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Original Article

Fracture Resistance of Endodontically Treated Teeth Restored with Different Types of Intracanal Posts

Lucy Coimbra de Magalhães Resende[1], Túlio Pessoa de Araújo[2], Ângelo Barbosa Resende[3], Yuri Wanderley Cavalcanti[4], Leopoldina de Fátima Dantas de Almeida[4], Wilton Wilney Nascimento Padilha[4], Rejane de Andrade Carvalho[1], Samira Albuquerque de Sousa[1]

[1]Department of Dentistry, Potiguar University, Natal, RN, Brazil.
[2]Department of Restorative Dentistry, Federal University of Paraiba, Joao Pessoa, PB, Brazil.
[3]Department of Dentistry, State University of Pernambuco, Recife, PE, Brazil.
[4]Department of Clinical and Social Dentistry, Federal University of Paraiba, Joao Pessoa, PB, Brazil.

Author to whom correspondence should be addressed: Yuri Wanderley Cavalcanti. Department of Clinical and Social Dentistry. Health Sciences Center. Federal University of Paraiba. Cidade Universitária, Campus I, Joao Pessoa, PB, 58051900, Brazil. E-mail: yuri@ccs.ufpb.br.

Abstract

Objective: To evaluate the fracture resistance of endodontically treated teeth restored with different types of intracanal posts. **Material and Methods:** Sixty human upper central incisors (n = 60) were divided according to the performance of different protocols for restoration with intracanal posts. Groups without endodontic treatment (NT) and with endodontic treatment (TR) without placement of intracanal posts, served as controls. The experimental groups received endodontic treatment and were restored with: fiberglass post with composite resin filling core (PFV-NP); carbon fiber post with composite resin filling core (PFC-NP); nickel-chromium metal cast and core posts (NiCr); or copper-aluminum metal cast and core posts (CuAl). The specimens were then tested to determine the maximum fracture resistance and the failure types of fracture (infra-crestal and supra-crestal). Data were analyzed by one-way ANOVA and Tukey test ($\alpha < 0.05$). **Results:** Increased fracture resistance was observed for NT group ($p < 0.05$). Within endodontically treated teeth groups, NiCr showed higher resistance to fracture, differing statistically from groups FV+NP and FC+NP ($p < 0.05$). Higher frequency of infra-crestal fractures was observed in NT and TR groups. **Conclusion:** The installation of nickel-chromium intracanal cast and core posts contributed to higher fracture resistance and lower risk of fractures difficult to repair.

Keywords: Post and Core Technique; Tooth, Nonvital; Endodontics.

Introduction

The rehabilitation of teeth undergoing endodontic treatment still remains as a frequent occurrence at the dental office; however, the literature has no consensus about the best restorative protocol to adopt in such situation [1-6]. The current evidence supports that extensively destroyed teeth should be restored with intraradicular posts and core, obtained from casted metal or fiber post associated with composite resin [2,3,6,7].

According to some clinical trials and systematic reviews recently published, the placement of intraradicular posts has contributed to increase the survival rate of endodontically treated teeth [4,5,8-10]. However, not all studies agree that intraradicular posts promote the reinforcement of the dental structure [1,3,7]. Besides that, the diversity of mechanical, biological and aesthetic properties of materials used in such treatments makes proper indications difficult to be drawn and show how controversial is the literature [1,3-5,7].

Casted intraradicular metal posts and cores were considered for many years as the only option to the rehabilitation of extensively coronal destroyed teeth [3,11-13]. Besides that, noble alloys (based on gold, silver and platinum) were strongly recommended to perform such treatments in the past [14,15]. Aiming to reduce the cost of dental treatment, alternative metallic alloys based on nickel-chromium and copper aluminum were introduced and have been largely used [14]. So far, many studies has shown favorable biomechanical performance and survival rate of nickel-chromium and copper aluminum casted intraradicular metal posts and cores [4,11-13,16-20].

However, few studies have compared the biomechanical performance of intraradicular metallic posts among themselves and with prefabricated fiber posts. Although casted intraradicular metal posts and cores have satisfactory bio-mechanic properties and successful clinical survival rate, these metallic posts have poor aesthetics [21], high elasticity coefficient and high thermal expansion coefficient compared to tooth structure [15], numerous laboratory steps and difficult technical execution [11-13].

