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Effect of Post Material and Amount of Coronal Destruction on Fracture Resistance and Failure Mode of Endodontically Treated Maxillary Central Incisors

SUMMARY

Introduction: *The purpose of this study was to evaluate the effect of post material and remaining dentin heights on the fracture resistance and failure mode of endodontically treated maxillary central incisors.*

Material and Method: *100 non-restored maxillary central incisors were divided into 2 groups with respect to the residual coronal dentin, as 0 or 2 mm from the cement-enamel junction. Each group was randomly subdivided into 5 subgroups: Fibre posts (F), Zirconium posts (Z), Gold plated posts (G), Titanium posts (T), and cemented with self-adhesive and dual-curing universal resin cement. In the control group no post was applied in the canal (A). All specimens were restored with composite core and all ceramic crown restorations. Static loading tests were performed on each specimen.*

Results and Conclusion: *The mean failure loads (N) were: 569.34 (F), 541.42 (Z), 599.28 (G), 594.82 (T), 507.53 (A). Highest fracture strength was obtained from the teeth with 2 mm coronal dentinal tissue, restored with fibre posts (642.68 N). The availability of 2.0 mm of coronal tooth structure has been shown to provide a ferrule effect, enhancing fracture resistance. Adhesive restorations without posts had similar fracture resistances and failure modes compared to those with various post systems.*

Keywords: Fibre Post; Fracture; Ferrule Effect

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Introduction

Special care is indicated when selecting the most efficient way to restore endodontically treated teeth because they have a higher risk of biomechanical failure than vital teeth[1,2]. The fracture resistance of post-restored teeth has been the subject of numerous *in vitro* and *in vivo* studies[3-26]. The success achieved with aesthetic restorative techniques has resulted in increased patient demands, particularly for anterior teeth. Consequently, there has been a significant increase in the use of all-ceramic crowns, as well as endodontic post and core materials that do not affect the aesthetic results[10,11]. Many dentists prefer to use prefabricated post systems because they are more practical, less expensive and, in some situations, less invasive than customized post and core systems[15].

Restorative methods for pulpless teeth with post core systems have been widely investigated with the aim of achieving long-term promising prognoses. Despite the various attempts that have been made, vertical root fractures of pulpless teeth are still encountered in every day clinical practice. Although it is acknowledged that minimal tooth cutting in endodontic and restorative procedures is the most effective measure for preventing vertical root fractures in pulpless teeth[13], it is often necessary to restore teeth with extensive loss of structure, such as those without coronal portions. In such cases, the best restorative methods for effectively reinforcing pulpless teeth need to be identified.

Since endodontically treated teeth often suffer extensive defects, post placement is often clinically necessary to generate retention to core and restoration[17].

It was previously stated that further research is needed to elucidate whether a high or low elastic modulus of post and core materials helps to distribute occlusal forces to remaining dentin and improves the clinical outcome in the oral environment[23].

In recent years more emphasis has been placed on the "ferrule effect" in the restoration of endodontically treated teeth with posts and cores. It is a generally accepted restorative strategy to include a ferrule in the design of tooth preparation when restoring an endodontically treated tooth with a post and core and then restored with a crown. The availability of 2.0 mm of coronal tooth structure between the shoulder of the crown preparation and the tooth/core junction has been shown to provide a ferrule effect, enhancing fracture resistance and preventing fracture and dislodgement of the post[8,22].

Today, many adhesive systems which are not fully investigated regarding their ability for luting endodontic posts, are on the market. Furthermore, it is still not fully understood which mode of luting is most reliable to bond posts; however, conventional etch-and-rinse systems with dual-cured resin composites have been reported to be the gold standard for luting[27,28]. Simplified versions of these adhesives have made bonding simpler, faster, and more user-friendly[28].

Since it still remains unclear which endodontic post material is preferable, this study was carried out to investigate the impact of a rigid material in comparison to a more flexible post material. The influence of ferrule preparation and composite build-up alone was furthermore evaluated. The purpose of this *in vitro* study was to evaluate the effect of 5 different post materials, cemented with self-adhesive and dual-curing universal resin cement resin cement in 2 different amounts of remaining dentin heights, on the fracture resistance and failure mode of endodontically treated teeth. The null hypothesis tested was that the fracture resistance and failure pattern of endodontically treated teeth with 2 mm of coronal dentin will not be affected by the use of posts and, in teeth with no coronal dentin, the use of fibre posts will increase the fracture resistance.

