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Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength

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Abstract

Objectives This study aims to evaluate the fracture resistance of endodontically treated anterior teeth restored with crowns made of composite or ceramic and retained without the use of a post (endocrowns) or with posts of 5 mm (short) and 10 mm in length (long).

Material and methods Forty-eight intact maxillary incisors were selected for the study. After endodontic treatment, the crowns were sectioned 2 mm coronally to the cemento-enamel junction provided with a ferrule of 2 mm. The roots were randomly divided into six groups ($n=8$) according to the post length and type of coronary restoration. The crowns were fabricated with the chairside economical restoration of esthetic ceramics system. Group 1 was restored with a 10-mm glass fiber post, composite core, and a full-coverage ceramic crown (LPCer); group 2, with a 5-mm glass fiber post, composite core, and a full-coverage ceramic crown (SPCer); group 3, with a 10-mm glass fiber post, composite core, and a full-coverage composite crown (LPCpr); group 4, with a 5-mm glass fiber post, composite core, and a full-coverage composite

crown (SPCpr); and groups 5 (EndoCer) and 6 (EndoCpr) were restored with ceramic and composite endocrowns, respectively. The teeth were then thermomechanically loaded in a chewing machine. After fatigue, the specimens were loaded to fracture. Data were analyzed with ANOVA and chi-square test. Mode of failure was defined as repairable or non-repairable.

Results Presence of post, post length, and crown material had no significant effect on the fracture resistance. Groups restored with endocrowns presented a higher number of repairable fractures in respect to the other groups.

Conclusions Presence of a post had no effect on the restorations' fracture strength.

Clinical relevance Although this in vitro study has some limitations in respect to its clinical relevance, the restoration of largely destroyed anterior teeth with the use of an endocrown or a short glass fiber post might have advantages over a large glass fiber post.

Keywords Anterior teeth · Endodontically treated teeth · Fracture strength · Post length

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Introduction

Restoration of endodontically treated teeth (ETT) is compromised primarily because of coronal destruction that results in an increased risk of tooth fracture during function. Before the introduction of adhesion technology in dentistry, the coronal restoration of ETT has been mainly performed with metallic and macromechanically retained posts. In the past, a post length equal to three fourths of the root canal length or at least equal to the crown length was recommended [1, 2]. Metallic posts generated high stresses, often leading to non-restorable root fractures [3]. In order to avoid these problems,

metal-free posts with mechanical characteristics similar to those of dental tissues have been developed. Subsequently, fiber-reinforced post systems were introduced [4, 5]. At present, restoration of posterior ETT with a direct composite without placing any post has been proposed by several authors [6–8]. Moreover, a recent study might show that in largely compromised premolars, no significant differences existed between teeth restored with and without posts [6]. These authors argued that the results were due to the use of an adhesive restorative design.

The fracture resistance of ETT has been reported to be mainly dependent on the amount of the remaining tooth structure, the amount of adhesive surface, and the quality of adhesion [7]. The role of a post in the retention of the core material is particularly relevant for posterior teeth where masticatory loads are essentially compressive. On the other hand, as upper incisors are loaded transversally, the influence of post length on the tooth's flexural behavior is an important issue to be considered in order to reduce tooth fracture [8].

Recent studies have demonstrated that shortening the post length has no negative influence on fracture resistance and may be used in anterior teeth without compromising the apical seal [9–13]. This is because in modern conservative dentistry, the retention of restorations is mainly based on adhesion; therefore, the use of macroretentive elements could be no longer required [14]. While the insertion of radicular posts may often become obsolete in posterior teeth [6], little or no information on anterior teeth has been reported in the literature.

An endocrown is a restorative option for ETT. It consists of a full or compact crown that extends a post into the pulp chamber and/or pulp canals as one unit [15]. It is interesting to note that, to the author's knowledge, this type of crowns on anterior teeth has been evaluated to test how forces are transmitted along the tooth through the finite element analysis (FEA) [16]. No in vitro studies on adhesive restoration of anterior endodontically treated teeth have been tested to analyze fracture strength and mode of failure.

Innovative computer-assisted design/computer-assisted manufacturing (CAD/CAM) technologies have introduced new systems for dental restorations. CAD/CAM system has the advantage of being the only chairside system available.

In addition, its efficacy has been proven in both in vitro and in vivo studies [17–20].

The purpose of the present study was to evaluate the fracture strength and mode of failures between a new model called endocrowns for anterior teeth, a 5-mm glass fiber post and a 10-mm glass fiber post retained crowns made out of ceramic and composite.

