Comparison of resistance to fracture between three types of permanent restorations subjected to shear force: An *in vitro* study

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Abstract

Introduction: Our study's objective was to compare resistance to fracture between endocrown and conventional post and core restorations when subjected to shear force.

Materials and Methods: Thirty human mandibular premolars were extracted for orthodontic reasons, endodontically treated, and restored using three different methods: endocrown, glass fiber post and composite resin core, and metal post. All the crowns were made from IPS e.max ceramic. Shear forces were applied to these restorations using a test machine until breakage. Load and displacement were recorded every 0.1 s.

Results: No significant difference was observed in resistance to fracture between glass fiber post and metal post. No relationship between the displacement of prosthetic dental system and type of material used was uncovered and by comparing the type of fracture with the restoration material used. However, a greater number of favorable fractures were observed in the glass fiber group whereas most of the fractures in the endocrown and metal post groups were unfavorable.

Conclusion: Endocrown displays better resistance to fracture compared to conventional post and core restorations. In addition, endocrown did not show more displacement or cause more unfavorable fractures than the conventional restorations. This restoration may represent a reliable alternative for restoring a damaged, endodontically treated tooth.

Keywords: Endocrown, glass fiber post, metal post, shear force

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INTRODUCTION

With the advances today in cementation techniques, there is an increasing trend toward adhesive restorations. It is now even possible to etch ceramic, provided that it is reinforced by leucite or lithium disilicate. The ceramic can then bond to different cements.[1]

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The first scientific study focused on endocrowns was conducted by Pissis[1] and published in 1995.

The endocrown, as proposed in 1999 by Bindl and Mörmann,[2] is an indirect restoration that is cemented as a

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single piece so as to sit in the pulpal chamber of a severely damaged endodontically treated tooth.

An endodontically treated tooth is a weak tooth for several reasons:

1. Dehydration. However, according to Huang *et al*.,[3] there is no significant loss in resistance to traction and compression after a tooth has been endodontically treated Water loss only concerns free water and not the water bound to the collagen. According to Papa *et al*.,[4] it accounts for only 9% or less of total water, so the loss is not significantly great. What is more, Sedgley and Messer[5] have shown there to be no change in the elastic modulus or hardness of dentin after endodontic treatment
2. Loss of dental substance, not only due to carious disease but also to the access cavity for endodontic treatment, also weakens an endodontically treated tooth. According to the study by Reeh *et al*.,[6] the loss of the marginal ridges reduces dental resistance by 63%. This is due to a rupture in the continuity of the peripheral circle of the tooth, which may result in flexion and so in microfractures or microinfiltration since it creates a gap in the edges of our restoration
3. An endodontically treated tooth suffers deterioration in its neurosensory feedback system following removal of the pulp tissue. This seems to reduce the endodontically treated tooth's protection against masticatory forces.[7]

The questions that we investigated were the following: "What impact does the length of the post have? What are the role and consequences of the type of material chosen?" Our main objective is to attempt to compare the fracture resistance of premolars that were extracted, endodontically treated, and restored using three different prosthetic methods when they were subjected to a load-simulating shear forces.

By means of this study, we have attempted to outline the scenarios, in which it is better to use an endocrown rather than a conventional restoration, in addition to highlighting this technique's limitations.

MATERIALS AND METHODS

The mandibular first premolar was selected to standardize our experiment as much as possible by performing it on single canal teeth.

Overall, thirty human mandibular first premolars extracted for orthodontic reasons were selected for their absence of caries, fracture, cracks, or periapical lesions. They were preserved in normal saline solution following extraction. The Ethics Committee's approval had been granted to us beforehand.

The dental crowns were sectioned up to 1 mm from the cementoenamel junction so that our edges remained supragingival. The teeth then underwent complete endodontic treatment using the ProTaper NEXT System (Dentsply Maillefer, Ballaigues, Switzerland) and finishing with the X2 file so that all specimens had the same cone shape in the canal. The canals were filled using gutta-percha cones that were tailored to the ProTaper NEXT system, that matched the cone shape of the prepared canals, and whose tip diameter was calibrated to the master apical file. RoekoSeal Single Dose Sealer (Coltene Whaledent GmbH, Altstàtten, Switzerland) was used to fill the canal by hybrid compaction, which comprised finger spreader compaction in the apical third, followed by thermomechanical compaction using a Gutta compactor. The root canal irrigant used was a 4% (or 12°) concentration of sodium hypochlorite.

The teeth were divided into three groups (n = 10): Group 1: (all ceramic endocrown), Group 2: (glass fiber post + composite resin core + ceramic crown), and Group 3: (cast post and core + ceramic crown).

Figure 1a-c illustrates the different prosthetic pieces that made up the restoration system of each group.

For Groups 2 and 3, the filling material in the dental canals was partially removed (by half relative to the length of the root) using Gates–Glidden III and II drills. The post space was prepared by the drills provided by manufacturer (3M ESPE) according to their protocol; half (50%) of the gutta-percha proportionally to the root canal length of each tooth individually was removed to standardize.

