Journal of Dentistry (2006) **34**, 326–335

ELSEVIER

Journal of Dentistry

www.intl.elsevierhealth.com/journals/jden

Influence of different posts and cores on marginal adaptation, fracture resistance, and fracture mode of composite resin crowns on human mandibular premolars. An in vitro study

Elisabeth J. Stricker, Till N. Göhring*

Clinic for Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Plattenstrasse 11, 8032 Zurich, Switzerland

Received 11 April 2005; received in revised form 27 July 2005; accepted 29 July 2005

KEYWORDS
Post;
Core;
Cast gold;
Glass fiber;
Zirconium oxide;
Composite resin;
In vitro;
Marginal adaptation;
Fracture resistance;
Cyclic loading

Summary *Objective*: To evaluate marginal adaptation, fracture modes, and loads to failure of composite crowns with different substructures on root-canal-treated premolars.
Methods: Forty-eight mandibular teeth with single root canals were selected and assigned to six equal groups: group I, untreated; group II, root-canal-treated (RCT), access cavity restored with composite resin; group III, RCT, ferrule (2 mm), no post, standardized composite resin crown (SRCC); group IV, RCT, ferrule, glass fiber post, SRCC; group V, RCT, ferrule, zirconium post, SRCC; group VI, RCT, ferrule, cast gold post, SRCC. All teeth were subjected to thermocycling and mechanical loading (TCML) in a computer-controlled masticator (1,200,000 loads, 49 N, 1.7 Hz, 3000 temperature cycles of 5–50–5 °C). Marginal adaptation was evaluated before and after TCML with scanning electron microscopy at ×200 at the tooth-to-luting-composite (IF1) and the luting-composite-to-crown (IF2) interfaces. After TCML, all specimens were loaded to failure in a universal testing machine at 0.5 mm/min.
Results: A significant decrease in marginal adaptation was found in groups III and IV after TCML at IF1. A significant decrease was observed at IF2 in group V. Mean loads to failure did not differ significantly between the groups with SRCCs. Those of groups II, III, and IV did not differ from that of unrestored teeth. Half the specimens exhibited partial root fractures, independent of the substructures used. No deep or vertical root fractures were observed in any group.
Conclusion: All studied posts had a positive effect on marginal adaptation at IF1, but not on failure modes or loads to failure of composite resin crowns.
© 2005 Elsevier Ltd. All rights reserved.

* Corresponding author. Tel.: +41 44 634 3470; fax: +41 44 634 4308.
E-mail address: till.goehring@zzmk.unizh.ch (T.N. Göhring).

0300-5712/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jdent.2005.07.007

Introduction

After root canal treatment, the dental practitioner is faced with the task of restoring the tooth to rehabilitate oral functions. The restoration must achieve adequate retention and circumvent damage to the remaining hard tissue through the prevention of bacterial microleakage and hard-tissue fractures. Studies indicate that the tooth is less prone to fracture when less dental hard tissue is removed during treatment.[1,2] On the other hand, endodontic therapy is often necessitated by pulpal infection after substantial hard-tissue loss by caries or following extensive tooth preparation for crown- and bridgework. In both cases, much hard tissue has already been lost before root canal therapy. Therefore, there is often insufficient dental hard tissue left to ensure adequate retention of a functional restoration after endodontic treatment.

Some years ago it was thought necessary to place posts and cores in every tooth that underwent endodontic therapy. It was considered that a post with an ideal length of two-third of the total root length would reinforce the compromised tooth. Later studies indicated that the length of the post is less important for the survival of the tooth than the presence of a ferrule of at least 1.5 mm.[3,4] Materials with a high modulus of elasticity, like cast gold alloys (90 GPa), stainless steel (170 GPa), or titanium (115 GPa) were favored and, as an esthetic alternative, zirconium posts (200 GPa) were introduced. Stainless steel and titanium posts were mainly used with plastic core materials, like composite and amalgam. Gold posts and ceramic posts were used either with plastic core materials or with indirect cast gold or pressed ceramic cores, respectively. About 10 years ago, glass, polyethylene, quartz, or carbon-reinforced composites (20–30 GPa) with a lower, more dentin-like (18 GPa) modulus of elasticity were introduced to dentistry. These fiber-reinforced posts fulfill the requirements of dentists who prefer to use prefabricated posts and resin-based composite core buildups. The advantages of this direct post-and-core technique include lower costs due to the exclusion of the dental technician, one less appointment, and the preclusion of unnecessary temporization.[5]

