Amherst, NY) with the aid of a centrifugal casting machine (Centrifico; Kerrlab; Orange, CA). The cast post and cores were tried-in and cemented using a resin-modified glass ionomer cement (RMGI) (Fuji Plus; GC America; Chicago, IL). The cemented cast post and cores were further refined with finishing chamfer carbide burs (Brasseler USA; Savanna, GA). Impressions of the preparations were made using polyvinyl siloxane (Examix; GC America; Chicago, IL). Then, porcelain fused to metal (PFM) full coverage crowns were fabricated using same alloy (4ALL; Ivoclar Vivadent Inc.; Amherst, NY) and corresponding ceramic. Prior to PFM fabrication, two layers of die relief material were painted on the dies. All the facial porcelain was supported with metal. PFM crowns were tried in, and then cemented in using RMGI cement. To simulate a periodontal ligament space, tooth root surfaces were coated with 0.2 mm of silicone film (Plasti Dip; Plasti Dip Intl; Blaine, MN) to within 1.0 mm of the coronal floor. The teeth were embedded into dual-component model resin (Polyurock; Gendres& Metaux; North Attleboro, MA) over PVS molds (Remasil; Dentaurum USA; Newtown, PA). After the resin was cured, samples were kept in 100% humidity container, at 37ºC for 24 hours prior to testing.

A universal testing machine (Instron model 5565; Instron Corp. Grove City, PA) with a rounded loading plunger of 1.0 mm diameter was used (Figure 2A and 2B). A crosshead speed of 0.5 mm/min was used to apply a load on the center of the lingual surface of the crowns, perpendicular to the long axis of the tooth until catastrophic failure occurred (Figure 2C and 2D). The maximum loads at failure were recorded. The results were interpreted using a two-way analysis of variance (ANOVA). A significance level of 0.05 was used. In addition, a two-way ANOVA compared fracture forces resulting from changes in two independent variables: the presence of ferrule and post diameter.

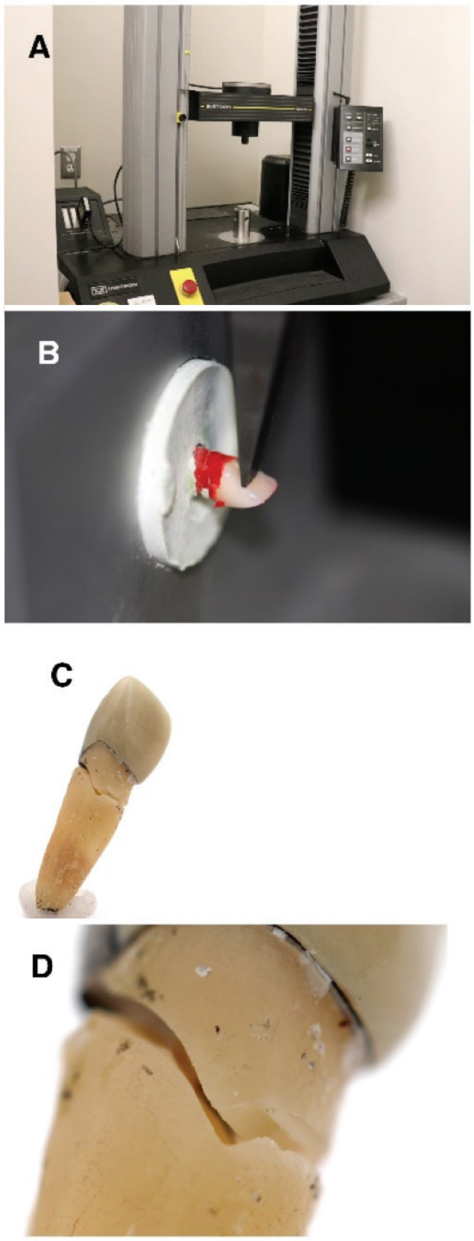

Figure 2 - Methods used for this study. A- Universal testing machine (Instron 5565); B- Force applied perpendicularly to long axis of central incisors, using a round-end fixture; C- Fractured sample after test; D- Close-up image of fractured root (darker spots in root surface are remains of PVS material).

RESULTS

Table 1 demonstrates the statistical report for maximum load at failure (N). Statistically significant differences were found between samples with and without ferrules (P=0.004). In addition, statistically significant differences between the two evaluated diameters of posts used (P=0.013) were found. However, there was no significant difference found between the two independent variables: ferrule presence and post diameter (P=0.937) indicating that ferrule presence and post diameter might influence fracture load independently (Figure 3). The presence of a ferrule increased the fracture strength in a rate of 36% to 49% for wide and narrow posts, respectively. In addition, the wider diameter increased fracture strength at 41% for the samples without ferrules and 29% for the samples with ferrules. The highest mean values were found for the samples with ferrules and wider post size (490N) while the lowest were found for the samples without ferrules and narrower post size (254N).