The null hypotheses tested were that (1) there would be no effect of post length on fracture strength of devital anterior teeth; (2) there would be no influence of restorative material, i.e., composite or ceramic, on fracture strength; and (3) there would be no difference on fracture patterns of teeth restored with the different groups.

Material and methods

Forty-eight sound upper central human incisors stored in 0.1 % thymol solution for 1 month following extraction were randomly divided in to six experimental groups (Table 1). Bucco-palatal and mesio-distal dimensions and root lengths of all teeth selected were measured using digital calipers. The inclusion criteria were that teeth had to be free of carious lesions with complete and straight roots, as well as no visible fracture lines in the root.

Endodontic treatment

Before endodontic treatment, the root was sealed using a filled light-curing adhesive (OptiBond FL, KerrHawe Neos, Orange, CA, USA). The pulp chamber of each tooth was opened following a standardized procedure, and working length was determined visually by placing a size no. 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) at the apical foramen. Root canals were instrumented using stainless steel K-files nos. 10, 15, and 20 (Dentsply Maillefer) followed by rotary Ni-Ti instruments (ProTaper U®, Dentsply Maillefer) according to the manufacturer's instructions. All canals were prepared up to the F5 rotary file, and instruments were discarded after four canal preparations or if instrument deformation was visible. Root canals were irrigated between each of the instrumentation with 1 ml of sodium hypochlorite at a concentration of 4.2 %. The roots were filled using the warm

Table 1 Description of the experimental groups

Group	Description	Abbreviation
1	10-mm glass fiber post (long)/composite core/ceramic crown	LPCer
2	5-mm glass fiber post (short)/composite core/ceramic crown	SPCer
3	10-mm glass fiber pots (long)/composite core/composite crown	LPCpr
4	5-mm glass fiber post (short)/composite core/composite crown	SPCpr
5	Ceramic endocrown	EndoCer
6	Composite endocrown	EndoCpr

vertical condensation technique (SystemB and Guta-percha Extruder, Elements Obturation Unit™, Analytic Endodontics, Sybron Endo, USA), using calibrated gutta-percha (Autofit®, Analytic Endodontics) and an endodontic sealer (AHplus, Dentsply Maillefer). Then the access cavity was sealed with a light-cured resin reinforced glass ionomer restorative (Fuji II® LC, GC America Inc., Alsip, IL). After a setting period of 48 h, each tooth was fixed on a custom-made metallic holder (Provac FL, Balzers, Liechtenstein) with a self-curing acrylic resin (Technovit 4071, Heraeus Kulzer GmbH, Wehrheim, Germany).

Root preparation, post selection and luting procedure

The crown of each tooth was sectioned 2 mm above the cemento-enamel junction. Gutta-percha was removed with a Reamer size no. 3 (Ivoclar Vivadent, Schaan, Liechtenstein) using a handpiece at 800–1,220 rpm. Dowel spaces were prepared with calibrated diamond rotary cutting instruments specifically designed for the post system used. Endocrown preparation was limited to removal of the pulp chamber, excessively retentive areas, and alignment of the pulpal walls. The canal was deepened for 5 mm (3 mm seated in the root).

The groups were divided according to their post lengths. In groups 1 (LPCer) and 3 (LPCpr), 10 mm of glass fiber posts (FRC Postec Plus, size 3, Ivoclar Vivadent) were used (7 mm seated in the root); gutta-percha was removed, leaving 4 mm of root filling to preserve the apical seal. In groups 2 (SPCer) and 4 (SPCpr), 5 mm of glass fiber posts (FRC Postec Plus, size 3, Ivoclar Vivadent) were used (3 mm seated in the root). Translucent glass fiber posts with a standardized size (FRC Postec Plus, size 3, Ivoclar Vivadent) were selected to be placed in each root canal. In group 5 (EndoCer) and group 6 (EndoCpr), coronal gutta-percha was also removed with a Reamer size no. 3 at the same level as that of groups 2 and 4. Endocrowns were directly prepared with the CAD/CAM system. The canal and core portions were considered as a one-component machined from a ceramic and a prepolymerised composite block (Paradigm MZ100, 3M ESPE, Seefeld, Germany/IPS Empress CAD, Ivoclar Vivadent).

Table 2 show the composition of adhesive system and restorative materials used.