Group 1 did not undergo this step. However, we ensured for Group 1 that there was a depth of 3.5 mm between the supragingival plateau, and the bottom of the cavity made by the filling material so that the pulp chamber was able to provide at least some hold for the crown [Figure 1a]. The endocrown preparation consisted of a circular supragingival butt margin with a depth of the central retention cavity of 3.5 mm from the cavosurface margin with round internal line angles. Diamond flat disc (4 mm diameter) to reduce the height of the occlusal surface was used. Alignment of the pulpal walls was made with a cylindrical-conical (green diamond bur) without touching the pulpal floor. The circular thickness was 2 mm. The supragingival height was 1 mm above the cementoenamel junction.

The size and preparation of the teeth are shown in Table 1.

The metal cores and the crowns were made directly on the models.

The cast posts were sculpted in wax and then transformed into nonprecious metal (Wirobond C Cobalt-chrome). The composite and metal cores measured 4 mm in height for the 20 specimens [Figure 1b and c].

The ceramic was pressed from the all ceramic IPS e.max (Ivoclar Vivadent, Liechtenstein) after the crowns had been sculpted in wax. The lost wax technique consists of placing the structure in an oven whose temperature reaches 1200°C to melt the wax and preserve an impression or negative of the crowns in the investment material.

For the cementation step, the same resin cement (PANAVIA kit, a self-adhesive cement) was employed for cementing the prosthetic pieces in the three groups. The PANAVIA (PANAVIA SA Cement Plus; Kuraray Noritake, Tokyo, Japan) dual-cure (i.e., both photopolymerizable and auto polymerizing) cement was used. This cement is known for its attractive properties, including high resistance to shear forces.

Composite resin cores (3M ESPE Filtek Supreme XTE; St. Paul, MN, USA) were made after the dental surfaces had been etched using the MR2 technique with 37% phosphoric acid (for 30 s on the enamel and 15 s on the dentin) and with OptiBond Solo Plus (Kerr, Orange, USA), an agent that acts as both primer and adhesive. After 20 s of photopolymerization, the composite was shaped to produce the cores as well as 1 mm-wide peripheral edges for all of the specimens. The steps involved in cementing are shown in Table 2.

Figure 2 shows the apical radiographs taken after the prosthetic pieces had been cemented in place.

The restorations were subjected to a fracture test by exerting a static load at a crosshead speed of 1 mm/min to the center of the vestibular cusp using a test machine. The stress was applied to the same point in all specimens. Before this, to obtain uniform positioning for all the specimens, a laser (Candulor Statik Laser) simulated the future point of impact of the force on the tooth. The root of each tooth was plunged into a resistant thermally polymerizable resin (Novodur resin by Novodent Ets, made of powder and liquid placed in a pot under a 2.5 bar pressure; Eschen, Liechtenstein).

Table 1: Preparation and limits

Groups	Limits	Burrs
Endocrown	Flat surface, supra-gingival	Diamond wheel
Fiber and metal core	Strapping, chamfer	Diamond wheel + diamond burr

Table 2: Steps and protocol, depending on the substrate

Substrates	Prior treatment I	Prior treatment II	Localization d' injection
Tooth or post (fiber or metal)	Primer teeth 20 s	____	Tooth or post (fiber/metal)
Ceramic (endocrown)	Fluorhydric acid 2 min, rinse 1 min	Primer ceramic plus, drying	Intrados + tooth
Fiber post	K-etchant 5 s, rinse and drying 5 s	Primer ceramic plus, drying	Root + post
Metal core	Laboratory sandblasting	Primer ceramic plus, drying	Root + core

K-etchant: Phosphoric acid at 35% + colloidal silica, Primer: Clearfil ceramic primer plus, Lamp: BLUE LED (800-1400 mW/cm^2), ____: Nothing, Fluorhydric acid 9.6% (Watertown, MA 02471 USA)

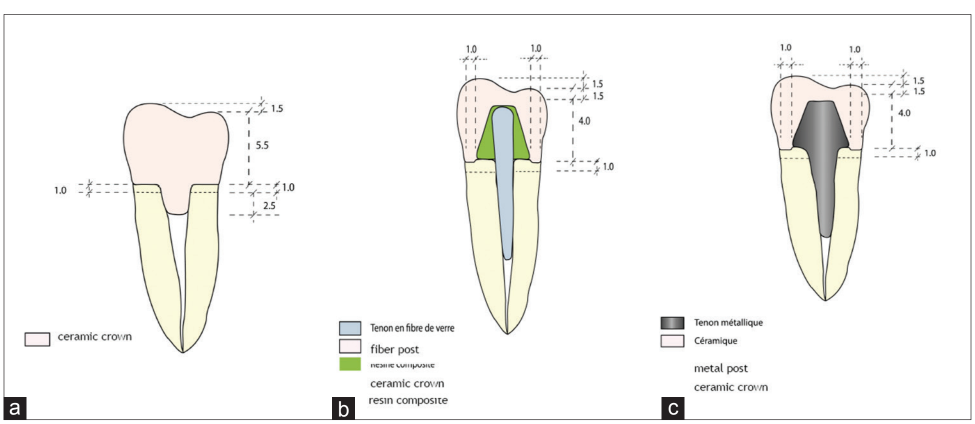

Figure 1: Schema illustrating crown-endocrown (a), fiber post and resin composite (b), and metal post restorations, (c) and their dimension

Each tooth was placed into a machined steel cylinder which acted as a base. The junction between the tooth and the prosthesis was 2 mm above the resin base [Figure 3a]. The base was placed in a device so as to simulate shear forces [Figure 3b]. Standing in its base, each tooth tilted 45° relative to the vertical. The Instron 5585 test machine delivers a load expressed in newtons and detects the exact moment of fracture by stopping the compression. Load and displacement were recorded every 0.1 s.