These disadvantages have been overcome by the use of glass-fiber and carbon-fiber posts [4,10,11,16]. These materials present a current trend for use in the dental office due to the more satisfactory esthetics [21], coefficients of elasticity and thermal expansion close to the dental structure [15,22], greater ease of execution of the clinical protocol and absence of laboratory stages.

However, many aspects can influence their clinical success, such as the fiber dental cement thickness [22], the fiber post length and diameter [18,22] he remaining tooth structure [12,16,18], the adhesive protocol success [4], among others. Therefore, the indication of such materials should be performed with caution.

Although prefabricated fiber posts have demonstrated satisfactory aesthetic and biomechanical properties, there are not enough long-term clinical studies to support their superiority to casted intraradicular metal posts and cores [3-5].

The literature has been very controversial in comparisons between cast metal posts and core and prefabricated fiber posts. In vitro studies have concluded that endodontically treated teeth have increased fracture resistance when restored with nickel-chromium cast metal posts and cores [11,13,17]. Other reports have demonstrated better biomechanical performance of teeth restores with prefabricated fiber posts [12,16], whilst some publications have shown the absence of differences between treatments [4,10].

Therefore, this study evaluated the fracture resistance of endodontically treated teeth restored with different restorative protocols. Here we compared the performance of two types of aesthetic intraradicular posts with two types of casted intraradicular metal posts and cores.

Material and Methods

Experimental Design

An in vitro and randomized experimental study was conducted. Human upper central incisors (n = 60) were randomly distributed into six groups (n = 10), divided according to the execution of different protocols for intra-radicular retention. Not-treated (NT) and endodontic-treated (CR) groups received total crown preparation and did not receive intra-radicular retainers, serving as controls. The experimental groups received endodontic treatment, canal preparation, pin installation and preparation for total crown. The types of intraradicular retainers evaluated were: fiberglass pin with filling core in composite resin (GFPC); Carbon fiber pin with composite resin fill core (CFPC); with nickel-chromium cast metal post and core (NiCr); copper-aluminum cast metal post and core (CuAl). The maximum fracture strength and the fracture types (infra-crestal and supra-crestal) were the response variables.

Sample Collection and Group Allocation

Sound human upper central incisors were collected teeth and cleaned, placed individually into 1% thymol, and stored at 4ºC, in 100% humidity. Teeth with pronounced apical curvatures, with less than 21 mm length and greater than 24 mm length, were excluded from the sample. In addition, teeth with caries, cracks, fractures and previous endodontic treatment were excluded. The selected teeth were given numerical values and subsequently randomly divided into six experimental groups (n=10), in accordance with Table 1. Sample size was considered adequate to demonstrate statistical differences between groups, according to pilot studies and other studies of literature [11,13,17].

Table 1. Description of treatment protocols that constituted groups for allocation of samples.

Groups (n=10)	Description
NT	Control Group I. Sound teeth without (endodontic treatment); with tooth preparation for full crown.
CR	Control Group II. Endodontically treated teeth; with tooth preparation for full crown; composite resin restoration at the endodontic access.

GFPC	Endodontically treated teeth; with tooth preparation for full crown (ferule); restored with glass-fiber post and composite resin filling core.
CFPC	Endodontically treated teeth; with tooth preparation for full crown (ferule); restored with carbon-fiber post and composite resin filling core.
NiCr	Endodontically treated teeth; with tooth preparation for full crown (ferule); restored with nickel-chromium cast metal post and core.
CuAl	Endodontically treated teeth; with tooth preparation for full crown (ferule); restored with copper-aluminum cast metal post and core.

Specimens' Preparation – Treatment Protocols

The specimens' preparation was based on endodontic treatment; followed by tooth preparation for full crown, root canal preparation for intraradicular post; and finally, installation of intraradicular posts. One trained operator prepared all the samples. Among the steps performed, the specimens were kept at 4° C, in 100% relative humidity (wet sponge).

Specimens from NT group were not endodontically treated, and had their intraradicular structure preserved. All other groups were subjected to the endodontic treatment, initiated by coronary opening and root canal access with 1014 drills (KG Sorensen, São Paulo, São Paulo, Brazil). Root canals systems were prepared using 1% sodium hypochlorite irrigation and endodontic hand files, up to #45 memory instrument (crown-down technique). Final irrigation was performed with 17% EDTA to remove smear layer. The root canals were filled using active lateral heat condensation with gutta-percha points and endodontic sealer (Sealer 26, Dentsply, Petrópolis, Rio de Janeiro, Brazil).