Each post was tried in the root canal and sectioned at the adequate length with a diamond bur. Prior to the luting procedure, the fiber post surface was cleaned with etching gel (K-etchant gel, Kuraray, Japan) for 15 s, rinsed, and air-dried. Silicatization was performed with a 27- μ m silicated Al₂O₃ powder (CoeJet, 3 M ESPE, Seefeld, Germany), and silane (Clearfil Ceramic Primer, Kuraray, Japan) was then applied on the surface of the posts for 60 s. Then, the bonding system (Clearfil DC Bond, Kuraray, Japan) was applied on the post and air-dried for 30 s. All materials used in root canals were

applied using superfine-sized microbrushes (Microbrush® International, Wisconsin, USA). The following bonding protocol was adopted, strictly following the manufacturer's instructions: 37 % phosphoric acid (K-Etchant Gel) was applied to the canal wall surfaces for 15 s and rinsed thoroughly with water for at least 15 s. Excess water was removed from the canal with mild air pressure and paper points (Dentsply Maillefer). The surface was not overdried in order to avoid dentine desiccation. The adhesive system (Clearfil DC Bond, Kuraray, Japan) was dispensed onto a disposable microbrush and immediately rubbed on all root canal surfaces for at least 20 s. The solvent was removed by blowing air gently from a dental syringe for at least 5 s. The posts were then luted with a dual-cured resin cement (Clearfil Esthetic Cement, Kuraray), according to the manufacturer's instructions. The luting cement was applied to the post and to the post space with a superfine-sized microbrush. The posts were seated into the root canals and stabilized, and the cement excess was removed with paper points. Both the adhesive system and resin cement were simultaneously light-cured for 60 s (Demi LED, Kerr Corp. Middleton, WI, USA) directly in contact with the post. In order to ensure an appropriate light intensity, the emitted light was measured before each exposure with the digital radiometer of the light unit.

Core preparation

After luting the posts, the core was prepared with the same adhesive system (Clearfil DC Bond, Kuraray), following the same application technique described above. The core was built up by using a dual-cured core material (Clearfil Photo Core, Kuraray) light-cured for 40 s. Transparent matrices (Hawe Striproll, KerrHawe, Bioggio, Switzerland) were used to confine the restorative material. The core preparation was finished with diamonds burs (Advanced Preparation Set for Cerec Anterior Restorations, Intensiv, Lugano, Switzerland). Dimensions of the test specimen mounted in a resin block are shown in Fig. 1. All crown margins were located in the dentin with a ferrule effect of 2 mm. The anatomical shape was prepared following the chairside economical restoration of esthetic ceramics (CEREC) approach, and the minimum thicknesses recommended for anterior crowns were considered.

Crown design and milling

The prepared abutments were scanned with a camera (CEREC 3D, software V2.40 R1800, Sirona, Bensheim, Germany). In group 5 (EndoCer) and group 6 (EndoCpr), ceramic and composite endocrowns were directly prepared with the CAD/CAM system. After the crown preparation, the surface was uniformly

Table 2 Summary of products used

Material	Product name (manufacturer)	Composition (main constituents)	Application mode	Batch numbers
Fiber post	FRC Postec Plus (Ivoclar Vivadent, Schaan, Liechtenstein)	Glass fibers (70 vol %), dimethacrylate resin matrix (21 vol %), ytterbium fluoride (9 vol %)		35052
Ceramic blocks	IPS Empress CAD (Ivoclar Vivadent)	Components: SiO ₂ . Additional contents: Al ₂ O ₃ , K ₂ O, Na ₂ O, CaO, and other oxide pigments		57343
Composite blocks	MZ100 (3M ESPE, Germany)	Conventional hybrid composite resin, bisphenol A diglycidylether dimethacrylate (bis-GMA), triethylene glycol dimethacrylate (TEGDMA), and ultrafine zirconia silica ceramic particles as filler. Particles have spherical shape and average size 0.6 mm.		20071221
Dual-cure resin-based cement system	Clearfil Esthetic Cement (Kuraray)	<i>Clearfil ceramic primer</i> : 3-MPS, 10-MDP, ethanol; <i>Paste A</i> : Bis-phenol A diglycidylmethacrylate, TEGDMA, methacrylate monomers, silanated glass filler, colloidal silica. <i>Paste B</i> : Bis-phenol A diglycidylmethacrylate, TEGDMA, methacrylate monomers, silanated glass filler, silanated silica, colloidal silica, benzoyl peroxide; CQ: pigments	Apply primer on ceramic and air-dry. Mix equal quantities of pastes A and B. Apply and light cure for 40 s.	13ABA
Adhesive system	Clearfil DC Bond (Kuraray)	K-Etchant Gel Liquid A: HEMA, MDP, bis-GMA, DL-camphorquinone, benzoyl peroxide, colloidal silica. Liquid B: water, ethanol	Etch for 15 s; rinse with water spray and gently dry with air and paper points; mix liquid A and B (1:1); apply with a brush; gently air-dry for 2–3 s.	41119
Buildup	Clearfil Photo Core (Kuraray)	Silanated silica, silanated barium, glass, CQ, bisphenol A diglycidylmethacrylate	Apply on the tooth; light cure for 40 s.	2295BA