Results obtained for the load are depending on the moment of fracture for each system (restoration + teeth). The force value required to cause failure was recorded

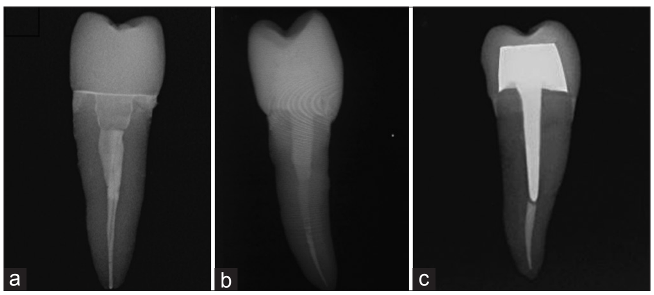

Figure 2: Apical radiography of bonded endocrown (a), fiber post, (b) and metal post (c)

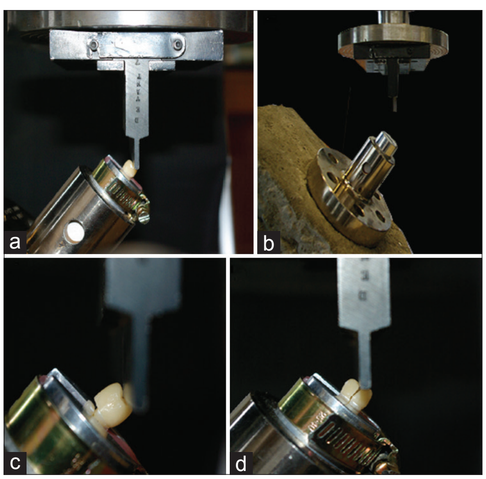

Figure 3: Picture of the tooth at 45°, with the prosthodontic-dental junction, emerged at 2 mm, after positioning the tooth (a) and before testing (b). Irreversible fractures (crown and root) from endocrown group (c and d, respectively)

for each specimen in Newton. The maximum load obtained was recorded at the moment of the fracture. The load was applied at a 45° angle to the long axis of the tooth, on the internal and central face of the vestibular cuspid of all ceramic restorations (this point was marked by a pen).

The values obtained and fracture modes were noted and submitted to statistical analysis by means of the IBM SPSS Statistics program (version 23, IBM, Boston, MA, USA).

RESULTS

The results obtained for each group have been provided in Tables 3 and 4. In the endocrown group, specimens 9 and 10 were excluded following a handling error.

Statistical analysis revealed the role played by the material used (ceramic, glass fiber or metal) on load and displacement by means of the Games–Howell test. Student's *t*-test found a relationship between the length of the post (short, long) and load/displacement. The Chi-square test showed there to be no link between the length of the post and type of fracture but did make it possible to compare the three groups according to type of fracture.

Effect of material used on load and displacement values: because one-factor (material) analysis of variance (ANOVA) was significant ($P = 0.011$), we compared the means of the groups' loads in a pairwise fashion using the Games–Howell procedure since the variances between the groups were also significant ($P = 0.014$).

Effect on load: the parametric test showed no significant difference between the glass fiber and metal groups [$P = 0.963$; Figure 4a]. When the endocrown was compared against the glass fiber group, a highly significant difference was found [$P = 0.018$; Figure 4b]. Similarly, a highly significant difference was found for 7 the endocrown versus the metal post group [$P = 0.015$; Figure 4c].

When we examined absolute values [Table 4], the mean of the loads withstood before rupture was highest in the group

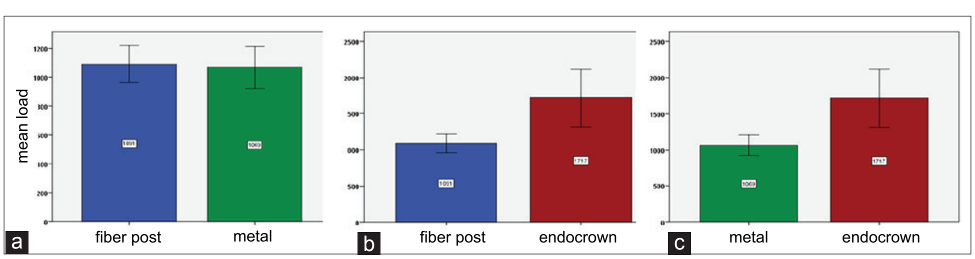

Figure 4: Mean load comparison between fiber post and metal core (a), fiber post and endocrown (b) and metal core, and endocrown (c)

with endocrown restorations [1717.17 ± 481.13; Figure 5, upper panels]. The endocrown group achieved the highest load [2414.97 N, Table 4].

