Ex vivo fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars

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Abstract

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Aim To investigate *ex vivo* the fracture resistance and failure mode of direct resin composite complete crowns with and without various root canal posts made on maxillary premolars.

Methodology The clinical crowns of 40 human extracted single-rooted maxillary premolars were sectioned at the cemento-enamel junction. The canals were prepared with Gates Glidden drills up to size 4. Thirty samples were provided with standardized post spaces in the palatal canal and all roots were embedded in acrylic. Minimal standardized preparations in the canal entrances were made. Groups of 10 samples were treated with (i) prefabricated metal posts, (ii) prefabricated glass fibre posts, (iii) custom-made glass fibre posts, and (iv) no posts (control). Posts were cemented with resin cement and resin composite complete crowns were made. All specimens were thermocycled (6000×, 5–55 °C). Static load until fracture was applied using a universal loading device (crosshead speed 5 mm min^{-1}) at a loading angle of 30°. Failure modes were categorized as favourable and unfavourable failures.

Results No significant difference was observed between the mean failure loads (group 1: 1386 N, group 2: 1276 N, group 3: 1281 N, and group 4: 1717 N, $P > 0.05$), nor between frequencies of failure modes ($P > 0.05$). All failures were fractures of the resin composite crown in combination with tooth material (cohesive failures).

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

Keywords: composite crown, endodontically treated, failure mode, fibre reinforced, fracture resistance, post.

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Introduction

The restoration of root filled teeth remains controversial. Traditionally, custom-made cast post-and-cores covered by metal or porcelain-fused-to-metal crowns were the restorations of choice. In the early 1970s prefabricated metal posts used in combination with direct composite cores became available (Spalten 1971, Baraban 1972) and enabled the clinician to use them without the necessity to remove tooth material for elimination of undercuts in the pulp chamber. Thus, compared to custom-made cast post-and-cores, this procedure preserves sound tooth structure.

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Prefabricated posts were initially made of gold-plated brass or stainless steel, but were improved later by using titanium alloys as the basic material. Today prefabricated ceramic and fibre-reinforced composite (FRC) posts are being used increasingly. Recently, materials became available to construct custom-made FRC posts (Sirimai *et al.* 1999, Rosentritt *et al.* 2000, Eskitascioglu *et al.* 2002, Le Bell *et al.* 2003, Lassila *et al.* 2004). The latter materials allow adjustment of the post geometry to the anatomy of the root canal rather than adjustment of the root canal to the geometry of a prefabricated post. For instance, when a canal is not straight it is possible to make an individually formed curved post instead of preparing a straight post-space canal. As a result, tooth structure can be preserved and root integrity remains intact (Trope *et al.* 1985, Baratieri *et al.* 2000, Fuss *et al.* 2001). Even more tooth structure can be preserved by omitting posts. It was demonstrated that post-free core restorations can perform as well as restorations with posts for a period up to 5 years (Creugers *et al.* 2005a,b).

Another development is related to the crown build-up. By using particulate filler composites as both core and veneering material by direct means, root filled teeth can be restored without conventional crown coverage. Initially meant as temporary restorations, these resin composite complete crowns were improved by the application of resin composites with higher wear-resistance and fracture toughness and the development of efficient dentinal adhesives. Although some anecdotal clinical reports (Roeters 2001, Emilson & Lindquist 2004) suggest that the direct resin composite crown is a promising alternative to conventional treatment modalities, there is only scarce information on this subject. A laboratory study on cusp replacing restorations in teeth without endodontic procedures showed acceptable fracture resistance for resin composite partial crowns (Fennis *et al.* in press). A laboratory study on complete crowns investigated the fracture resistance of fatigued resin composite crowns with or without endodontic posts and showed promising results for clinical use (Krejci *et al.* 1994). Reports of two clinical trials demonstrated that extensive resin composite restorations with FRC posts (Mannocci *et al.* 2002) and direct resin composite (partial) crowns with prefabricated metal posts (Creugers *et al.* 2005a,b) were comparable to the conventional post-and-core/crown combinations. However, it is unknown to what extent posts are beneficial to the functional performance of direct resin composite crowns made on teeth with extensive loss of tooth substance.

This *ex vivo* study investigated the fracture resistance of direct resin composite complete crowns made on severely damaged and maxillary premolars with and without various root canal posts. The hypotheses of this study were:

1. There is no difference in mean fracture resistance of direct resin composite crowns with or without posts.
2. Direct resin composite crowns without posts have more frequent favourable failures than those with posts.