The optimal modulus of elasticity of a post is controversial. Stiffer posts and cores may better support the coronal restoration and lead to a more uniform distribution of stress, but may result in catastrophic failure modes, like vertical root fractures, if the tooth is overloaded. A more elastic post may bend under high loads, which may lead to failure or loss of the restoration, but would leave the root intact for retreatment. On the other hand, an elastic post may allow the restoration to move and thus leak, after breakdown of the luting cement, with coronal leakage that puts the tooth at risk of secondary caries or root canal reinfection.

A completely different approach recommends the use of so-called endo-crowns instead of posts and cores.[6,7] This technique limits the amount of dentin removed around the root canal to a 2 mm deep canal inlay. This avoids additional weakening of the tooth by a postspace preparation and procedural errors such as root perforation. In a clinical study, CAD/CAM-generated all-ceramic endo-crowns in molars showed good survival rates of about 87% after up to 7 years, whereas premolars had only around 70% survival over the same observation period.[8] Although the survival rate in premolars was lower than in comparable studies, it must be noted that none of the roots fractured. Some in vitro studies have investigated the fracture resistance of incisors with and without posts and cores. Omitting posts had either no effect or a positive effect on the fracture strength of teeth.[2,9,10]

The aim of the present in vitro study was to evaluate the fracture resistance of natural human premolars before and after root canal treatment and compare these data with the results of the same test applied to root-canal-treated, highly damaged premolars with cast gold or heat-pressed glass ceramic cores and zirconia posts, glass-fiber-reinforced posts with composite resin core build-ups, or endo-crowns. All restored teeth were covered with standardized, laboratory-made composite resin crowns and were subjected to cyclic loading before static loading to failure. Marginal adaptation was evaluated before and after thermomechanical loading at the crown-to-luting-composite interface, where clinical failure may lead to discoloration, and at the luting-composite-to-dental-tissue interface, where failure may lead to discoloration or secondary caries. The hypotheses tested were: (1) Composite resin endo-crowns show similar marginal adaptation and failure loads as post-and-core systems with prefabricated glass fiber, custom cast gold alloy, or all-ceramic post systems. (2) Composite resin endo-crowns with a dentin-like modulus of elasticity and glass-fiber-post-reinforced composite crowns show fewer catastrophic failures than metal or all-ceramic post-and-core systems with a high modulus of elasticity.

Materials and methods

For this study, 48 single-rooted teeth were selected from mandibular premolars and canines by visual inspection, digital caliper measurement (CAPA 150, Tesa SA, Renens, Switzerland), and radiographs (Digora, Soredex, Helsinki, Finland). Thirty-two teeth were randomly divided into four experimental groups of eight teeth each. The remaining 16 teeth were caries-free mandibular premolars and were used as controls, i.e. their clinical crowns were not removed (groups I and II). In all groups the teeth had one radiologically visible root canal, no cervical or root caries, and similar dimensions measured at the cemento-enamel junction. Teeth with curved roots and wide or atypically shaped root canals were excluded. As mandibular premolars exhibit a wide variance in root shape, it was considered appropriate to include some mandibular canine roots in groups III to VI. These roots matched the selection criteria and did not differ from premolar counterparts after removal of their clinical crowns. All teeth were stored from extraction until treatment in 0.1 M thymol solution. The patients had been informed before extraction that their teeth would be used for research purposes. The extraction had no influence on the individual treatment plan of the patient. All teeth were cleaned with scalers, nylon bristle brushes, and pumice.

Root canal treatment

The teeth in one group were not root canal treated. In the remaining five groups, all teeth were root canal treated. After access cavity preparation with a high-speed contra-angle handpiece (Sirius; Micro-Mega, Besancon, France) and a diamond bur (FG 8514, Intensiv SA, Grancia, Switzerland), a step-down procedure was performed using Gates Glidden burs (sizes 3 to 1; Maillefer, Ballaigues, Switzerland) in a low-speed contra-angle handpiece (Micro Mega) for the first 3 mm.