Material and Methods

In this study 100 non-restored maxillary central incisors extracted for periodontal reasons were used. Immediately after extraction, the teeth were cleaned by scaling and stored in distilled water at room temperature. To ensure that the mean dimensions of the teeth were similar between the groups and subgroups, the root lengths measured from the root apex to the buccal midpoint of the cemento-enamel junction (CEJ), and the bucco-lingual and mesio-distal dimensions (at the level of the cervical margin), were measured using a calliper (Renfert 1119, Renfert GmbH, Hilzingen, Germany). Overall, the mean root length was 13.8 mm, while the mean bucco-lingual and mesio-distal dimensions were 6.7 mm and 6.1 mm, respectively. Analysis of variance (ANOVA) affirmed the absence of any significant differences in these variables between the groups and subgroups.

Then the teeth were mounted individually in acrylic resin (Meliodent Denture Material, Heraeus Kulzer, Berkshire, USA) with the long axis parallel to the centre of the ring with the guidance of a dental surveyor (Kavo EWL, Typ 990, Kavo Elektrotechnisches Werk GmbH, Leutkirch im Allgau, Germany). Each tooth was suspended in the middle of the ring by means of 0.8 mm orthodontic wire (Leowire round spring hard wire 0.8 mm, Leowire s.p.a. Firenze, Italy) that engaged the tooth at the CEJ and rested on the edges of the ring.

Endodontic treatment and preparation of coronal dental hard tissues: All teeth underwent root canal shaping and obturation. The canals were mechanically prepared using rotary endodontic instruments (Anthogyr, Sallanches, France). After the root canal preparation, the canals were obturated with gutta-percha (Dentsply DeTrey, Konstanz, Germany) and sealer (AH26; Dentsply DeTrey, Konstanz, Germany), using a lateral condensation technique. The anatomical crowns of the specimens were then sectioned to allow for uniform circumferential residual dentin heights of 0 and 2 mm (50 specimens for each residual dentin height) with a water-cooled diamond fissure bur making the coronal surface contours parallel to the CEJ profile. The same operator performed the root canal preparation and crown sectioning.

Within each residual dentin height, the specimens were divided into 5 subgroups: Fibre post (Postec, Vivadent, Schaan, Liechtenstein), Zirconium post (Cosmopost, Vivadent, Schaan, Liechtenstein), Gold plated posts (Gold plated posts, Svenska Dentorama AB, Solna, Sweden, Lot no: 07017/554), Titanium post (Euro. Post Titanium Screwpost, Anthogyr, Sallanches, France). They were cemented with self-adhesive and dual-curing universal resin cement (Multilink Automix, Vivadent, Schaan, Liechtenstein). In the control group no post was applied in the canal. In all groups, the cores were constructed with light cured composite (Multicore Flow, Vivadent, Schaan, Liechtenstein).

In the control group, excess gutta-percha was removed to a depth of 2 mm from the coronal surface of the preparation. In the test groups with no coronal dentin, post space was created by removing the gutta-percha within the root canals, to a depth of 8 mm from the coronal surface of the preparation. A stop was placed on the engine mounted drill at an 8 mm depth, and the twist drill was not forced, but used passively, following the course of the previously established canal. In other specimens with 2 mm of residual dentin height, the stop on the engine-mounted drill was placed at 10 mm to maintain the post space length into the canal at a constant of 8 mm[20]. All the preparations of specimens were summarized in figure 1.

An additional silicone impression material (Virtual, Ivoclar Vivadent AG, Schann, Liechtenstein) was used for the impressions of prepared teeth. Custom acrylic trays were used, and each tray allowed an impression of 4 specimens. Impressions were cast in vacuum mixed die stone (GC Fujirock EP, GC Europe NV, Leuven, Belgium). Stone dies were recovered from impressions, and 2 coats of die spacer (Yeti Dental Clear Spacer, Yeti Dentalprodukte Gmbh, Engen, Germany) were painted 1 mm short of the finish lines of the preparations. Full ceramic crown restorations were made of a leucite-reinforced glass ceramic material, IPS Empress (IPS Empress Esthetic, Ivoclar Vivadent AG, Schann, Liechtenstein), using the staining technique, according to the manufacturer's recommendations.

The fracture loads were determined using a universal testing machine (Testometric Micro 500, Testometric Company Ltd., Lancashire, United Kingdom) at a crosshead speed of 0.5 mm/min. The load was applied at a 135° angle to the lingual surface of the test tooth. This orientation was standardized with a custom made mounting jig (Fig. 2). The load was consistently applied at 2.5 mm from the incisal edge with a customized plunger.