Materials and methods

Specimen preparation

Forty extracted single-rooted human maxillary premolars with almost straight roots and completely formed apices were selected on the basis of similar root sizes, absence of caries in the root and crown up to 2 mm above the cemento-enamel junction (CEJ), and absence of visible fracture lines in the root. The premolars were stored in water until further processing. The clinical crowns were removed up to approximately 1.5 mm above the buccal CEJ using a diamond stone in a water-cooled hand-piece (40 000 cycles min^{-1}). Root canal preparations were made in the root canal with Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) up to size 4 for the total length of the canal (4000 cycles min^{-1} with water-cooling). These root canal preparations defined the long-axis of the roots. If a second (buccal) root canal was present, it was prepared in a similar manner. The prepared teeth were divided into four groups of 10 specimens each.

In three groups, 8 mm deep post-preparations were created as measured from the buccal CEJ, using cylindrical drills (Parapost stainless steel drills; Coltène Whaledent Inc., Mahwah, NY, USA) with increasing diameters of 0.9, 1.14 and 1.25 mm (4000 cycles min^{-1} with water-cooling). In the fourth group (control) no post-space preparations were made. The root sample surface of each was flattened using a flat-ended diamond stone in a parallelometer drilling device perpendicular to the long-axis of the experimental root canal up to the level of the buccal CEJ. Standardized cavities in the canal entrances were made using a cylindrical diamond stone (40 000 cycles min^{-1} with water-cooling; 2 mm of depth and diameter 1.75 mm). The lengths, largest bucco-palatal and mesio-distal widths of the roots were measured with a digital calliper. Mean root sizes were: length 15.0 mm (SD = 1.2 mm), bucco-palatal width 8.3 mm (SD = 0.5 mm), and mesio-distal width 4.6 mm (SD = 0.4 mm). The mean root sizes of the four groups did not differ significantly (ANOVA, $P > 0.05$).

After preparation, the roots were stored in a Chloramine solution (1%) for 24 h. They were then embedded in an acrylic resin cylinder (Palapress; Heraeus Kulzer GmbH & Co. Hg, Hanau, Germany) (diameter 20 mm, height approximately 20 mm). The flattened occlusal root surface was situated approximately 1.5 mm above the acrylic level (to simulate bone) and the buccal side of the root was located about 1 mm from the outer surface of the acrylic cylinder to simulate buccal bone crest. During the whole procedure the samples were maintained in a wet condition and then stored in water until loading.

Restorative procedures

Materials used in the restorative procedures are listed in Table 1. Three different post systems were used: (i) prefabricated metal posts (Parapost XH, diameter 1.25 mm), (ii) prefabricated glass FRC posts (Parapost Fiber White, diameter 1.25 mm), and (iii) custom-made glass FRC posts (EverStick Post, diameter 1.2 mm). All posts were placed to the total depth of the prepared post-space. A grinding machine (grit 500) was used to standardize the length (13 mm) of the prefabricated posts.

The custom-made glass FRC posts were handled following the manufacturer's instructions. A bundle of pre-impregnated glass fibres was cut to a length of 13 mm. This bundle was inserted in the canal and initially light cured (Optilux 501; SDS Kerr, Danbury, CT, USA, 660 W cm^{-2}, light tip diameter 10 mm) for 20 s. Thereafter, the post was removed from the canal and additionally light cured for 40 s. The post was inserted in the canal and an additional bundle of pre-impregnated glass fibres was placed along and attached to the customized post, and initially light cured (20 s). Then the FRC post was removed from the canal and finally light cured (40 s). The FRC post system was then wetted with resin (Stick Resin; StickTech, Turku, Finland) and protected from any light sources (by a light-proof box) whilst the cement was being prepared.

Before cementation of the post of each of the three systems the canal was cleaned with 0.5% sodium hypochlorite, rinsed with water spray for 10 s, and dried for 5 s and then with paper points. Next, the dentinal surfaces were conditioned by applying a self-etching primer (ED primer). This was left for 60 s, and a gentle air stream was used to evaporate the excess fluid. Resin cement (Panavia F) was mixed for 20 s and applied to the total post surface. Subsequently the post was seated in place using finger pressure for 10 s. Excess cement was spread with a brush in a thin layer covering the occlusal surface of the specimen. The cement was light cured for 20 s from the occlusal direction.