All groups were then subjected to characteristic preparation of teeth for metal-ceramic full crowns. Tooth preparation consisted of 1.5 mm wear at convex areas and 0.8 mm wear at cervical regions, which had chamfer finishing. After initial preparation, axial walls achieved 8° angulation to occlusal and 8.0 mm cervical-occlusal length. Additional cervical-occlusal wear was performed in groups reserved to intraradicular post installation (GFPC, CFPC, NiCr, CuAl), aiming to produce a 2.0 mm ferule [11-13]. All tooth preparations were performed with KG 4138, 3118, 3101, 4138F and 3118F drills (KG Sorensen, São Paulo, São Paulo, Brazil), using air-water cooling high-speed turbine. The cervical term distanced 1.0 mm from the cement-enamel junction, in an attempt to match the space of the gingival sulcus under normal conditions [10].

Subsequently, the endodontically treated teeth were prepared for intraradicular posts insertion by removing part of the endodontic filling. The endodontic filling of CR group was removed up to 1.0 mm beyond the enamel-cement junction. The endodontic access aperture in such group was restored with Z350 composite resin (3M-ESPE Dental, St. Paul, Minn. USA). In groups assigned to intraradicular post restorations (GFPC, CFPC, NiCr, CuAl), the root canal preparations preserved 4.0 mm apically of the endodontic filling.

Root canals from GFPC and CFPC groups were prepared using endodontic drills to remove the filling material and regularize of the inner walls of the canals. Glass-fiber posts (Reforpost n°1, Angelus, Londrina, Paraná, Brazil) and carbon-fiber posts covered with glass fiber

(Reforpost Mix n°1, Angelus, Londrina, Paraná, Brazil) were used to restore, respectively, GFPC and CFPC groups.

Fiber posts luting was performed after conditioning posts with 37% phosphoric acid for 60 seconds. The adhesive system (Single Bond, 3M ESPE Dental, St. Paul, Minn, USA) was applied on posts surfaces after treatment with bonding primer agent (Silano, Dentsply, Petrópolis, Rio de Janeiro, Brazil). Root canals were conditioned with 37% phosphoric acid for 15 seconds, being toughly washed with water (15 seconds) and gently dried with absorbent paper cones. The adhesive system (Single Bond, 3M ESPE Dental, St. Paul, Minn, USA) was then applied on root canals inner surfaces and excess removed with paper points. Adhesive layers were light-cured for 10 seconds with a light-curing unit (Radii Cal. SDI Brasil Ind. Com. Ltda., São Paulo, Brazil).

Following, fiber posts were covered with luting agent (RelyX ARC, 3M-ESPE Dental, St. Paul, Minn, USA) and inserted into root canals. Posts insertions were done performing little movements to allow full luting agent flow. Luting agent cure was completed with a light-curing unit (Radii Cal. SDI Brasil Ind. Com. Ltda., São Paulo, Brazil) for 40 seconds, onto the four sides of the teeth (vestibular, lingual, medial and distal). Specimens were then stored for 24 h, at 37°C and 100% humidity. Later, composite resin cores were built using Z350 composite resin. Final coronal preparation was executed after coronal reconstruction, to assure the same coronal characteristics accomplished for other groups.

Root canals inner surfaces from NiCr and CuAl groups were prepared using n°2 or n°3 Largo drills, accordingly to root canals inner diameters, after radiographic selection. Here, this procedure aimed to remove only the endodontic filling material and not the tooth structure.

Cast metal posts and cores were obtained after root canals and coronal modeling with chemically activated acrylic resin (Duralay, Reliance Dental, Worth, USA) and resin pins (Pin Jet, Angelus, Londrina, Paraná, Brazil). The coronal region, modeled in acrylic resin, was prepared to assure the same coronal characteristics accomplished for other groups. Afterwards, the acrylic resin posts and cores were casted into nickel-chromium and copper-aluminum alloys, respectively, to groups NiCr (Fitcast SB, Talladium, Curitiba, PR, Brazil) and CuAl (Goldent, AJE, São Paulo, SP, Brazil).