10-MDP 10-methacryloxydecyl dihydrogen phosphate, *3-MPS* 3-methacryloxypropyltrimethoxysilane, *TEGDMA* triethyleneglycol-dimethacrylate, *CQ* camphorquinone

covered with an antireflecting powder (Vita Cerec Powder, Vita Zahnfabrik, Bad Säckingen, Germany), and a digital impression was procured with the 3D camera. The digital design and milling of the crowns were performed with the CEREC software. The composite and ceramic crowns were milled from prefabricated blocks (Paradigm MZ100, 3M ESPE, Seefeld, Germany and IPS Empress CAD, Ivoclar Vivadent) with a cylinder pointed bur and a step bur 10. All restorations were milled in Endo mode, and a new set of milling burs was used for each group even though this was not requested by the software.

Tooth/core preparation for the luting procedure

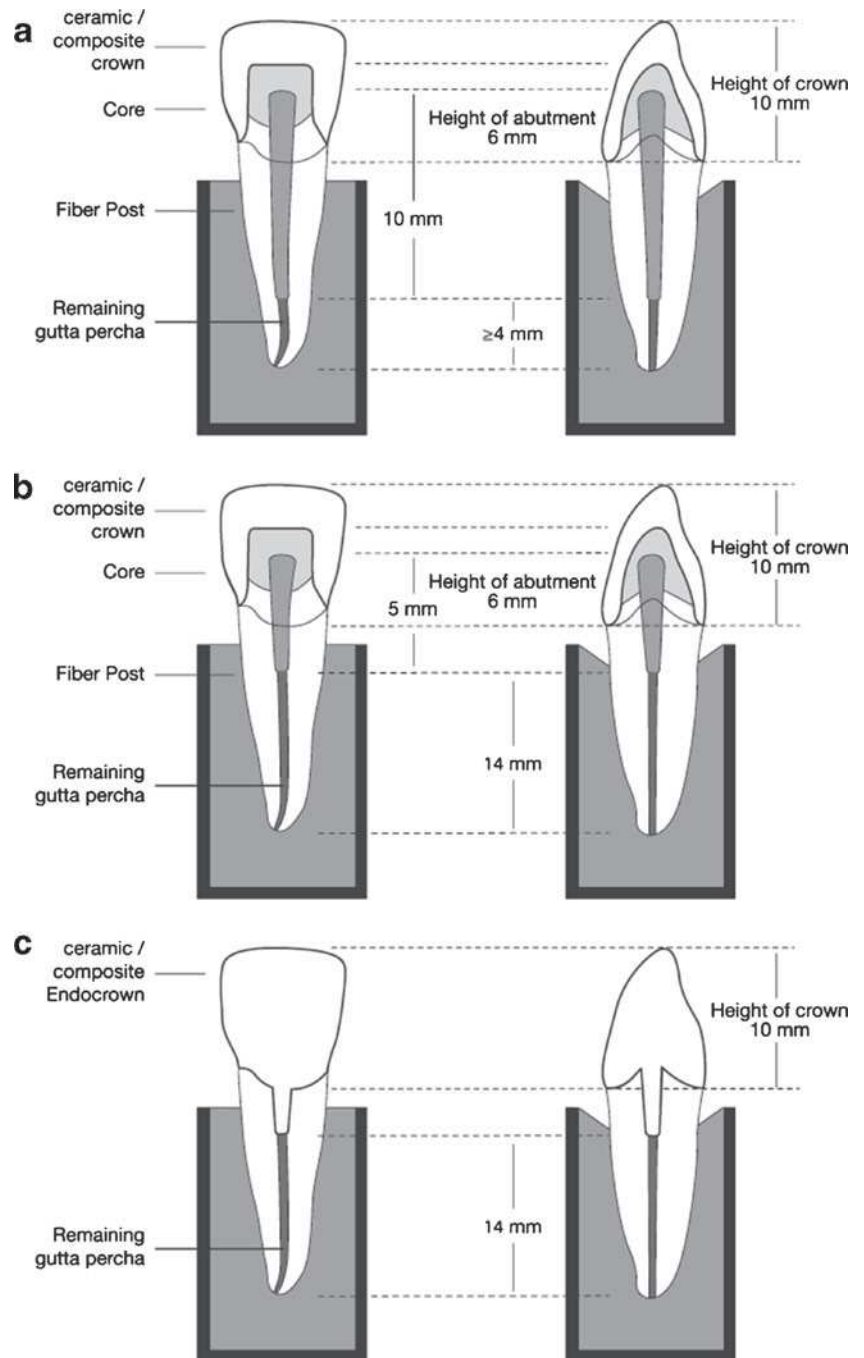
The bonding agent (Clearfil DC Bond, Kuraray) was applied following the manufacturer's instructions: 15 s of dentin etching with 37.5 % phosphoric acid, abundant rinsing, air-drying for 5 s, and application of adhesive agent with a light brushing motion for 20 s. The composite core was treated with airborne particle