Table 1 - Two Way ANOVA Comparing Fracture Load at Failure as an Effect of Presence of Ferrule and Post Diameter Dependent: Fracture Load (N)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Ferrule/No Ferrule	1	163694	163694	9.513	0.004
Post Diameter	1	117176	117176	6.81	0.013
Ferrule x Diameter	1	108	108	0.006	0.937
Residual	36	619474	17207		

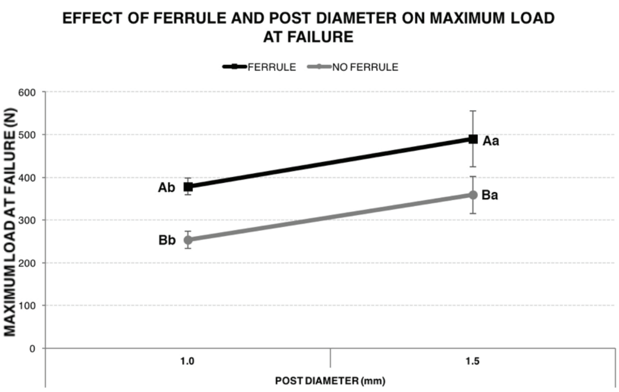

Figure 3 - Effect of ferrule and post diameter on maximum load at failure. Different letters represent statistical difference among groups (uppercase letters represent statistical difference between ferrule, lowercase represent difference between post diameter) (P<0.05).

DISCUSSION

It was shown using this laboratory model that the presence of a ferrule was a factor in improving fracture resistance and the prognosis for teeth with posts and cores, consistent with the findings of similar studies. [26-29] Thus, first hypothesis was accepted. In the absence of a circumferential remaining coronal tooth structure, the location of axial structure (incisal to the preparation finish line) may be an important factor in determining the fracture resistance of endodontically treated tooth. The remaining palatal tooth structure was shown to provide significant support to the crown in one study. [30] It has also been demonstrated that teeth restored with ceramic crowns on a no ferrule substrate presented higher fracture resistance and lower strain when compared to metallic crowns. [28,31-32] This study was designed to simulate a clinical situation where there is no ferrule on the preparation design, and the retention and resistance are dependent on a post-and-core system. Additionally, a perpendicular angle of loading to the long axis of the tooth was used since it has been shown to be the most traumatic to a post-and-core system. [21,33] Resin-modified glass ionomer (RMGI) cement was used in the present study as it has greater retention properties than other cements. [34-35] This may be due to chemical bonding between remaining tooth structure and RMGI, which could provide additional reinforcement against dislodging forces. [21] Initial failure may start from the de-bonding of the core, and further failure may occur with the post loosening. Post de-bonding has been reported to be the most common complication found clinically in post-and-core systems [20,21] and may play a significant role in the incidence of root fractures that occur clinically. [35]

The choice of post design becomes an important factor when remaining coronal tooth structure is compromised, especially when longer posts are used. [36] The parallel sides of a cast post and core may increase retention and resistance to displacement between the internal root canal and cast post, thereby resulting in less de-bonding of the post from the internal root canal. [3] In this study, parallel-sided / serrated cast posts were used. A serrated post may increase surface area of the post and, consequently, increase the retention. [37-38] Furthermore, the use of parallel posts may interfere with the cement flow and settlement, and adaptation must always be evaluated. Natural, and sound, teeth respond differently to physiologic loads due to the presence of resilient periodontal ligaments and bone tissue. A coat of PVS layer was applied to the root surface, in order to simulate periodontal tissues. For this study, one limitation was that some samples were dislodged from the model resin due to a failure on the silicone layer, on the root surface. A resilient layer which could penetrate into both the cementum and the embedding resin would simulate periodontal ligaments of natural teeth, and its behavior.

Failure was consistently observed to be associated with dentin tissue, for this study. No deformation was observed for the cast posts under the applied loads. The maximum load at failure observed may be acceptable clinically since these values are considerably higher than reported maximal physiologic forces acting on the teeth, in the oral cavity. [39] Fracture resistance of restored teeth and the mode of failure are the results of interaction between multiple mechanical properties. [40] For this study, the fracture resistance was investigated using destructive testing. Further research should be conducted where specimens are subjected to cyclic loading instead of static loading, in a moist environment.