Nickel-titanium files (No. 20; NitiFlex, Maillefer) were inserted, and the working length was assessed with digital X-ray (Digora). The master apical file was No. 40 (Nitiflex) and a step-back in 1 mm steps was performed until No. 60. After each file, the canal was rinsed with sodium hypochlorite (1%, wt: vol). After root canal preparation, the canals were dried with paper points No. 40 (Dr Wild & Co., Basel, Switzerland) and obturated with lateral condensation using gutta-percha points No. 40 (Roeko, Langenau, Germany), accessory point size A (Roeko), and a sealer (AH-Plus; Dentsply, Konstanz, Germany). Digital control X-rays were taken and the distance between the root canal filling and the radiological apex was measured. The access cavities were covered with a temporary restorative (Cavit; 3M Espe, Seefeld i. Obb., Germany) and the teeth were stored in tap water.

Tooth preparation

Group I: The non-root-canal-treated group received no preparation at all.

Group II: The temporary restorative was taken out and the root canal filling was removed to the cementoenamel junction. The dentin and enamel of the access cavity were finished using a 45 μm diamond bur (Intensiv). The enamel was etched for 30 s, and rinsed with water spray for 40 s, and a dentin adhesive system (Syntac Classic; Ivoclar Vivadent, Schaan, Liechtenstein) was applied according to the manufacturer's instructions. The access cavity was filled with a fine hybrid composite (Tetric Ceram; Ivoclar Vivadent) in one horizontal and two oblique increments, polymerized separately for 60 s (Optilux 500; Demetron Kerr, Danburry, CT, USA). The restoration surface was finished with 8 μm finishing diamond burs (Intensiv) and polished (Occlubrush; Kerr-Hawe, Bioggio, Switzerland).

Groups III to VI: The clinical crowns of the teeth were removed, leaving roots 13 ± 1 mm long. These were fixed in carriers in a parallelometer (PFG 100; Cendres & Metaux, Biel, Switzerland) and a circular preparation 0.5 mm wide and 2 mm deep was made with 4° tapered 80 μm diamond burs (FG 8514, Intensiv) with water cooling (Fig. 1). With the same

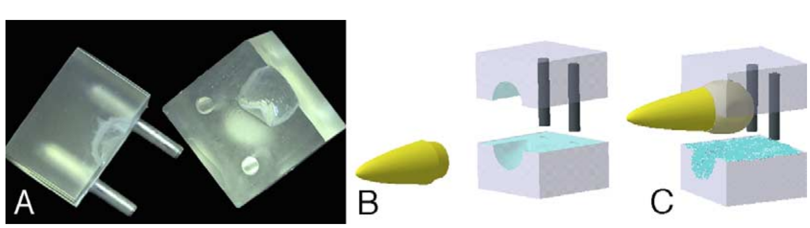

Figure 1 To produce standardized crowns, a translucent split mold was manufactured using epoxy resin (A). The latter was isolated and filled with resin composite (Targis). The prepared teeth of groups III to VI were isolated and positioned in the mold (B). After initial light polymerization, the crown could easily be removed (C).

tapered bur, a 2 mm deep central inlay cavity was prepared in a rotation-protecting oval shape, leaving a minimum dentin thickness of at least 1 mm. The finishing line was prepared to follow the cementoenamel junction.

Group III: No posts were inserted. After coarse preparation, the preparation was finished using 45 μm finishing diamond burs (FG 2504, Intensiv) of the same shape and taper, resulting in a circular preparation 0.8 mm wide and 2 mm deep.