This shows that using a single-piece ceramic restoration results in better resistance to fracture compared with conventional restorations made of different materials [glass fiber and metal; Figure 5, upper right panel]. This may be due to the fact that there was greater occlusal ceramic thickness with the endocrown than with the conventional post and core restorations.[8]

The composite resin post and core and metallic cast core showed no significant difference regarding their resistance to fracture. However, the mean of the maximum loads before fracture was higher in the glass fiber + composite resin group.

Table 3: Maximum load and displacement results when breaking for each group

Samples	Endocrown		Metal core		Fiber post	
	Maximum load (*n*)	Deplacement at maximum load (mm)	Maximum load (*n*)	Deplacement at maximum load (mm)	Maximum load (*n*)	Deplacement at maximum load (mm)
1	2279.02	2.35	1491.23	2.78	907.42	2.53
2	1206.59	1.96	949.33	1.22	1018.43	1.50
3	1798.11	1.74	1143.40	1.79	1045.01	2.18
4	1707.53	1.10	1119.48	1.29	1274.50	1.63
5	1873.33	2.12	1158.36	1.01	1235.21	1.54
6	2414.97	2.35	1099.81	1.96	1153.41	1.74
7	1071.98	1.31	1150.75	1.43	1141.52	1.23
8	1385.84	1.40	908.63	1.68	1123.55	1.41
9	694.46	1.05	749.86	1.39	1298.42	1.18
10	____	____	917.31	0.96	713.67	0.91

____: Nothing

Table 4: Summary of the mean values, standard deviation, median standard error, minimum load, and maximum load for each group

Groups	Samples	Mean±SD	Median	SE	Minimum load	Maximum load
Endocrown	8	1717.17±481.13	1752.82	170.10	1071.98	2414.97
Fiber post	10	1091.11±179.03	1132.54	56.61	713.67	1298.42
Metal core	10	1068.82±201.90	1109.65	63.85	749.86	1491.23

SD: Standard deviation, SE: Standard error

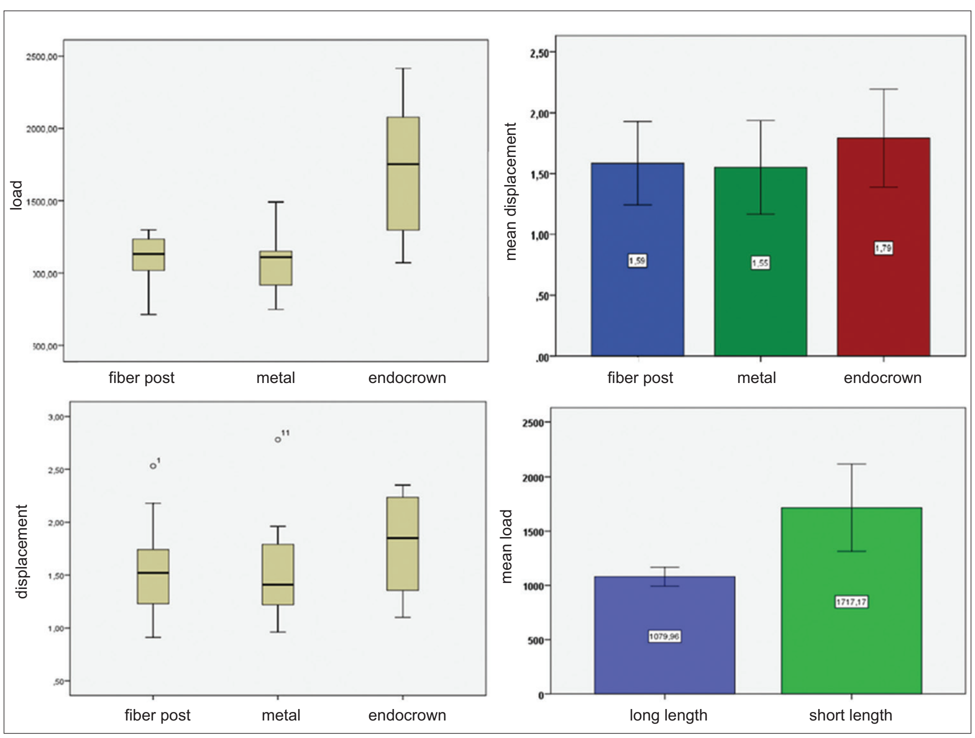

Figure 5: Effect of the load (upper panels) and displacement (lower panels) values for each type of restorations

Effect on displacement: according to ANOVA, no significant difference was found between the groups ($P = 0.569$).

Using an all-ceramic restoration rather than metal + ceramic or resin + glass fiber + ceramic did not influence the displacement of the prosthetic dental system [Figure 5, lower panels].

Effect of the length of the post on load and displacement values: Our analysis considered the endocrown group to have a "short" post and the other two groups to have a "long" post.

Effect on load: according to Student's *t*-test, a significant difference existed between the endocrown group and the other two groups taken together [$P = 0.007$; Figure 6a]. Therefore, a "short" post may withstand a greater load before breaking than a "long" post.

Effect on displacement: no significant difference was observed between the two groups [$P = 0.288$; Figure 6b]. Hence, no link appears to exist between the length of the post and displacement of the prosthetic system.