Second tested hypothesis was rejected, since a wider diameter post resulted in higher maximum load at failure when compared to narrower posts. This may be explained by the fact that stress is higher when a same load is applied on a smaller area (narrow post). Thus, a wider post might concentrate and/or distribute stresses differently than a narrower one, resulting in a higher resistance to fracture. Without a ferrule, the prognosis of the tooth is compromised, [41] however, the mean failure loads for this situation with wider post diameters are higher when compared to the narrow diameter posts. In addition, large standard deviations were observed for wider diameter posts, in teeth with ferrule. Natural teeth have large variations in size and mechanical parameters, often resulting in large standard deviations. [42] Other teeth beside maxillary central incisors could be incorporated in the test sample size. Other post systems such as tapered, prefabricated and fiber posts need similar studies. Based on the results of this study, in a clinical situation with minimal ferrule, a wider diameter, parallel-sided, passive serrated post could be indicated. However, even though a wider post seems advantageous for these cases, a minimum remaining of 1.75 mm of sound dentin around the entire circumference of the post to resist fracture of the tooth is required. [29]

Young patients with endodontically treated teeth and minimal remaining tooth structure may not be able to receive a dental implant since their skeletal growth is incomplete. [12] Restoring a less-than optimal tooth structure with a wider post and full coverage crown allows these patients to have a longer-lasting restoration until they reach skeletal maturation. At this point the patient could consider a dental implant with more favorable prognosis. For this reason, the benefit of a wider diameter cast post must be carefully balanced with the need to preserve internal tooth structure during post preparation. The use of other post systems, such as prefabricated alloy and fiber posts, has been investigated and compared in other studies [31,34,43] but further studies are required in this regard, using identical methodology.

CONCLUSION

Based on the results obtained on this study, it can be concluded that both the presence of a ferrule and the use of a wider diameter cast post resulted in significant increase in maximum load at failure, when endodontically treated maxillary central incisors were subjected to horizontal loading.

REFERENCES

1. Gelfand M, Goldman M, Sunderman EJ. Effect of complete veneer crowns on the compressive strength of endodontically treated posterior teeth. J Prosthet Dent. 1984 Nov;52(5):635-8.

2. Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont. 1995 Mar-Apr;8(2):155-61.

3. Torbjörner A, Karlsson S, Ödman PA. Survival rate and failure characteristics for two post designs. The Journal of prosthetic dentistry 1995;73:439-44.

4. 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 Oct;88(4):442-8.

5. Akkayan B. An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent. 2004 Aug;92(2):155-62.

6. Barkhordar RA, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent. 1989 Jun;61(6):676-8.

7. 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 Apr;89(4):368-73.

8. Gegauff AG. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. J Prosthet Dent. 2000 Aug;84(2):169-79.

9. Meng Q, Chen Y, Guang H, Yip KH, Smales R. Effect of a ferrule and increased clinical crown length on the in vitro fracture resistance of premolars restored using two doweland-core systems. Oper Dent. 2007 Nov-Dec;32(6):595-601.

10. Gómez de Diego R, Mang de la Rosa MR, Romero Perez MJ, Cutando Soriano A, López-Valverde Centeno A. Indications and contraindications of dental implants in medically compromised patients: update. Med Oral Patol Oral Cir Bucal. 2014 Sep 1;19(5):e483-9.

11. Naujokat H, Kunzendorf B, Wiltfang J. Dental implants and diabetes mellitus—a systematic review. Int J Implant Dent. 2016 Dec;2(1):5. Epub 2016 Feb 11.

12. Oesterle LJ, Cronin Jr RJ, Ranly DM. Maxillary implants and the growing patient. Int J Oral Maxillofac Implants. 1993;8(4):377-87.

13. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002 Mar;87(3):256-63.

14. Hansen EK, Asmussen E. In vivo fractures of endodontically treated posterior teeth restored with enamel-bonded resin. Endod Dent Traumatol. 1990 Oct;6(5):218-25.

15. Sahafi A, Peutzfeldt A, Ravnholt G, Asmussen E, Gotfredsen K. Resistance to cyclic loading of teeth restored with posts. Clin Oral Investig. 2005 Jun;9(2):84-90. Epub 2005 Mar 4.

16. Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent. 1984 Jun;51(6):780-4.

17. Guzy GE, Nicholls JI. In vitro comparison of intact endodntically treated teeth with and without endo-post reinforcement. J Prosthet Dent. 1979 Jul;42(1):39-44.

18. Ichim I, Kuzmanovic D, Love R. A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root. Int Endod J. 2006 Jun;39(6):443-52.