The first layer (thickness 1–2 mm) of particulate filler resin composite (Filtek Z250) was applied around the post to cover the cement and light cured for 20 s. The resin composite crown was built up in layers of approximately 2 mm; each layer was light cured for 20 s. A transparent polyvinylsiloxane mould (Memosil 2; Heraeus Kulzer GmbH & Co. Hg) with an anatomically formed occlusal surface was used to standardize the occlusal plane. A resin composite layer of approximately 1 mm covered the 'head' of the post occlusally. Finally, the cervical outline of the resin composite crown and the surface of the restoration were finished using diamond stones and polishing tips (40 000 cycles min^{-1} with water-cooling).

In the control group, the dentinal surfaces were etched (Ultra-etch, 35% phosphoric acid) for 15 s,

Table 1 Materials used in the restorative procedures

Brand name	Manufacturer	Lot number
Parapost XH	Coltène Whaledent Inc., Mahwah, NY, USA	MT-06866
Parapost Fiber White	Coltène Whaledent Inc., Mahwah, NY, USA	MT-31945
EverStick Post	StickTech, Turku, Finland	2030307-P2-003
Stick Resin	StickTech, Turku, Finland	207265
ED primer	Kuraray Co., Ltd, Kurashiki, Okayama, Japan	Liquid A: 00150B, liquid B: 00035A
Panavia F	Kuraray Co., Ltd, Kurashiki, Okayama, Japan	Paste A: 00136A, paste B: 00012A
Filtek Z250	3M ESPE, St Paul, MN, USA	20021028
Ultra-etch	Ultradent Products Inc., South Jordan, UT, USA	4XFL
3M Scotchbond Multipurpose Primer	3M ESPE, St Paul, MN, USA	2AC
3M Scotchbond Multipurpose Adhesive	3M ESPE, St Paul, MN, USA	2NA

rinsed with water spray for 15 s and dried with an air stream for 5 s. Primer (Scotchbond Multipurpose Primer) was applied and air blown for 5 s. Application of adhesive (Scotchbond Multipurpose Adhesive) was followed by 10 s light curing. A 2 mm thick layer of resin composite (Filtek Z250) was applied in the canal entrance and light cured for 20 s. The resin composite crown was build up similarly to the other crowns.

Mechanical loading

The samples were subjected to thermocycling (6000 cycles at 5–55 °C, dwell 30 s, transfer time 5 s) and stored in 37 °C sterile water for 10 days. The samples were then fixed in a metal holder in a universal testing machine (Lloyd LRX; Lloyd Instruments, Fareham, UK) with the long-axis of the roots at an angle of 30° to the direction of load (Fig. 1). A stainless steel cylindrical bar (diameter 2 mm) was used to load the samples until fracture, with a crosshead speed of 5.0 mm min^{-1}. The site of loading was the central fissure of the occlusal surface in the direction of the buccal cusp (Fig. 1).

After fracture, all samples were assessed for failure mode by two independent and calibrated observers. 'Favourable failures' were defined as repairable failures, including adhesive failures, above the level of bone simulation. 'Unfavourable failures' were defined as nonrepairable failures, including (vertical) root fractures, below the level of bone simulation (Fokkinga *et al.* 2004). Disagreements were resolved by discussion.

Figure 1 Position of a specimen with a direct resin composite complete crown in the test set-up for static loading.

Statistical methods

One-way ANOVA was used to compare the failure load data at a significance level of 5%. Cohen's κ-coefficient was used for assessing the intra-observer agreement of failure modes and chi-square test (Fisher's exact test) was used to compare the failure modes of the specimens. The analyses were performed with SPSS version 11.0 (SPSS Inc., Chicago, IL, USA).

Results

Specimens fractured at failure loads of 540–2369 N. Although one-way ANOVA did not show significant differences ($P > 0.05$) between the mean failure loads of the four groups, a trend was observed for a higher mean failure load in the control group (Table 2). The intra-observer agreement regarding the failure mode assessment was high ($\kappa = 0.84$). Almost all failures of all groups were unfavourable (90%). Fisher's exact test did not show a significant difference in frequencies of favourable/unfavourable failure modes between the four groups ($P = 0.98$). In most cases the buccal cusp fractured (65%) and the origin of the main fracture line corresponded with the site of loading. However, some palatal cusp fractures (10%) were observed and also failures of both cusps (25%) (Table 3 and Fig. 2). All failures were fractures of the resin composite crown in combination with tooth material (cohesive failures), no pure adhesive failures were seen. In 23 specimens (58%) the post was exposed after fracture, but none of the posts came loose.