The mode of failure was recorded for each specimen and classified as either favourable (that would allow repair) or catastrophic (that would not allow repair)[19]. Fracture propagation was classified into 3 categories as follows: above CEJ (favourable), below CEJ extending to 1/3 depth longitudinally from cervical portion (favourable), fracture extending between 1/3 and 2/3 from cervical toward apical portion (catastrophic). The same operator recorded the mode of failure for all the specimens.

Statistical analyses were performed using Variance Analysis and the Tukey's Multiple Range Test.

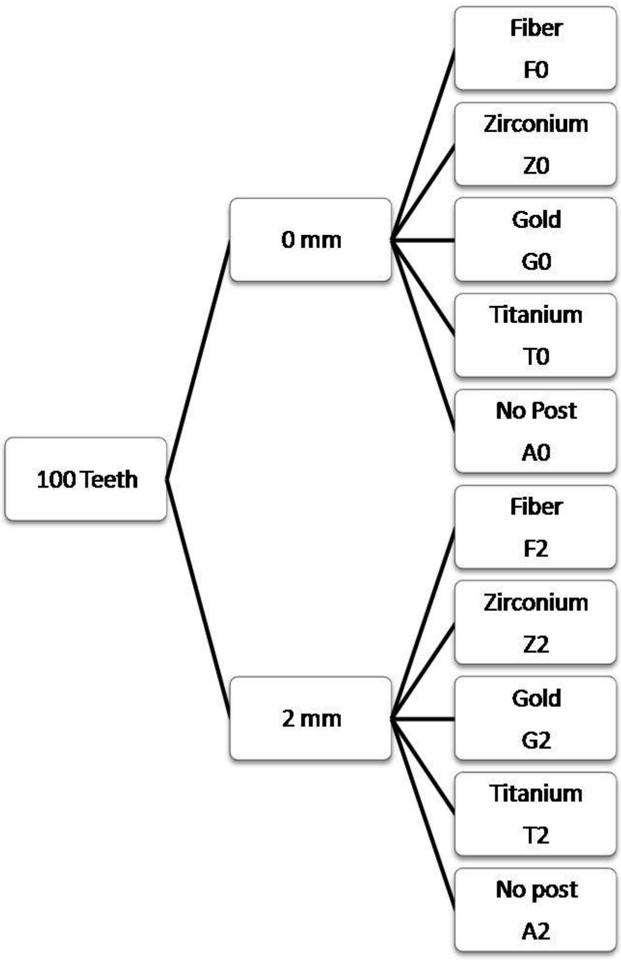

Figure 1. Schematic presentation of groups

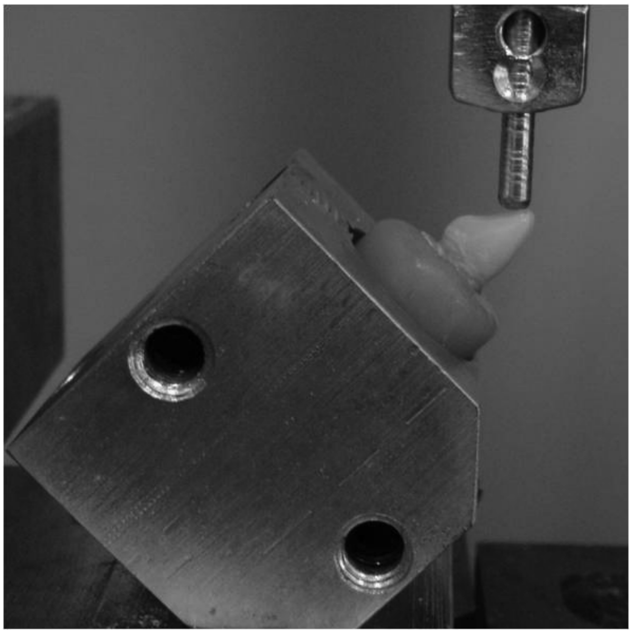

Figure 2. Determination of fracture resistance with a custom made mounting jig

Results

Means and standard deviations of failure loads of the fracture test are listed in table 1. ANOVA was performed to test the effect of post and amount of coronal dentinal tissue. The mean failure loads (N) were: 569.34 (F), 541.42 (Z), 599.28 (G), 594.82 (T), and 507.53 (A). Highest fracture strength was obtained from the teeth with 2 mm coronal dentinal tissue, restored with fibre posts (F2) (642.68 N).