Previously to cementation, casted metal posts and cores were adjusted using lightweight consistency silicon (Xantopren, Heraeus Kulzer, Hanau, Germany). This impression material was used to assure 0.5 mm luting interface. Also previously to cementation, casted metal posts and cores were spot-blasted with 50.0 μm aluminum-oxide particles during 30 s. Luting procedures performed for NiCr and CuAl groups were the same described for GFPC and CFPC groups. After cementation, the coronal portion of cast metal posts and cores were prepared to assure the same characteristics accomplished for other groups.

Specimens' Preparation – Mimicking Maxilary Insertion

After conclude the treatments protocols, the specimens were embedded into acrylic resin bulks to mimic the maxillary insertion of upper central incisors [12,13].

Twenty layers of polyether adhesive system (Polyether Adhesive, 3M – ESPE AG, Germany) were applied onto external surface of teeth roots to mimic the periodontal ligament. The adhesive layers were applied 1.0 mm beyond the enamel-cement junction (apically), waiting the minimum of 5 min. between each layer. The adhesive thickness had approximately 0.2 mm, similarly to healthy periodontal ligaments.

Following, the specimens were placed at the center of plastic cylinder matrixes (21 mm inner diameter and 25 mm height) containing chemically activated acrylic resin, to mimic the bone insertion. Specimens positioning was executed using a parallel-meter (BioArt B2, Bio-Art, São Carlos, São Paulo, Brazil). The enamel-cement junction was positioned 1.0 mm bellow the acrylic resin level. Adding cold water to the periphery of plastic matrixes minimized acrylic resin heating during curing.

Fracture Resistance Assay

The specimens (teeth embedded in acrylic resin) were then placed vertically into a metal device, angled at 45° to its base in the labial direction of the teeth. Figure 1 illustrates the specimens correctly positioned into the metal device. Following, the conjunct was transferred to a universal testing machine (Kratos Model IKCL3, Kratos Equipamentos Industriais, Cotia, São Paulo, Brazil).

To perform the fracture resistance test, a spherical load cell (2.0 mm diameter) was positioned on the lingual surface of the coronal area of the specimens with an angle of 135° relative to the long axis of the tooth. This position represented the usual occlusal relation between the upper and lower incisors [11-13]. The compression force was then applied at speed 0.5 mm/min until fracture was observed. The peak force at the time of fracture was recorded in Kgf.

Figure 1. Tooth embedded in acrylic resin and correctly positioned into the metal device, before fracture resistance mechanical testing. The samples were angled at 45° to its base in the labial direction of the teeth.

The fracture pattern was examined under an optical microscope (Callmex, model - Q705M, Florianopolis - Santa Catarina, Brazil), under 20× magnification. Fractures were classified as supra-crestal (SC) and infra-crestal (IC), considering the limit of dental insertion in acrylic resin (1.0 mm below the cement-enamel junction, coronally). Figure 2 illustrates examples of specimens with fractures classified as supra-crestal (SC) and infra-crestal (IC).
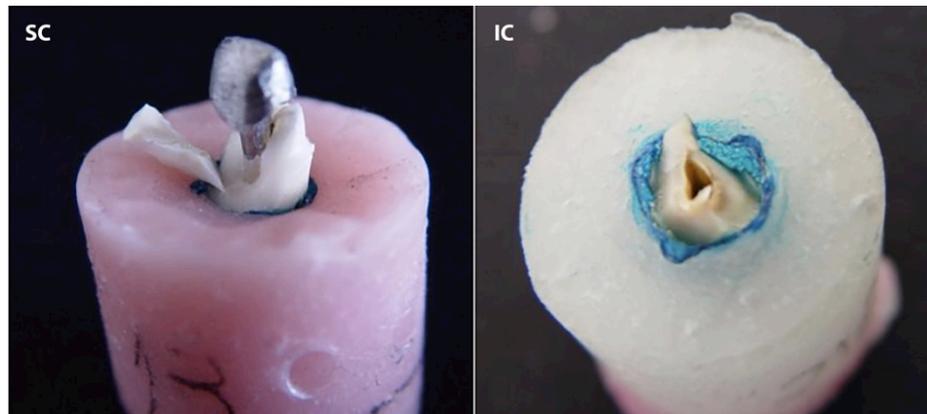
Figure 2. Specimens, after fracture resistance mechanical test, with fractures classified as supra-crestal (SC) and infra-crestal (IC).