abrasion with 27 µm of silicized Al₂O₃ powder (CoeJet, 3M ESPE, Seefeld, Germany). The surface was then rinsed with water for 20 s and air-dried. A silane (Clearfil Ceramic Primer, Kuraray) was applied on the surface and air-dried after an exposure time of 60 s. One coat of adhesive resin (Clearfil DC Bond, Kuraray) was then applied on the surface and left unpolymerized until the application of the luting material.

Crown preparation for the luting procedure

In the leucite-reinforced glass–ceramic groups (groups 1, 2, and 5), the internal surfaces of the crowns were etched with hydrofluoric acid (Vita Ceramic Etch, Vita Zahnfabrik, Bad Säckingen, Germany) for 60 s. Then a silane (Clearfil Ceramic Primer, Kuraray) was applied and blow-dried after an exposure time of 60 s. Lastly, the bonding agent (Clearfil DC Bond, Kuraray) was applied, and excesses were blown out. In the micro-hybrid composite groups (groups 3, 4, and 6), the

Fig. 1 Schematic drawing of a test specimen mounted in a resin block. The dimensions of the tooth preparations, the post-and-core, and the crown are shown for each group restored with large post (a), short post (b), and endocrown (c)



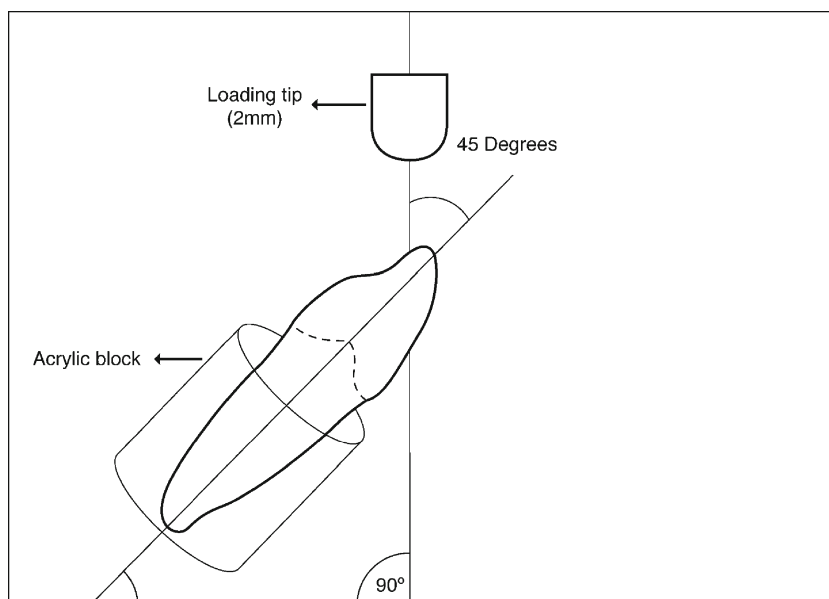
internal surfaces of the crowns were treated with $27 \mu\text{m}$ of silicized Al_2O_3 powder (CoeJet, 3M ESPE, Seefeld, Germany). Then the surface was rinsed with water for 20 s and air-dried. A silane (Clearfil Ceramic Primer, Kuraray) was applied and blow-dried after an exposure time of 60 s. Lastly, the bonding agent (Clearfil DC Bond, Kuraray) was applied, and excesses were blown out. The crowns from all groups were adhesively luted with a dual-cured luting cement (Clearfil Esthetic Cement, Kuraray) and cured with the same light-curing device as mentioned above. All margins were then

finished and polished under $\times 10$ magnification with abrasive disks (Soft-Lex XT, 3M ESPE) and intermittent water spray.