Effect of the length of the post on the type of fracture: the post lengthhad by far no effect on the type of fracture (favorable, unfavorable) ($P = 1.00$) according to the Chi-square test [Figure 6c and d].

Thus, we may conclude that a short post does not lead to more unfavorable fractures than a long one. An unfavorable fracture is a root fracture that compromises the tooth and makes extraction necessary.

A favorable fracture is defined as a favorable fracture, i.e., a fracture that leaves the root intact, so the root does not need to be extracted. Nonetheless, it should be kept in mind that removing a post for repair may result in even greater damage and cause a possible fracture of the root.

In the endocrown group, two detachments were noted on the side opposite the force exerted. One was accompanied by root fracture [Figure 3c]. With specimen 6, a fracture of the endocrown occurred which left the "post" in the pulp chamber without fracturing the root. In the group with glass fiber posts, most of the fractures occurred in the restoration (oblique fracture of the ceramic + composite core + coronal portion of

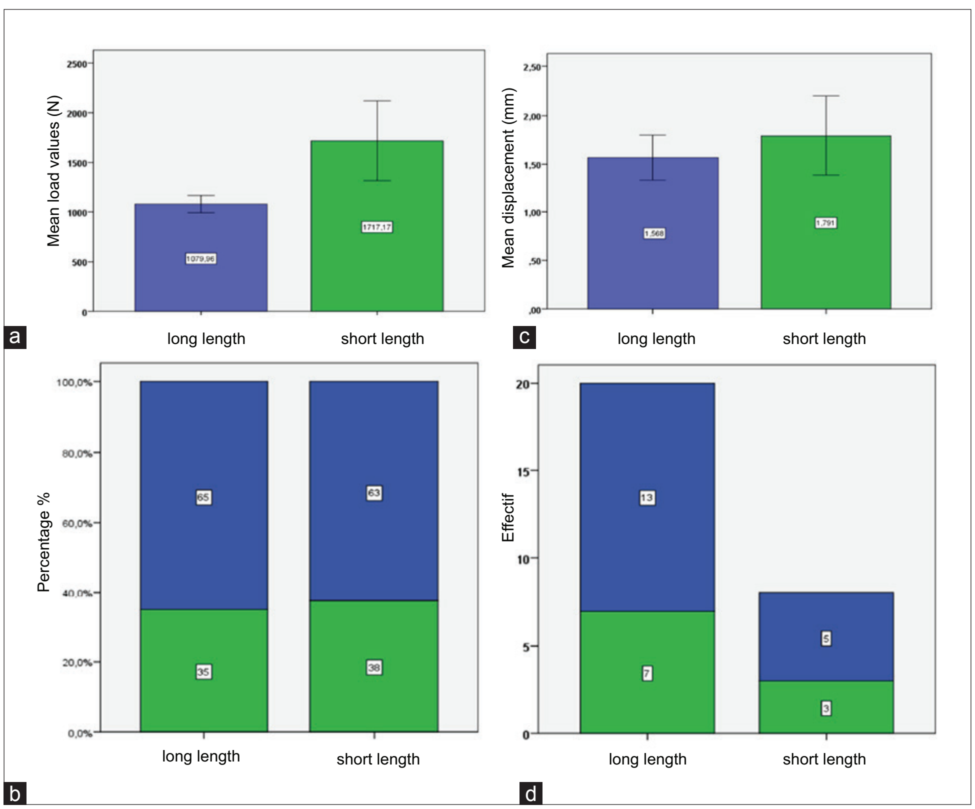

Figure 6: Effect of the post length on load and displacement (a: mean load values, b: mean displacement values) and effect of the post length on the type of fracture (c and d: favorable vs. unfavorable). (c) favorable and unfavorable fracture percentages have been calculated as 100% (as "short length" group has eight samples). (d) favorable and unfavorable fracture rates (*n* = 8 for the endocrown group and *n* = 10 for the other two groups). Blue: Defavorable fracture, green: Favorable fracture

the glass fiber post) leaving the root portion of the glass fiber post and the root intact.

In the group with metal posts, most of the fractures were unfavorable; in other words, the fractures were oblique, beginning in the neck and extending into the coronal two-thirds of the root. However, no metal core fractured. A classification of the type of fracture for each group is shown in Table 5.

Effect of the material used on the type of fracture: When the glass fiber and metal post groups were compared, a Chi-squared test showed there to be no significant difference between them [P = 0.057; Figure 7a]. The difference was nearly significant. We may therefore conjecture that the material (glass fiber, metal) influences the type of fracture (favorable, unfavorable). Moreover, an overrepresentation of favorable fractures (6/10) was noted in the glass fiber group, as well as an underrepresentation of favorable fractures (1/10) in the metal post group [Figure 7b].