Statistical Analysis

The values of the maximum force at fracture resistance, in Kgf, were tabulated and statistically analyzed using the Statistical Package for Social Sciences (SPSS v. 20). Data distribution was evaluated by descriptive statistics and the Kolmogorov-Smirnov test. Given the normal variable distribution, the data were compared statistically by ANOVA at a fixed criteria (group) and Tukey, considering the significance level of 5%. The analysis of the type of fracture was descriptive, considering the proportion of supra-crestal fractures (SC) and infra-crestal (IC).

Ethical Aspects

The local ethical committee in research (Potiguar University) previously approved this study (process number 001/2007) authorizing the use of human teeth. Patients with indicated extractions of sound human upper central incisors, assisted in a private dental office, donated their teeth after provide informed consent term.

Results

The fracture resistance performance of groups is illustrated in Table 2. The NT group had higher fracture resistance (p<0.05) compared to the other groups that were submitted to endodontic treatment and/or post space preparation. Among the samples subjected to the insertion of intraradicular post, highest fracture resistance was observed for the NiCr group, which differed significantly (p<0.05) from groups treated with prefabricated fibre posts made of glass (GFPC) and

carbon (CFPC). The groups treated with prefabricated fiber posts and filling cores (GFPC and CFPC) had the lowest fracture resistance rates, but showed no difference with CR and CuAl groups (p>0.05).

Table 2. Fracture resistance (mean ± standard deviation) in kgf, of teeth endodontically treated and restored according to the different proposed treatments.

Treatment Protocol (Groups)	Maximum Fracture Strength (Kgf)
NT	74.48±(15.30) [A]
CR	43.49±(6.92) [BC]
GFPC	30.85±(4.92) [C]
CFPC	30.83±(8.51) [C]
NiCr	51.31±(8.18) [B]
CuAl	45.36 ±(11.89) [BC]

Different letters indicate statistically significant difference between groups (p<0.05).

On further analysis of fracture types (Figure 3), the increased rate of infra-crestal (IC) fractures occurred in specimens that did not receive any intraradicular retainer (NT and CR). Groups restored with prefabricated fiber posts (GFPC and CFPC) and with cast intraradicular retainer of copper-aluminum alloy (CuAl) showed 100% supra-crestal (SC) fractures.
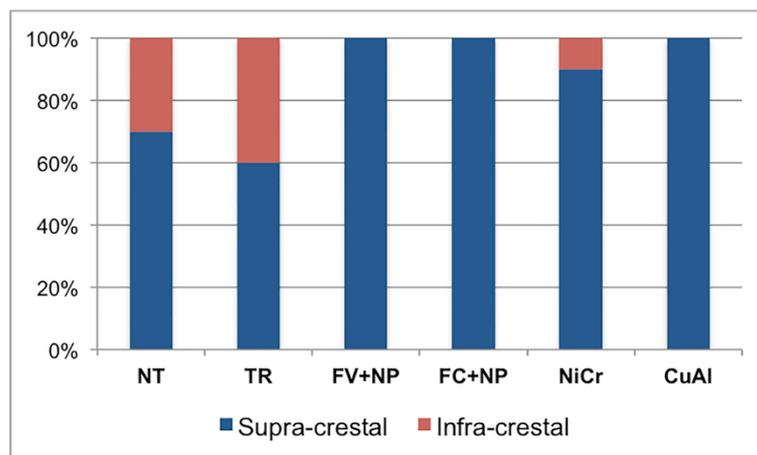
Figure 3. Graphical representation of the proportion of supra-crestal and infra-crestal fractures, obtained for teeth endodontically treated and restored with different treatment protocols.

Discussion

The results of this study corroborate the literature by showing that teeth without endodontic treatment have a higher resistance to fracture [23,24]. This report also confirmed that any evaluated restorative procedure cannot completely recover the same biomechanical strength observed in sound teeth [23-25].