Table 1. Means and Standard Deviations (SD) of the Fracture Loads (N)

Group	n	Mean	SD	Min	Max
F0	10	496	63.35	421.9	625.6
F2	10	642.68	38.99	605	729.9
Z0	10	517.6	59.58	414.7	596.6
Z2	10	565.23	23.72	530	596
G0	10	575.9	97.71	404	674.9
G2	10	622.66	117.38	416	761.5
T0	10	569.44	92.21	453	693.2
T2	10	620.2	108.48	413	694.7
A0	10	439.86	101.73	328	571.5
A2	10	575.2	20.94	542.5	598
Ferrule					
No coronal dentin	50	519.76	95.77	328.1	693.2
2 mm coronal dentin	50	605.19	77.84	413.5	761.5
Post					
Fibre	20	569.34	91.01	421.9	729.9
Zirconium	20	541.42	50.45	414.7	596.6
Gold	20	599.28	107.81	404.1	761.5
Titanium	20	594.82	101.4	413.5	694.7
No post	20	507.53	99.65	328.1	598
Total	100	562.48	96.86	328.1	761.5

There was statistically significant difference between groups (p=0.001). Results from the pairwise comparisons are shown in table 2. Lowest fracture strength was obtained from the teeth with no coronal dentinal tissue, restored without posts (A0) (439.86 N). The difference between A0 and F2, Z2, G0, T0, T2, A2 were statistically significant. The differences between the teeth without coronal dentinal tissue and restored with fibre posts (F0) exhibited lower fracture values than and F2, G2, T2 (p=0.001). In each group, the greater the height of the residual dentin, the greater the fracture resistance was. The teeth with no coronal dentinal tissue (693.2 N) showed lower strength values than teeth with 2 mm coronal dentin (761.5 N). The difference was statistically significant (Tab. 2).

Table 2. Results of statistical analysis

Groups	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	352526.388	9	39169.599	6.117	.001
Within Groups	576271.149	90	6403.013		
Total	928797.537	99			
Ferrule					
Between Groups	120527.009	1	120527.009	10.960	.001
Within Groups	1077747.728	98	10997.426		
Total	1198274.737	99			

Table 3. Frequencies of failure modes in the tested groups

Groups	Above bone level	Below bone level; upper one-third	Below bone level; middle one-third of root	Debonding of post
F0	10			
F2	10			
Z0	1	4	5	
Z2	7	3		
G0	2	2	4	2
G2	7	2	1	
T0	1	6	3	3
T2	6	1	3	1
A0	4	6		
A2	6	4		

The failure mode frequencies are shown in table 3. There were distinct differences in failure patterns between teeth restored with glass fibre posts and those restored with metal and zirconium posts. All of the teeth restored with fibre post fractured in a horizontal pattern through the facial side at the cervical part of the crown. All the teeth in the Z group fractured in a horizontal pattern through the facial side at the level of CEJ. In G and T groups most of the teeth experienced a horizontal fracture at the cervical and middle parts of the root and none of the metal posts fractured. Debonding of the post was seen in 2 samples in G0, 3 in T0, 1 in T2. In the groups with no post, all the restorations experienced a bond failure at the junction of the tooth and the composite core. The failure mode was catastrophic for none of A and F specimens.

Fractures that would allow repair of the tooth with 2 mm ferrule were observed in groups F, Z and A, whereas non-restorable, catastropic fractures were observed in groups G and T.

Discussion

Size deviations are inevitable when using natural teeth; therefore, in the present study, central incisors were allocated to experimental groups so that the mesio-distal and bucco-palatal dimensions were not significantly different among groups with different restorations.

The restoration of endodontically treated teeth frequently poses a challenge for the clinician. Apart from substantial tissue loss, which can be considered as one of the major obstacles, endodontically treated teeth are assumed to be more prone to fracture because of desiccation or premature loss of moisture supplied by a vital pulp.

Several studies have been performed to assess the mechanical resistance to fracture of post restored teeth[3-26]. Most studies have tried to identify the best technique and material to be used to increase the strength of the tooth restoration complex[14,15]. The use of static forces permits to simplify the study realization[17,19] and requires universal testing machines easier to use and less expensive than fatigue and thermo-mechanical cycling test workstations[14,16,19]. Different loading jigs were described in the literature in shape and material[14,19].

The loading was applied to the experimental teeth at an angle of 135° to the long axis to simulate Class I occlusion. This mode of loading was adopted from the method utilized by those authors who also evaluated the fracture resistances of maxillary incisor teeth[22,23]. In this study, rounded tip with a diameter of 5 mm have been chosen to homogeneously apply loads[14,17]. Due to the large number of secondary variables involved (i.e. tooth type and condition, restorative procedures and materials), it is hard to compare experimental data extrapolated by different *in vitro* studies[19], but the results obtained from this fracture test were comparable with some earlier reports[4,5].