Group IV: About 10 mm deep preparations for size M (cervical diameter 1.5 mm) cylindroconical glass fiber posts (FRC Postec, lot ZZ0329) were made using the appropriate drills in a slow-speed contra-angle handpiece. The canal was rinsed with tap water and an adhesive system (Syntac Classic) was applied according to the manufacturer's instructions. The bonding agent (Heliobond) was applied with paper points and not polymerized separately. A dual-curing resin luting material (Variolink; Ivoclar Vivadent) was mixed 1:1 with base (lot C15031) and catalyst (lot C1307). This was applied to the surface and brought into the prepared root canal with a No. 25 lentulo spiral (Maillefer). The glass fiber post was air-particle abraded at 1 bar pressure (Microetcher; Danvill Engineering, Danville, CT, USA), silanated (Monobond-S; Ivoclar Vivadent) for 60 s, covered with a thin film of bond (Heliobond), and inserted into the soft luting-composite-filled root canal. Excess material was removed with a probe before polymerization from the buccal and oral surfaces with a light gun (Optilux 500 with 'turbo' light tip) for 60 s each. Fine hybrid composite (Tetric Ceram, lot A10588) was then used to build up a core, which was polymerized from the buccal and oral surfaces using a light gun (Optilux 500 with 'turbo' light tip) for 60 s each. The core was coarsely prepared and finished in a parallelometer with tapered diamond burs under water cooling.

Group V: About 10 mm deep preparations for size 2 (cervical diameter 1.7 mm) cylindroconical zirconium oxide posts (Cosmo Post, lot C15178) were made using the appropriate drills in a slow-speed contra-angle handpiece. The posts were placed in the canal and impressions were taken (President light, surface activated; Coltène Whaledent, Altstätten, Switzerland). In the dental laboratory, casts were produced (Fujirock; GC Corp., Tokyo, Japan). The casts were hardened (Margidur; Benzer, Zurich, Switzerland), two layers of spacer (Puragent; Benzer) were applied, and the core was built up with wax (Schuler Dental, Ulm, Germany). The zirconium oxide posts with wax cores were embedded (Empress 2 Speed, lot C09087 and liquid lot C09092). After warming for half an hour at 850 °C, liquid glass ceramic (Empress 2, lot C25473) was pressed into the lost-wax space at 900 °C. After slow cooling to room temperature, the posts and cores were removed and air-particle abraded using aluminum oxide at 2 bar pressure. The posts were cleaned with steam and inserted with Variolink and dentin bonding as described for group IV.

Group VI: About 10 mm deep preparations for size 2 (cervical diameter 1.5 mm) cylindroconical precious alloy posts (Moser RCP, lot 009929; Cendres & Metaux) were made with the appropriate drills using a slow-speed contra-angle handpiece. The posts were placed in the canal and impressions were taken (President light). In the dental laboratory, casts were produced (Fujirock). The casts were hardened (Margidur), two layers of spacer (Puragent) were applied, and the core was built up with wax (Schuler Dental). The posts with wax cores were embedded with Fujivest Super, (GC powder, lot 20000331; liquid, lot 19990301). After warming for 50 min to 750 °C, the cores were cast with a gold alloy (Aurofluid, lot 0052577). After slow cooling to room temperature, the posts and cores were removed, air-particle abraded, and cleaned. For insertion, the dentin was cleaned with alcohol and glass-ionomer cement (Ketac Cem, 3M Espe) was rotated into the prepared root canal. After the removal of excess cement and setting, the core was finished in a parallelometer with tapered diamond burs under water cooling.

The finished product was a 0.8 mm wide preparation with a 2 mm high ferrule in all groups III–V.

Crown fabrication

To allow the use of standardized, well-fitting crowns on all teeth despite slight differences in the cervical diameters of the teeth, an impression was made from one randomly selected premolar after post and core placement. A cast was produced (Fujirock) and a premolar-shaped clinical crown was built up with a composite resin (Tetric Ceram), resulting in a standardized prototype tooth. Subsequently, a split mold was built using epoxy resin (Stycast; Emerson & Cuming, Westerlo, Belgium), as shown in Fig. 1. The mold and all prepared teeth, with and without posts, were isolated with a thin film of vaseline (Kantonsapotheke, Zürich, Switzerland). For each tooth, the isolated form was filled bubble free with composite (Targis Dentin; Ivoclar Vivadent) with a ball-shaped instrument and spatulas (MB 1, 2, 5, & 6; Deppeler, Rolle, Switzerland). The isolated tooth was subsequently inserted into the composite until its finishing line was reached. At the finishing line, the composite was adapted with spatulas. The composite was light polymerized from occlusal, buccal, oral, and both proximal surfaces for 60 s each, through the transparent epoxy mold. After careful removal of the tooth, the internal surface was also polymerized (Optilux 500, 'turbo' light tip). The form was split, the crown was removed, covered with glycerin gel (Targis-Gel), and postpolymerized at 95 °C for 25 min (Program 1, Targis Power; Ivoclar Vivadent).