Samples that were not submitted either to endodontic treatment, nor to the insertion of intra-radicular retainer, (NT) had their dental structure preserved; and, therefore, the highest fracture resistance values. In this way, the literature argues that the preservation of healthy tooth structure contributes more to prevent catastrophic fractures of endodontically treated elements,

than the installation of intraradicular retainers25. However, when enough reminiscent coronal tooth structure is not preserved, the installation of intraradicular retainers is shown as a beneficial and indispensable procedure [12,16,18,25].

As observed in this study, the group whose samples were submitted to endodontic treatment, but not restored with an intraradicular retainer (CR) had intermediate resistance values to groups restored with cast metal posts and cores and prefabricated posts. It is noteworthy that the CR group had its coronary structure preserved (cervical-occlusal height of 8.0 mm), with only the endodontic access restored with composite resin. Groups restored with intraradicular posts (GFPC, CFPC, NiCr and CuAl), however, had cervical-occlusal height merely preserved in just 2.0 mm (ferule). This phenomenon reinforces that the preservation of tooth structure plays a key role of the fracture resistance of endodontically treated teeth [12,16,18,24,25].

The experimental groups treated with intraradicular retainers have not statistically differed from the CR group. However, the results from present study points out that teeth with extensive coronary destruction have a greater resistance to fracture if restored with intraradicular nickel-chromium metal cast post and core (NiCr). This result corroborates other studies [11,13,17], which recommend that the installation of prefabricated fiber posts in endodontically treated teeth should occurs only when the coronal structure is greater than 2.0 mm height [16,18,24,25].

Satisfactory results for the fracture resistance of NiCr group confirms the findings of other studies [11,13,17], which demonstrate that metal intraradicular retainer cast in nickel-chromium present superiority over prefabricated fiberglass posts. This effect may be associated with a higher elasticity modulus of this alloy, which allows the material to support higher load without undergoing bending [16,17,26]. In addition, the juxtaposition of cast metal post to the inner canal surface may favour a smaller cement layer thickness, which contributes to reducing stresses on the root [11,22,27].

Although little explored in the literature, the intraradicular retainers cast in copper-aluminum alloy showed similar performance to glass and to carbon fiber posts, which corroborates the findings of the literature on the fracture resistance of these restorations [18,19,28]. The main difference between nickel-chromium and copper-aluminum alloys is the elasticity coefficient set at 205 GPa and 109 GPa, respectively [16,19]. Thus, it is considered that the copper-aluminum alloys have lower resistance to bending, so that the material transmits compressive forces to the dental tissue, generating the fracture.

The lower fracture strength values, observed for GFPC and CFPC groups, can be justified by the absence of satisfactory remaining tooth structure to ensure the support for the restoration [18,24,25]. The low elasticity modulus of this fiber posts is insufficient to support all the stresses without transmitting them to the dental tissue [19,20,22]. Thus, the excessive concentration of tensions on the weakened restored tooth can lead to failure of the restoration. In addition, the cross-sectional thickness of the post, the cement layer thickness and the post's length consist of factors that can negatively influence the success of the restoration [18-20,22].

In this study, the cross-sectional thickness of the post was standardized for GFPC and GFPC groups. However, the root canal inner size varied among the samples, influencing the thickness of the cement. As demonstrated in other studies, the increased thickness of the gap between the post and the inner diameter of the canal contributes to greater tensions [22]. Furthermore, studies have shown that the fracture resistance is increased when the endodontically treated teeth are restored with 10 mm minimum length posts [18]. In this study, the minimum length of the prefabricated posts was 10 mm, but this was insufficient to confer greater resistance to fracture compared to the other groups, especially to NiCr group.

The absence of differences between the groups GFPC and CFPC is because these materials have a similar composition, although aesthetic posts are marketed as carbon fiber posts. The prefabricated carbon fiber posts are consisting of 5% carbon fibers, 80% glass fiber and 15% epoxy resin; whilst the glass fiber posts have in their composition 85% glass fiber and 15% epoxy resin.

Regarding the type of failure, the teeth that were not restored with intraradicular retainers were more susceptible to infra-crestal fractures (60-70%), considered difficult to repair, or possibly irreversible. Although some studies declare that intraradicular retainers do not favour the strengthening of tooth structure [1,3], the results of this research indicate that the restoration with intraradicular posts helps reduce the depth of tooth fractures, making them reversible [23,24].