Table 2 Failure load data of the four groups

				95% Confidence interval for mean failure load (N)	
Post	*n*	Mean failure load (N)	SD (N)	Lower bound	Upper bound
1. Prefab Metal	10	1386.3[a]	598.6	958.1	1814.5
2. Prefab Fibre	10	1276.1[a]	405.7	986.0	1566.3
3. Custom-Fibre	10	1281.3[a]	452.0	958.0	1604.6
4. No Post	10	1716.5[a]	304.9	1498.4	1934.6

[a]Failure loads not significantly different, $P = 0.12$ (ANOVA).

Table 3 Frequencies of different failure modes of the four groups

		Unfavourable failures/fracture of						Favourable failures/fracture of				
		Buccal cusp[a]		Palatal cusp		Both cusps		Buccal cusp		Palatal cusp		
Group	Post exposed:	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	*n*
Prefab metal		8		1				1				10
Prefab FRC		5	3		1			1				10
Custom FRC		3	2		1	2		1		1		10
No post			2				8					10

[a]See Fig. 2.

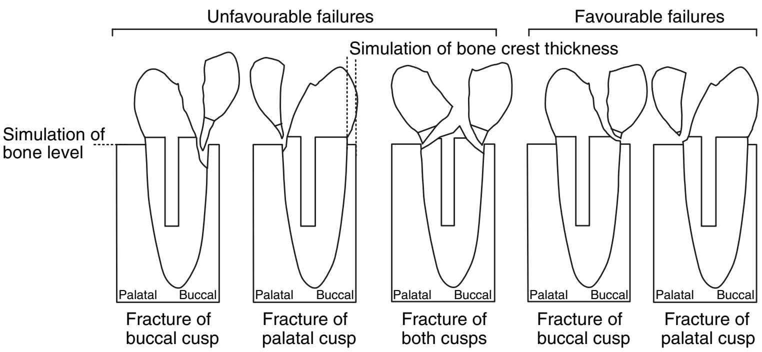

Figure 2 Schematic representation of the observed failure modes of fractured specimens.

Discussion

This study simulated the 'worst case scenario' of extracted maxillary premolars representing severely damaged and root filled teeth. The conventional restoration would be a metal post-and-core and crown coverage with sufficient ferrule (Stankiewicz & Wilson 2002). In clinical textbooks, additional treatment such as tooth extrusion or gingivectomy is advised if the desired ferrule cannot be obtained by the preparation itself. Conclusions with respect to the contribution of the ferrule to a higher fracture resistance of crowned prefabricated post and resin composite core combinations are controversial (Al-Hazaimeh & Gutteridge 2001, Akkayan 2004). With resin composite as a core and crown build-up material, creating a ferrule might even be a drawback, because sound tooth tissue will be lost and a lack of enamel may result. Enamel is preferred over dentine to bond to (Tezvergil *et al.* 2003, Van Meerbeek *et al.* 2003). Another aspect of these severely damaged teeth is the use of posts. A recent paper discussed the need for a re-evaluation of post use especially where adhesive techniques are used to construct the core (Krejci *et al.* 2003). In this context the purpose of the present study was to obtain data on the behaviour of the direct resin composite complete crown with or without posts, without a ferrule and with minimal remaining tooth-crown material.

Due to large confidence intervals of the mean loads (Table 2) only large differences will attain significance. It is almost impossible to plan for this problem in this kind of laboratory study, as it is known that testing human teeth results in a large standard deviation (Krejci *et al.* 2003) compared with artificial manufactured teeth (Ottl *et al.* 2002). Although the internal validity of testing natural teeth is relatively low, these tests are preferable because of their high external validity. The trend that the restored premolars without a post showed similar or even higher fracture resistances than those with the three post-systems is in agreement with observations of a laboratory study on teeth with indirect resin composite crowns with or without posts (Krejci *et al.* 2003). The tendency for those specimens without posts to have a higher fracture resistance might result from their thicker bulk of composite. With the posts in this study, a maximum of post length inside the crown was achieved to obtain optimal adhesion of the composite to the post. One millimetre composite was placed on top of the post. A thicker layer of covering composite might result in an increased fracture resistance.

No difference was found in the failure modes between the four groups in this study, which justifies rejection of the second hypothesis. Almost all specimens fractured in an unfavourable mode (Table 3, Fig. 2). The absence of adhesive failures can be attributed to good dentine bonding. This is quite remarkable but it should be appreciated that the circumstances in clinical practice might influence bonding efficacy (i.e. influence of moisture). Nevertheless, posts placed in severely damaged root filled maxillary premolars seem to have no additional value in cases where direct resin composite complete crowns are used.