After postcuring, the crown was carefully polished with descending-grain-size discs (Soflex-discs; 3M Espe) and bristle brushes (Occlubrush). The subsurface was air-particle abraded with 50 μm aluminum oxide (Delta Blast; Kaladent, Zürich, Switzerland). Composite resin thickness was at least 2 mm.

Crown placement

All teeth were cleaned with water, toothpaste (Signal AntiCaries; Elida Fabergé, Zug, Switzerland), and slowly rotating nylon brushes (Kerr Hawe). All preparations were carefully refinished with 25 μm finishing diamond burs under water cooling at ×10 magnification (Stemi 2000; Zeiss, Oberkochen, Germany). Syntac Primer was applied for 15 s. After another 15 s, the primer was dried slightly with care. Syntac Adhesive was applied and slightly dried after 20 s. Heliobond was then applied and carefully thinned with air after a penetration time of at least 40 s. Care was taken to leave a very thin but intact film and to avoid any pooling, which would lead to an ill-fitting crown. The bonding agent was then polymerized occlusally for 60 s (Optilux 500, standard light tip).

The crowns were conditioned with silane (Monobond-S; Ivoclar Vivadent). After 60 s, the solvent was air-dried and the silanated surface was covered with a thin film of Heliobond, which was not polymerized separately. A restorative composite (Tetric) was filled into the crowns and carefully adapted to all walls. The crowns were placed on their respective prepared teeth and brought to their end positions with ultrasound (SP Tip and Piezo-Master 400; EMS, Nyon, Switzerland). The surplus composite was removed with a probe and after a final ultrasonic action, the composite was polymerized through the crown from all five aspects for 60 s each (Optilux 500, 'turbo' light tip). The small amount of polymerized surplus composite was removed and the surface polished with Soflex discs of descending grain size at ×10 magnification.

The roots of all teeth were covered with an air-thinned 0.3 mm layer of polyvinylsiloxane (President light, surface activated) to simulate a periodontal ligament. They were then centrally mounted on scanning electron microscopy (SEM) specimen carriers (Balzers Union, Balzers, Liechtenstein) with autocured resin (Paladur, Kulzer) with a centering device (PPK, Zurich, Switzerland). The distance between the finishing line and the resin was 3 mm at the buccal and oral surfaces and 4 mm at the proximal surface to simulate the biological width.

To quantify the changes in marginal adaptation using SEM, teeth and restorations were cleaned with toothpaste (Signal AntiCaries), rotating nylon brushes (Kerr Hawe), and water. Impressions were made from the restored surfaces of the teeth before and after thermomechanical loading (President light, surface activated). Replicas were manufactured with epoxy resin (Stycast 1266; Emerson & Cuming, Westerlo, Belgium) and were sputtered with gold for 1 min (Sputter SCD 030, Balzers, Liechtenstein). Marginal adaptation at the interfaces between tooth and luting composite and between luting composite and restoration were analyzed quantitatively with SEM at 15 kV and a working distance of 20–30 mm (Amray 1810/T, Bedford, MA, USA) at ×200 original magnification, by a calibrated operator who was blinded to the group membership of the specimen. Finish lines and crown margins were assessed for the following characters, expressed as a percentage of the total margin length examined: continuous margin (no gap, no interruption to continuity), noncontinuous 'imperfect' margins (gap due to adhesive or cohesive failure; fracture of the restorative material or fracture of the dentin related to restoration margins).

All specimens (groups I–VI) were loaded mechanically at the center of the occlusal surface in the computer-controlled masticator (CoCoM 2; PPK, Zürich, Switzerland). Stressing comprised 1.2 million occlusal loads of 49 N at 1.7 Hz and simultaneous thermal stress with 3000 temperature cycles of 5–50–5 °C.