19. Zhang YX, Zhang WH, Lu ZY, Wang KL. Fracture strength of custom-fabricated Celay all-ceramic post and core restored endodontically treated teeth. Chin Med J (Engl). 2006 Nov 5;119(21):1815-20.

20. Qualtrough A, Mannocci F. Tooth-colored post systems: a review. Oper Dent. 2003 Jan-Feb;28(1):86-91.

21. Malone WF, Tylman SD, Koth DL. Tylman's theory and practice of fixed prosthodontics. 8 ed. Ishiyaku EuroAmerica 1989.

22. Heydecke G, Peters MC. The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review. J Prosthet Dent. 2002 Apr;87(4):380-6.

23. Isidor F, Brøndum K. Intermittent loading of teeth with tapered, individually cast or prefabricated, parallel-sided posts. Int J Prosthodont. 1992 May-Jun;5(3):257-61.

24. Nissan J, Dmitry Y, Assif D. The use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent. 2001 Sep;86(3):304-8.

25. McLaren JD, McLaren CI, Yaman P, Bin-Shuwaish MS, Dennison JD, McDonald NJ. The effect of post type and length on the fracture resistance of endodontically treated teeth. J Prosthet Dent. 2009 Mar;101(3):174-82. doi: 10.1016/S0022-3913(09)60024-X.

26. Sokol DJ. Effective use of current core and post concepts. J Prosthet Dent. 1984 Aug;52(2):231-4.

27. Standlee JP, Caputo AA, Holcomb J, Trabert KC. The retentive and stress-distributing properties of a threaded endodontic dowel. J Prosthet Dent. 1980 Oct;44(4):398-404.

28. Robbins JW. Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc. 1990 May;120(5):558, 560, 562 passim.

29. Halle EB, Nicholls JI, Van Hassel H. An in vitro comparison of retention between a hollow post and core and a custom hollow post and core. J Endod. 1984 Mar;10(3):96-100.

30. 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.

31. Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont. 2001 Jul-Aug;14(4):355-63.

32. Da Silva NR, Raposo LHA, Versluis A, Fernandes-Neto AJ, Soares CJ. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. J Prosthet Dent. 2010 Nov;104(5):306-17. doi: 10.1016/S0022-3913(10)60146-1.

33. Milot P, Stein RS. Root fracture in endodontically treated teeth related to post selection and crown design. J Prosthet Dent. 1992 Sep;68(3):428-35.

34. Torres-Sánchez C, Montoya-Salazar V, Córdoba P, Vélez C, Guzmán-Duran A, Gutierrez-Pérez J-L, et al. Fracture resistance of endodontically treated teeth restored with glass fiber reinforced posts and cast gold post and cores cemented with three cements. J Prosthet Dent. 2013 Aug;110(2):127-33. doi: 10.1016/S0022-3913(13)60352-2.

35. Balkaya MC, Birdal IS. Effect of resin-based materials on fracture resistance of endodontically treated thin-walled teeth. J Prosthet Dent. 2013 May;109(5):296-303. doi: 10.1016/S0022-3913(13)60304-2.

36. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. J Prosthet Dent. 1990 May;63(5):529-36.

37. Maniatopoulos C, Pilliar R, Smith D. Evaluation of shear strength at the cement endodontic post interface. J Prosthet Dent. 1988 Jun;59(6):662-9.

38. Nergiz I, Schmage P, Platzer U, McMullan-Vogel CG. Effect of different surface textures on retentive strength of tapered posts. J Prosthet Dent. 1997 Nov;78(5):451-7.

39. Lyons M, Baxendale R. A preliminary electromyographic study of bite force and jaw-closing muscle fatigue in human subjects with advanced tooth wear. J Oral Rehabil. 1990 Jul;17(4):311-8.

40. Soares PV, Santos-Filho PCF, Martins LRM, Soares CJ. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: fracture resistance and fracture mode. J Prosthet Dent. 2008 Jan;99(1):30-7. doi: 10.1016/S0022-3913(08)60006-2.

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

42. Butz F, Lennon ÁM, Heydecke G, Strub JR. Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post-and-core systems: an in vitro study. Int J Prosthodont. 2001 Jan-Feb;14(1):58-64.

43. Huysmans MC, Peters M, Plasschaert A, Varst P. Failure characteristics of endodontically treated premolars restored with a post and direct restorative material. Int Endod J. 1992 May;25(3):121-9.

Rafael Rocha Pacheco
(Corresponding address)
2700 Martin Luther King Jr. Blvd
E-mail: pachecrr@udmercy.edu

Date submitted: 2019 Jan 17

Accept submission: 2019 Sep 16