Fatigue test

The restored teeth were loaded on the palatal surface at an angle of 45° with respect to the longitudinal axis of the root (Fig. 2). A computer-controlled chewing machine with 600,000 mechanical cycles at 49 N and 1,500 thermal cycles between 5 and 55°C was used to test fatigue [20].

Fig. 2 Schematic drawing of test specimens subjected to load at 45° in a universal testing machine. Pressure from the rod tip was applied at a crosshead speed of 1 mm/min (3 mm below the incisal edge) on the palatal surface of the crown



Fracture test

After the fatigue test, all groups were subjected to a fracture strength evaluation in a universal testing machine (Instron, model 1114, Instron Corp, High Wycombe, Great Britain). Each specimen was placed in a fixing device, and a controlled load was applied using a stainless steel rod at a 45° with respect to the longitudinal axis of the root. Pressure on the tip was applied 3 mm below the incisal edge on the palatal surface of the crown at a crosshead speed of 1 mm/min. The specimens were loaded until fracture, and the maximum breaking loads were recorded in Newtons (N). The modes of fractures were determined and classified as repairable or non-repairable/catastrophic. Fractures in the incisal third of root, core fracture, and dislodging of post or crowns were deemed repairable, and fractures below were deemed catastrophic.

Statistical analysis

Data were analyzed with statistical Statgraphics Plus 5.1. Fracture strength data were assessed using a multifactorial ANOVA test. Mode to fracture was submitted to chi-square test. The level of confidence was set to 95 % in the two tests.

Results

The results of fracture strength test on loaded specimens are presented in Table 3. All specimens survived the fatigue test, and no loss of retention or pretest fracture was observed.

The influence of the two crown materials (composite vs. ceramic) and the type of post (short, large, and endocrown) on fracture strength was not significant ($P=0.778$).

However, when considering the absolute values, the highest score of fracture strength was attained by the groups restored with endocrowns (552.4 ± 54.4). Endocrowns also showed the maximum load to fracture (662.5 N).

Analysis of fracture patterns observed after the fracture strength test offered interesting information. The numbers of specimens from each group with both repairable and non-repairable fractures are detailed in Table 4. A significantly higher number of non-repairable fractures were observed in groups in which a 10-mm-long post was used (4 repairable vs. 12 non-repairable). With endocrowns and groups restored with the 5-mm-long posts, repairable fractures were observed in 19 specimens, whereas only 13 specimens presented non-repairable fractures ($P=0.0246$). Figure 3 shows representative pictures of two specimens restored with endocrowns and 10-mm posts after the fracture strength test. The groups restored using long posts had catastrophic failures or fractures that could not be repaired intraorally, and therefore, tooth extraction would be necessary. This was not the case in the group restored with endocrowns.

Table 3 Results of fracture strength for post type and crown material. Mean and SD expressed in Newtons. Minimum and maximum loading forces registered for each group. Note that no significant differences between post type (short post, endocrown, and long post) and crown material, i.e., composite and ceramic, were observed ($P=0.778$)

Type of restoration	Mean±SD	Minimum	Maximum
SP	470.9±55.2	359.2	582.6
Endocrown	552.4±54.4	442.3	662.5
LP	432.6±55.3	320.6	544.6
Ceramic	483.1±46.2	389.6	576.6
Composite	487.5±42.4	401.7	573.4

Table 4 Statistical analysis of mode of fracture (reparable or unreparable). A significantly higher number of non-reparable fractures were observed in groups in which long post was used (4 reparable vs.