Due to the higher elasticity modulus of intraradicular metal retainers, some studies [11,17,25] suggested that these materials contribute to a higher incidence of infra-crestal fractures. However, this effect was not observed in this study. Possibly, the lightweight silicone adjustment procedure of metal cast posts, prior to cementation, provided a continuous line of resin cement around, dampening the stresses caused on the inner walls of the root [27].

The results of this research confirm the higher fracture resistance of teeth without endodontic treatment, compared to those who underwent this therapy. In addition, the present study suggests that the preservation of tooth structure contributes to greater resistance of endodontically treated teeth. For rehabilitation of these elements, the installation of intraradicular retainers cast in nickel-chromium is the best alternative treatment to ensure the fracture strength and survival of the restoration. Installing intraradicular retainers also contributed to higher frequency of repairable fractures. However, prefabricated fiber posts should be recommended only in well-preserved coronal tooth structures.

Additional laboratory studies are needed to evaluate in vitro the durability and strength of these restorations, after aging simulation by mechanical and thermal cycling. Also, further studies are needed to confirm the differences between NT and NiCr groups, since the variance was a bit big in those groups. Further studies using CuAl alloys are still necessary to confirm their success and differences relative to fiber posts. Randomized clinical trials are needed to compare the survival and success rates of metal cast intraradicular restorations and prefabricated fiber posts restorations.

Conclusion

Teeth without endodontic treatment are more resistant to fracture, therefore, are the best pillars for fixed, single or multiple stents. Endodontically treated teeth that underwent extensive carious lesions have fragile remaining tooth structure. For such situations, rehabilitation with metal intraradicular retainers casted in nickel-chrome is the best recommendation. Overall, compared to the absence of intraradicular treatment, the installation of any intraradicular restorations contribute to prevent the occurrence of dental fractures difficult to repair.

References

1. Trushkowsky RD. Restoration of endodontically treated teeth: criteria and technique considerations. Quintessence Int 2014; 45(7):557-67. doi: 10.3290/j.qi.a31964.

2. Kölpin M, Sterzenbach G, Naumann M. Composite filling or single crown? The clinical dilemma of how to restore endodontically treated teeth. Quintessence Int 2014; 45(6):457-66. doi: 10.3290/j.qi.a31802.

3. Mannocci F, Cowie J. Restoration of endodontically treated teeth. Br Dent J 2014; 216(6):341-6. doi:10.1038/sj.bdj.2014.198.

4. Sarkis-Onofre R, Jacinto RC, Boscato N, Cenci MS, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. J Dent 2014; 42(5):582-7. doi: 10.1016/j.jdent.2014.02.003.

5. Theodosopoulou JN, Chochlidakis KM. A systematic review of dowel (post) and core materials and systems. J Prosthodont 2009; 18(6):464-72. doi: 10.1111/j.1532-849X.2009.00472.x.

6. Gavranovic-Glamoc A, Redzepagic S, Ajanovic M, Kazazic L, Zukic S, Dizdarevic D. Comparing the retention of cast posts cemented with three different kinds of cement. Pesq Bras Odontoped Clin Integr 2010; 10(1):41-5. doi: 10.4034/1519.0501.2010.0101.0007.

7. Ariki EK, Gonçalves MC, Souza ROA, Zamboni SC, Pereira SMB, Takahashi FE, Bottino MA. Influence of different luting protocols on the bond strength of fiber posts to root dentin. Pesq Bras Odontoped Clin Integr 2013; 13(3):265-71. doi: 10.4034/PBOCI.2013.133.07.

8. Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C. Post placement affects survival of endodontically treated premolars. J Dent Res 2007; 86(8):729-34. doi: 10.1177/154405910708600808.

9. Marcos RM, Kinder GR, Alfredo E, Quaranta T, Correr GM, Cunha LF, Gonzaga CC. Influence of the resin cement thickness on the push-out bond strength of glass fiber posts. Braz Dent J 2016; 27(5):592-8. doi: 10.1590/0103-6440201600886.

10. Barcelos LM, Bicalho AA, Veríssimo C, Rodrigues MP, Soares CJ. Stress distribution, tooth remaining strain, and fracture resistance of endodontically treated molars restored without or with one or two fiberglass posts and direct composite resin. Oper Dent 2017; doi: 10.2341/16-224-L.