When the endocrown and glass fiber post were compared, there was no significant difference according to the Chi-square test [P = 0.370; Figure 7c]. When the endocrown was compared with the metal post, there was also no significant difference (P = 0.303) according to the Chi-square test [Figure 7d]. Hence, it is better to use a glass fiber post than a rigid metal post because the glass fiber post results in fewer unfavorable fractures, probably because its elastic modulus is closer to that of dentin in the root canal. Thus, metal posts and ceramic "posts" cause

Table 5: Fracture classification for each group

Groups	Number of favorable fractures	Number of unfavorable fractures	Unfavorable fracture description
Endocrown	3	7	2 loosening
Fiber post	6	4	Restoration fracture, root unbroken
Metal core	1	9	Restoration fracture, root unbroken

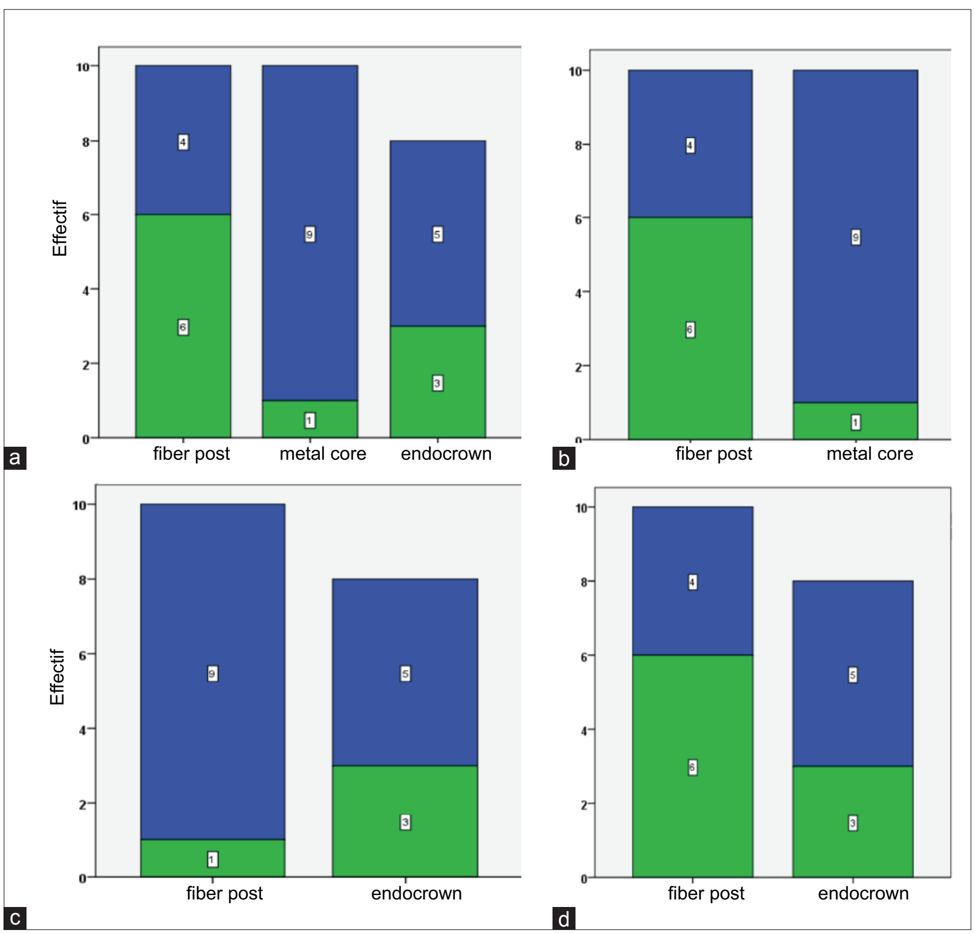

Figure 7: Effect of the material: on the type of fracture (a), the fracture rates comparing the post length (fiber/metal; b), the fracture rates comparing the fiber post length and the endocrown (c) and the fracture rates comparing the metal core length and the endocrown (d). Blue: unfavorable fracture, green: favorable fracture

more unfavorable fractures. No fracture of the metal core could be seen. It was the ceramic crown and tooth which usually fractured. However, in unfavorable fractures in the composite core group, it was the core that fractured.

DISCUSSION

Our results could be improved by providing an effective system that can simulate the presence of the periodontal ligament. In our case, we did not wish to simulate it using an impression paste because the material may be much too thick compared to reality, and so compromise our results. In addition, the paste's thickness cannot be standardized since it varies between 300 and 700 μm. This cannot be controlled *in vitro*.[9] Because the temperature in the mouth is higher than that in our experiment (23°C), relatively different results would probably have been observed given that the properties of materials change with temperature. Whereas a static load was applied in our study, cyclic loads are applied in the mouth.

The endocrown is indicated when there is excessive loss of coronal dental structure and limited freeway space, which makes it impossible to obtain sufficient ceramic thickness to cover the metal or composite resin core.[1]

Future clinical crowns will have to be relatively low, depending on the freeway space. Indeed, according to the study by Hasan *et al*.[10] that analyzed the distribution of stress on endocrowns when the load was applied at four different heights (5, 6, 7, and 8 mm), the stress and deformation increased as the load was applied further and further from the junction between the tooth and restoration. In other words, the higher the crown, the greater the stress, and deformation since the lever arm increases.

When the roots are relatively short, destroyed, damaged or weakened, post and core restoration may further enfeeble the root.