Test designs of laboratory studies can only partially simulate the clinical situation. Clinical loading of teeth is a dynamic process, in which loading force, frequency and direction vary greatly. The choices made in laboratory tests result in a large variation. Also due to a large number of other variables involved (i.e. tooth condition, tooth type, procedures and restorative materials) it is almost impossible to compare fracture resistance data between laboratory studies (Maccari *et al.* 2003, Fokkinga *et al.* 2004). The present study applied static load as to obtain data on direct resin composite complete crowns on extracted premolars. The crosshead speed used was within the range reported in the literature [0.5 mm min^{-1} (Ottl *et al.* 2002) to 5 cm min^{-1} (Sidoli *et al.* 1997)]. The lack of a simulated periodontal ligament is recognized. However, the failures occurred in the upper and cervical parts of the reconstructed premolars and it is not expected that the failures would have been substantially different with a shock-absorbing layer around the roots with this static loading test.

The posts used were chosen to represent prefabricated metal, prefabricated FRC, and custom-made FRC post systems, of which the first two posts have the same geometry (parallel with macro mechanical retention grooves on the parallel surface and a retention head). In this study drills were used to prepare all root canals receiving a post, because this facilitated the construction of the custom-made fibre post with comparable geometry (parallel, without additional macro mechanical retention features) to the other posts. A loading angle of 30° with the long-axis of the roots in buccal direction was used to simulate a relatively unfavourable load direction. If the loading angle would have been 45° for example, the specimens probably would have shown favourable failures more frequently with fewer exposures of the posts (Fig. 3b). The position of the loading site relative to the post may be of influence to the failure mode of the construction. In the loading design used in this study, the load-bearing cusp did not receive support from the post (Fig. 3a). In fact, the tensile stress at the adhesive interface between the post and composite restoration weakened the construction. If the load had been applied alternatively to the other cusp under the same angle to the tooth axis (Fig. 3a), more vertical root fractures would have been expected to occur.

From a mechanical point of view, the advantage of post placement, even FRC posts, has not been substantiated. A laboratory study on core restorations without covering crowns for root filled incisors and without additional post-space preparation, showed no difference in fracture resistance between custom-made polyethylene woven FRC posts and cast post-and-cores (Eskitascioglu *et al.* 2002). However, the polyethylene woven FRC post group showed fewer unfavourable root fractures than the cast post group (Eskitascioglu *et al.* 2002). Another aspect that could favour the use of FRC posts is the easier accessibility to the root canal if re-restoration is required. Furthermore, fibres in the composite restoration might stop or change the direction of probable crack propagation, which offers the

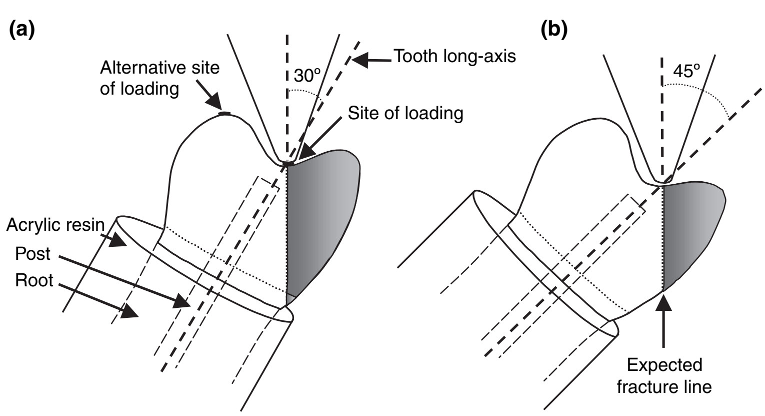

Figure 3 Expected fracture lines with alternative loading site and loading angles.

operator the possibility to apply the fibre reinforcement in accordance with the expected stresses in the construction. It remains attractive to test different geometries of custom-made FRC (post-) constructions without (additional) post-space preparation.

Conclusions

Within the limits of this laboratory investigation root filled and severely damaged maxillary upper premolars, restored with direct resin composite crowns with and without various posts had similar fracture resistances under static load. The failure modes of these kind of restorations were similar. Failures of direct resin composite complete crowns with various posts are unfavourable, the (cohesive) fractures of the buccal cusps end below the level of bone simulation. This suggests that posts are not necessarily required to improve fracture resistance of direct resin composite complete crowns as used in this study, however clinical studies are required to confirm these findings.

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