There was significant difference in fracture resistance between the metallic post-cores and fibre post groups; the majority of fractures in the metallic post-core groups propagated over the middle portion of the roots, while those in the fibre post groups were limited to the cervical portion. This indicates that most of the fractured teeth restored with metallic post-cores were not reparable. In contrast, the majority of fractures in the fibre post group were limited to the cervical portion of the root including the core-dentin interface, since the stress was concentrated in the cervical area and the outer root surface. This type of fracture is most easy for repeated repair[9].

When a post-core with a high modulus of elasticity, such as a stainless steel post, is forced against radicular dentin with much lower modulus, the stress is transferred from the rigid post to the less rigid dentin. When a post with a similar modulus of elasticity to that of radicular dentin is used for restoration, such as a fibre post, less stress is transferred from the post to the dentin. Root fractures originate from regions with excessive stress concentration and propagate by exploring mechanically inferior areas in the restored teeth. All teeth restored with post-core systems fractured at the interface between the post-core and root dentin. These fractures could originate from the adhesive interface between the cores and root dentin, and propagate down, towards the post, by exploring an inferior adhesive area.

The choice of an appropriate post material is controversially discussed[25]: fibre posts have been recommended due to their dentin-like Young's modulus[7,23]. Fibre posts allow teeth to flex under applied loads, leading to an improved stress distribution between post and dentin[3,10,11]. The risk of root fracture should be reduced[3], but may concentrate stress between cement and endodontic post, resulting in loss of adhesion. Further, it is argued that a more rigid post would allow less invasive preparation with smaller post diameters[1,12] and avoid deformation of the entire post-core assembly. Root fractures have been attributed to extreme differences in rigidity of post and root dentin, with stress concentrations inside the root. Torbjorner et al[25] summarize that there is a choice between a low modulus post, possibly leading to reparable failures, or a high modulus post with probably later but more irreparable failures.

Meng et al[21] reported that the teeth restored with cast Ni-Cr dowel-cores and 2.0 mm ferrules demonstrated significantly lower fracture strengths. They found significant differences in the root fracture patterns between 2 dowel systems, with the carbon fibre-reinforced dowel-resin core system, being the less severe.

The fracture loads in all groups were found to be sufficiently greater than the ordinary chewing force, and even greater than the maximum bite force. There were significant differences between the specimens with 0 and 2 mm of remaining coronal dentinal tissue. The availability of 2.0 mm of coronal tooth structure provided a ferrule effect, enhancing fracture resistance. This result is in agreement with the findings of other studies[8,22]. It has been shown that the ferrule effect significantly reduces the incidence of fracture in non-vital teeth by reinforcing the tooth at its external surface and redistributing the applied forces. Within the limitations of this study and regarding the influence of the ferrule on fracture resistance, the null hypothesis was accepted.

Bonding to dentin may be achieved using etch-and-rinse (i.e. total-etch) and self-etch adhesives[27]. Simplified versions of these adhesives have made bonding simpler, faster, and more user-friendly[28]. Due to the alleged technique-sensitivity of conventional adhesives, more and more all-in-one adhesives are at the market, promising easier handling combined with equally reliable results compared to etch-and-rinse adhesives. However, several studies clearly demonstrated that the simplification may ease handling for the general practitioner, but may not improve adhesive effectiveness. The choice of resin cements that rely on the use of etch-and-rinse adhesives has been shown to achieve higher interfacial strengths in post spaces when compared with those that utilize mild self-etching adhesives or self etching resin cement. For self-etching adhesives and the self-etching resin cements, the acidic monomers incorporated in these systems were not strong enough to etch through thick smear layers, to form hybrid layers along the walls of the post spaces. Dual-cured and self-cured adhesives and composites are generally favoured for post cementation[28]. In this study, self-adhesive and dual-curing universal resin cement with metal and zirconium primer was used.

Conclusions

Within the limits of this laboratory investigation, it is concluded that severely damaged and root filled maxillary central incisors, restored with direct resin composite restorations and full ceramic crowns without posts, have similar fracture resistances and failure modes compared to those with various posts, which suggest that posts are not necessarily required.

The load to failure of the gold plated and titanium posts were significantly stronger than fibre and zirconium posts. However, the mode of failure of the fibre posts is protective to the remaining tooth structure. The availability of 2.0 mm of coronal tooth structure has been shown to provide a ferrule effect, enhancing fracture resistance.

The results of this study suggest that the bond quality of new generation resin cements is adequate for cementation of different type of posts.

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