12 non-reparable). With endocrowns and short post, reparable fractures were observed in 19 specimens, whereas only 13 specimens presented non-reparable fractures

Group	Number of specimens with repairable fractures	Number of specimens with non-repairable fractures
LP	4 (2 fractures on incisal third of the root)	12
SP + Endo C	19 (2 fractures on incisal third of the root)	13

Discussion

The purpose of this *in vitro* study was to evaluate the fracture strength and failure types of endodontically treated anterior teeth restored with endocrowns and short-post and long-post retained crowns. The fracture strength evaluation was performed on previously fatigued specimens. The fatigue test was carried out with thermomechanical loading in a chewing machine that tries to closely simulate the clinical situation [21, 22]. The chewing force was applied to the specimens at 45° to the tooth long axis, in accordance with publications about fatigue testing followed by fracture strength test of anterior teeth [5]. The artificial chewing cycle (duration, force profile, and frequency) was designed to correspond as closely as possible to physiological conditions [23–25].

All specimens survived the fatigue test, and no loss of retention or pretest fracture was observed; no fracture of the root, post and core and no loss of crown occurred during the fatigue test, and all teeth could be used to fracture strength test.

In the present study, no artificial periodontium was placed around the abutment roots; the silicone is not standardizable and varies between 300 and 700 µm, which leads to uncontrolled and unstandardized mobility of the abutment teeth. In the clinical situation, increased mobility is only present in teeth that are severely periodontally compromised with a loss of attachment of six or more millimeters [26].

Several studies evaluated the mechanical resistance of endodontically treated teeth, in particular, of upper incisors [27–32]. Most of these studies included specimens with

different types of posts. It has been suggested that posts with a high elastic modulus such as metallic ones could improve the bending resistance of restored teeth by opposing their stiffness to the bending stresses arising from function [33]. However, a post with a high elastic modulus could be more prone to cause unrepairable fractures. This is why the use of posts with lower elastic modulus such as glass fiber ones have been proposed by several authors [34–36]. The advantage of glass fiber posts is that they are able to improve the bending resistance and that failures, if they occur, are more easily restorable. In addition, they have a modulus of elasticity similar to dentin. When they are submitted to loading, they can better absorb the forces concentrated along the root, thus reducing the probability of fracture [37, 38].

When the FEA was used, a favorable performance of endocrown restorations was observed [16, 39, 40]; however, this type of study evaluates how forces are transmitted along the tooth and depends on the computer-generated model. The models used in this type of study deviate from reality in several aspects and compare the stress distribution patterns of a sound tooth with teeth restored with different material configurations. This computer evaluation needs further laboratory and clinical research to prove its efficacy.

The modulus of elasticity is approximately 65.4 GPa for IPS Empress CAD and 16 GPa for MZ100 blocks, whereas the flexural strength is 160 MPa (ISO 6812) for IPS Empress CAD blocks [41] and ranges between 140 and 150 MPa for MZ100 [42]. These similar values of flexural strength may have influenced the results of this study, as will be further discussed in this section.

No significant differences could be detected between the composite and ceramic restorations either (Table 3). The similar values of flexural strength between ceramic and composite and the ferrule effect provided by 2 mm of dentin may account for the present findings. The importance of preserving a minimum amount (2 mm) of coronal dentin height after preparation on the fracture resistance and prevention of root fracture on ETT has been reported in various studies [43, 44]. It has been reported that when the ferrule effect is present, stresses are redistributed in the outer surface regions of the coronal third of the root, thus a possible fracture in this area can be repairable. When the ferrule is absent, occlusal forces must be supported by a post that may

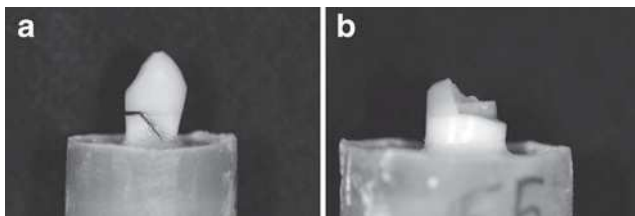


Fig. 3 Detail of fracture pattern (reparable or non-reparable) observed in teeth restored with long posts (a) or with endocrowns (b) after the fracture strength test. Fractures in the incisal third of root, core fracture, and dislodging of post or crowns were deemed reparable (b), and fractures below were deemed catastrophic and, thus, non-reparable (a)

fracture, and a vertical root fracture may occur. Fatigue studies have clearly demonstrated the importance of tissue conservation and the presence of a ferrule effect to optimize tooth biomechanical behavior [10, 35, 45]. In the present study, each tooth was prepared with a severe loss of coronal tooth structure preserving 2 mm of ferrule effect; the area of load application has also been widely described as one of the paramount factors to achieve reliable laboratory results [33, 46, 47]. The position of loading site seems to influence the results on failure mode, particularly in relation to the position of the post. It is important to know that anterior teeth are responsible for tearing and functional guidance [47]. It has been well documented that fracture resistance of teeth depends on the angle of applied load, since axial forces are less detrimental than oblique forces [27]. As a consequence, the restored anterior teeth were loaded on the palatal surface at an angle of 45° with respect to the longitudinal axis of the root.