An endocrown is indicated for premolars when the cementation surface area is sufficient that is when there remains 1–2 mm of wall above the gums to enable proper cementing, when the walls are 2 mm or more thick, and when the pulp chamber is at least 3 mm deep.[11]

Endocrowns are contraindicated if adhesion cannot be carried out, if the depth of the pulp chamber is <3 mm, and if the thickness of the peripheral walls is <2 mm.[11]

Endocrowns are contraindicated in an unfavorable occlusal setting (parafunctions).

The endocrown is a restoration that offers several advantages:

The gain in time is notable because the preparation involves fewer intermediate steps, as well as fewer laboratory steps than conventional restoration, which requires manufacturing the cast core, putting a provisional crown in place, and manufacturing a prosthetic crown. This increases the chances of bacterial infiltration and therefore, of recurrent infections in the endodontic system.[12]

The procedure is also simple and less costly for the patient.

According to Bouillaguet and Rocca, placing a post in the root canal does not increase the mechanical resistance of the root, but it does contribute to weakening the root, thus increasing the risks of root fracture.[12] Dietschi *et al*.[13] and Biacchi and Basting[14] have shown that the only role played by the post is in retaining the prosthetic crown.[1] What is more, finite element analyses conducted by Dietschi *et al*.[13] and Zarone *et al*.[15] show that a solid post strengthens the tooth in the cervical region only and that it plays no part in strengthening the tooth's rigidity.

It is also a less mutilating procedure and is less invasive than post and core restorations because the pulp floor (which has a saddle shape in molars) provides good stability in addition to the quality of the adhesive materials when conditions are met. That is why, a post, which may weaken the root canals because of the dental structure lost during drilling, is no longer needed according to Fages and Bennasar.[11]

Preserving the periodontium by remaining above the gum presents the advantage of facilitating the taking of an impression and of retaining a quantity of residual dental structure.

In conventional restorations, there is a risk of perforating the root while unfilling the canal. There is no such risk with endocrowns.

There are also fewer adhesive interfaces: conventional restorations with root posts have two interfaces whereas endocrowns have one. This makes the restoration less susceptible to the damaging efffects of deterioration of the hybrid layer.[2] According to the study by Zarone *et al*.,[15] using different nonhomogeneous materials together results in a greater concentration of stress. Several interfaces between materials of differing elastic moduli represent weak points in the restoration system.

According to the study by Hasan *et al*.,[10] since the endocrown is a monolithic restoration, from a biomechanical perspective it may have better resistance to stress.

However, there was no significant difference in the values of von Mises stress and total deformation when a monolithic endocrown model was compared with a two-part endocrown model (primary support in the pulpal chamber + coronal part) when a load was applied perpendicularly to the same point (height) of the crown; Bouillaguet and Rocca report that the cementation surface area provided by the pulpal chamber is usually equal to or greater than that obtained when cementing an 8 mm deep post;[12] applying and polymerizing resins is easier to control with an endocrown because it is closer than a root post that is 8 mm down the root canal, where we are forced to use a dual-cure cement (dual-polymerization, i.e., auto polymerizing and photopolymerizable). This restricts our options for many types of cement.

Most of our observations are consistent with the literature. Indeed, numerous authors, such as Lin *et al*.[8] (Student's *t*-test, $P = 0.0039$), Ramírez-Sebastià *et al*.,[9] Biacchi and Basting[14] (Mann–Whitney nonparametric test, $P = 0.002$), Chia-Yu *et al*.[16] (Student's *t*-test, $P = 0.0039$), and Dejak and Mlotkowski[17] have shown endocrowns to possess better resistance to fracture than post and core restorations that comprise glass fiber posts supporting composite resin cores and ceramic crowns. What is more, Lin *et al*.[18] obtained the lowest stress values in the enamel, dentin, and cement seal when samples were restored with an endocrown. Conversely, Forberger and Göhring[19] observed that the post and core restoration had better resistance to fracture.

Our study has shown that a "short" post displayed greater resistance to fracture than the groups restored with a "long" post or post and core. Ramírez-Sebastià *et al*.,[9] Isidor *et al*.,[20] and Nergiz *et al*.[21] observed there is to be no effect that casted doubt on the resistance to fracture of short posts when used in the posterior teeth.

Regarding the influence of the length of the post on the type of fracture, our observations coincide with the study by Forberger and Göhring,[19] who concluded there was no link between the type of fracture and the use or not of a post. Chia-Yu *et al*.[16] observed that there was no significant difference in fracture mode with endocrowns or glass fiber: The fractures were mainly unfavorable failures in both groups ($P = 0.639$). Biacchi and Basting[14] have also shown that the type of fracture was comparable whether the tooth was restored with an endocrown or glass fiber. Moreover, Lin *et al*.[8] have shown the risk of failure with both restorations to be similar. In both groups, most failures occurred because of a fracture of the ceramic. These observations coincide with our results.

However, Ramírez-Sebastià *et al*.[9] observed a significantly higher number of irreparable fractures in the group restored with a long glass fiber post (10 mm) than in the groups restored with an endocrown or short glass fiber post (5 mm), whose fractures were mostly favorable. They concluded that it was possible to restore teeth without a post. On the other hand, the study by Sherfudhin *et al*.[22] shows that using a post considerably reduces the risk of unfavorable failures.