11. Bacchi A, Dos Santos MB, Pimentel MJ, Caetano CR, Sinhoreti MA, Consani RL. Influence of post-thickness and material on the fracture strength of teeth with reduced coronal structure. J Conserv Dent 2013; 16(2):139-43. doi: 10.4103/0972-0707.108196.

12. da Silva NR, Raposo LH, 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; 104(5):306-17. doi: 10.1016/S0022-3913(10)60146-1.

13. Qing H, Zhu Z, Chao Y, Zhang W. In vitro evaluation of the fracture resistance of anterior endodontically treated teeth restored with glass fiber and zircon posts. J Prosthet Dent 2007; 97(2):93-8. doi: 10.1016/j.prosdent.2006.12.008.

14. Ferreira CB, Graça LFA, Bittencourt RC, Vallado ST, Gouvêa CVD. Stress distribution related to the use of retainers in endodontically treated teeth using the finite element method. Pesq Bras Odontoped Clin Integr 2012; 12(1):41-6. doi: 10.4034/pboci.v12i1.1070.

15. Varghese S, Ariga P, Padmanaban TV, Subramanian R. A finite element termal analysis of various dowel and core materials. Indian J Dent Res 2012; 23(2):176-81. doi: 10.4103/0970-9290.100422.

16. Veríssimo C, Simamoto Júnior PC, Soares CJ, Noritomi PY, Santos-Filho PC. Effect of the crown, post, and remaining coronal dentin on the biomechanical behavior of endodontically treated maxillary central incisors. J Prosthet Dent 2014; 111(3):234-46. doi: 10.1016/j.prosdent.2013.07.006.

17. Hegde J, Ramakrishna, Bashetty K, Srirekha, Lekha, Champa. An in vitro evaluation of fracture strength of endodontically treated teeth with simulated flared root canals restored with different post and core systems. J Conserv Dent 2012; 15(3):223-7. doi: 10.4103/0972-0707.97942.

18. Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM. In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 2009; 101(3):183-8. doi: 10.1016/S0022-3913(09)60025-1.

19. Coelho CS, Biffi JC, Silva GR, Abrahão A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. Dent Mater J 2009; 28(6):671-8.

20. Goncalves LA, Vansan LP, Paulino SM, Sousa Neto MD. Fracture resistance of weakened roots restored with a transilluminating post and adhesive restorative materials. J Prosthet Dent 2006; 96(5):339-44. doi: 10.1016/j.prosdent.2006.08.030.

21. Ge J, Wang XZ, Feng HL. Influence of different post core materials on the color of Empress 2 full ceramic crowns. Chin Med J 2006; 119(20):1715-20.

22. Lazari PC, Oliveira RC, Anchieta RB, Almeida EO, Freitas Junior AC, Kina S, Rocha EP. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite element analysis based on micro-CT data. J Appl Oral Sci 2013; 21(6):511-7. doi: 10.1590/1679-775720130203.

23. Shafiei F, Tavangar MS, Ghahramani Y, Fattah Z. Fracture resistance of endodontically treated maxillary premolars restored by silorane-based composite with or without fiber or nano-ionomer. J Adv Prosthodont 2014; 6(3):200-6. doi: 10.4047/jap.2014.6.3.200.

24. Aggarwal V, Singla M, Yadav S, Yadav H, Sharma V, Bhasin SS. The effect of ferrule presence and type of dowel on fracture resistance of endodontically treated teeth restored with metal-ceramic crowns. J Conserv Dent. 2014; 17(2):183-7. doi: 10.4103/0972-0707.128053.

25. Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of ferrule and post placement on fracture resistance of endodontically treated teeth after fatigue loading. J Dent 2013; 41(3):207-15. doi: 10.1016/j.jdent.2012.10.004.

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

27. Maccari PC, Cosme DC, Oshima HM, Burnett LH Jr, Shinkai RS. Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems. J Esthet Restor Dent 2007; 19(1):30-6. doi: 10.1111/j.1708-8240.2006.00060.x.

28. Pasqualin FH, Giovani AR, Sousa Neto MD, Paulino SM, Vansan LP. In vitro fracture resistance of glass-fiber and cast metal posts with different designs. Rev Odonto Cienc 2012; 27(1):52-7. doi: 10.1590/S1980-65232012000100010.