The findings of our study indicate that restorations may be possible without the use of a post. This is an advantage because more tooth substance is preserved, and the clinical procedure may be easier to achieve. Ferrule lowers the impact of the post and core system, luting agents, and the final restoration on the performance of ETT [48].

According to the results of this investigation, the two first null hypotheses stating that the post length has no effect on the fracture strength of devital anterior teeth, and that there is no influence of the restorative material, i.e., composite or ceramic, on the fracture strength have to be accepted. Recent studies have demonstrated that shortening the post length on the posterior teeth has no negative influence on fracture resistance and may be used without compromising the apical seal [9–12]. No differences were detected in the fracture strength scores of specimens restored either with an endocrown, a short post (5 mm), or a long post (10 mm). Based on our findings, the increase in post length did not increase the fracture resistance. This would mean that shorter posts might be used in anterior teeth. Contrary to our findings, significantly higher values of fracture resistance have been recently observed in groups restored with 10-mm-long glass fiber posts with respect to shorter post lengths [49]. However, their material and methods were different; metallic crowns were cemented with phosphate-based cement. Because non-adhesive anterior restorations were used to restore these teeth, it is reasonable to have better results with a long post, as these restorations are macromechanically retained. In addition, most studies used non-fatigued specimens; therefore, extrapolation of their results to those of our study may not be appropriate. The literature documented that coronal coverage significantly reduced the risk of tooth

fracture in teeth subjected to root canal treatment, so cuspal coverage have to be considered [10–12, 47, 48].

The findings of our study suggest that restoration of anterior teeth may be possible without the use of a post. This is an advantage because more tooth substance is preserved, and the clinical procedure may be easier to achieve. Ferrule lowers the impact of the post and core system, luting agents, and the final restoration on the performance of ETT [48].

The third null hypothesis that there is no difference in the fracture patterns of teeth restored with an endocrown, short post, and long post has to be rejected. Our results showed that groups restored with a long post presented fractures located in areas where intraoral repair is impossible, which means that, in clinical reality, the tooth must be extracted. This was not the case when short posts or endocrowns were used, as shown in Fig. 3.

From a clinical point of view, since endocrown restorations are fabricated from a single block, they have the advantage of reducing the interface of the restorative system. The clinical implication of this finding is important, as restorable root fracture prolongs the clinical longevity of endodontically treated teeth. Results obtained by the present study reinforce the advantages that have been presented in the clinical experiences of various authors on posterior teeth. Endocrowns and crowns with a short post are mechanically superior to conventional crowns with a long post [50]. Endocrowns are easy to make, cost less, and demand less clinical time when compared with conventional crowns with short and long posts. Through elimination of the post and filling core, the number of bond interfaces is also reduced. However, *in vitro* tests are known to have limitations in producing the mechanisms responsible for the occurrence of clinical failure. Nonetheless, the use of endocrowns has other technical limitations: the remaining pulp chamber should be of sufficient width and depth to provide adequate bulk and retention of the restoration, and an adequate dentin thickness around the pulp chamber is required for the tooth restoration continuum rigidity and strength [15, 51].

The most important task of conservative therapy is to restore a non-vital tooth which can resist fatigue forces without failures such as root fracture, structural failure of the post itself, or loss of retention. Preservation of coronal dental tissue, the use of dowels with elastic properties similar to dentine, and effective post adhesion are the principal factors for successful restorations of endodontically treated teeth.

We have demonstrated that anterior teeth can be restored with an endocrown or by using a short post. Nevertheless, *in vivo* validation of this finding is necessary before this technique can be safely recommended for clinical use.

Conclusions

The use of endocrowns or a short glass fiber post with an adhesive crown is sufficient for the restoration of largely destroyed anterior teeth provided with a ferrule effect of at least 2 mm. Coronal restorations with endocrowns and short posts were associated with repairable fractures, whereas long posts induced catastrophic failures under load. As no significant differences were observed between restorative materials, crowns fabricated from machinable composite resin blocks are a viable alternative to all-ceramic crowns for the restoration of anterior endodontically treated teeth.

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Conflict of interest The authors declare that they have no conflict of interest.

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