When we compared the different groups, we realized that the length of the post does not affect the type of fracture ([$P = 1.00$] according to the Chi-square test).

We then wondered if it was the type of material that involved more or less unfavorable fractures.

Even if there was no statistically significant difference when we compared the groups two by two, we suspected an effect of the material used on the fracture type (given that it was almost significant when comparing metal and fiberglass; furthermore unfavorable fractures are observed when using metal or ceramic).

Then, we searched a reason that might explain it.

This is why Hayashi *et al*.[23] observed that using a rigid post generated a greater concentration of stress in the root portion. Using rigid metal posts that can withstand lateral forces without distortion results in a transmission of the stress to the least rigid structure, the dentin. This may cause a root fracture.

This can be explained by the fact that the glass fiber has a modulus of elasticity closer to the dentins than metal or ceramic and can absorb tensions by deforming and then transmitting less stress to the dentine, an action that the metal and ceramic posts cannot do.

According to Dong-Yeol *et al*.,[24] the evaluation of the distribution of stress on the root reveals that there is a maximum concentration of stress at the apical part of the post.

For the « endocrown » group, in most of the cases, we obtained a fracture extending to the terminal part of the 3.5 mm corresponding to the root canal.

By means of finite element analysis, Dong-Yeol Lim *et al*.[24] assessed in different post and core restoration systems the influence on the distribution of stress of having restoration materials of differing elastic moduli, and therefore, of having several interfaces. The experiment used maxillary second premolars. There were three groups which were restored in three different ways: Group 1: (stainless steel post + composite resin core + porcelain-fused-to-gold crown); Group 2: (glass fiber post + composite resin core + sintered alumina crown), and Group 3: (composite resin endocrown).

In general speaking, the evaluation of stress distribution in the root structure revealed that maximum stress was concentrated in the apical portion of the post in the three groups. This coincides with the results that we obtained in our study, which revealed an overrepresentation of unfavorable fractures (9/10) in the group restored with a metal post. However, the study by Dong-Yeol Lim *et al*.[24] showed that Group 2, which was restored using a glass fiber post, displayed the highest stress concentration of all the groups. This clashes with our results.

In general, most authors recommend using materials whose elastic modulus is as close as possible to that of dentin so as to avoid root fractures. Bear in mind that the elastic modulus E of dentin is between 14 and 18 GPa. The elastic moduli of a ceramic post (170–213 GPa) and metal post (120–200 GPa) are very far from the elastic modulus of dentin, but the elastic modulus of a glass fiber post (45–49 GPa) is much closer to that of dentin.[25] The ideal post would be elastic enough to go with the natural flexion movements of the tooth, which a metal post cannot do.

In the study by Dong-Yeol Lim *et al*.,[24] the endocrown had the lowest concentration of stress in the external portion of the root surface. The study by Zarone *et al*.[15] showed similar results. Indeed, the author concluded that the stress generated in the apical portion by the tip of the post related to the elastic modulus of the type of crown used rather than to the rigidity of the post itself. Hence, higher is the elastic modulus of the most external part of therestoration (the crown), greater is the concentration of stress within thesystem. They thus recommend using a crown made of a material with a low elastic modulus. The type of post did not influence the distribution of stress observed. It should be noted that the study by Salameh *et al*.[26] yielded similar results.

Unlike our study, they used different types of crowns whereas our crowns were identical in terms of the material they were made of.

However, several authors, such as Hayashi *et al*.[23] and Zhou and Wang[24] advise using a glass fiber post rather than a metal post to prevent unfavorable fractures. Hayashi *et al*.[23] show that when we use a post with a high elastic modulus, such as a metal post, it causes tension in the dentin, whose elastic modulus is much lower. This is because stress is transmitted from the most rigid structure to the least rigid, which is the dentin. When we use a post whose elastic modulus is close to that of dentin, such as a glass fiber post, less stress is transmitted to the dentin. This seems to be the reason that reduced resistance to fracture was observed in the group restored with a metal post, as well as the reason that a much lower rate of root fractures was observed in the group with glass fiber posts compared with the group with metal posts. The study by Zhou and Wang[27] shows that a glass fiber post mainly causes favorable fractures whereas a metal post mainly causes unfavorable root fractures. This is consistent with our results.

As regards the ferrule effect, the study by Sherfudhin *et al*.[22] revealed there to be no significant difference in resistance to fracture between the groups with and without a ferrule. Other studies, such as those by Juloski *et al*.[28] and Tan *et al*.,[29] demonstrate the importance of having a ferrule to maximize the biomechanical behavior of the tooth so as to prevent unfavorable fractures.[9,13,28,29]

CONCLUSION

Within the limits of our study, the endocrown displayed the highest resistance to fracture, followed by the glass fiber post and metal post. What is more, the short length of the endocrown post did not result in greater displacement of the prosthetic dental system nor did it cause more unfavorable fractures than the other two restorations.

When we compared the two post and core restorations, the resin core with glass fiber post seemed more resistant and caused fewer unfavorable failures than did the metal cast core and endocrown, which mostly caused unfavorable fractures. However, we cannot extrapolate our results to a real clinical setting.

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Conflicts of interest
There are no conflicts of interest.

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