To detect coronal leakage after thermomechanical loading, the specimens were covered with nail varnish up to 1 mm cervical of the finishing line and immersed in 0.5% fuchsin solution (Kantonsapotheke) for 20 h.

Specimens were then placed in a custom-made carrier with an inclination of 60° (loading angle: 120 ± 5°) and loaded in a universal testing machine (Schenk Trebel, Baden, Switzerland) with a 5 mm steel sphere and a cross-head speed of 0.5 mm/min until the first major load drop. A 0.5 mm piece of tin foil between the steel sphere and crown allowed a more equal load distribution and avoided loading peaks on the composite resin crown surface. The load was recorded in newtons and mean values were calculated per group.

After failure, the fragments were analyzed for the failure mode: crown fracture, crown fracture and post-fracture, tooth fracture that might clinically allow a new crown placement, and tooth/root fracture that would necessitate tooth extraction.

Teeth were also sectioned longitudinally with a low-speed saw (Isomet; Bühler, Dietikon, Switzerland) under kerosene cooling. They were analyzed for visible coronal leakage by the penetration depth of fuchsin dye to four degrees: 0, no dye penetration; 1, penetration of up to 50% of the butt joint preparation; 2, penetration of 50–100% of the butt joint preparation; 3, penetration up to the core.

Statistical analysis

Marginal adaptation was compared between the groups using the Kruskal–Wallis test and the initial and terminal values were compared with the Wilcoxon signed rank test.

Loads to failure were compared using one-way analysis of variance (ANOVA). Post hoc testing was performed with *t* tests and a Bonferroni correction for multiple testing.

Results

All teeth and all restorations survived thermomechanical loading in the computer-controlled masticator without loss of retention or fractures, and were used for analysis and further tests.

Marginal adaptation

On initial replicas, 95.4±8.8% of margins between the dental hard tissue and luting composite were rated continuous and this value did not differ between groups. After thermomechanical loading, the percentage of continuous margins decreased to 31.6±14.3% in group III, 65.0±17.4% in group IV, 84.5±16.6% in group V, and 91.8±11.5% in group VI. The decrease in marginal adaptation compared with the initial replicas was significant for groups III ($p=0.012$) and IV ($p=0.017$). After thermomechanical loading, marginal adaptation was significantly poorer in group III than in any other group ($p<0.01$). Group VI exhibited the smallest decrease in the percentage of continuous margin, but did not differ significantly from group V. Group IV (glass fiber posts) performed better than group III (endo-crowns; $p<0.001$). Group IV was statistically similar to group V (zirconium oxide posts), but exhibited significantly less continuous margin than group VI (gold alloy posts) after thermomechanical loading ($p<0.01$).

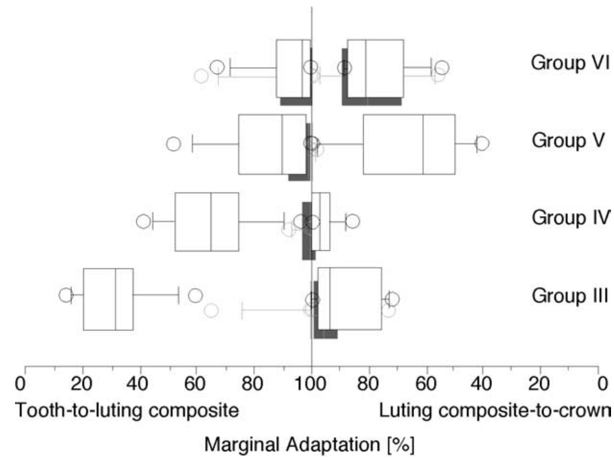

Figure 2 Marginal adaptation was analyzed at the tooth-to-luting-composite and at the luting-composite-to-crown interface before (gray box plots) and after (white box plots) cyclic thermomechanical loading.

Between the luting composite and the crown, the percentage of continuous margin was 97.4±3.4% before thermomechanical loading in groups III, IV, and V. In group VI (gold alloy posts), the percentage of continuous margin was 79.2±15%, which was significantly poorer than in the other groups ($p<0.01$). After thermomechanical loading, a significant decrease in marginal adaptation was observed only in group V (zirconium oxide posts), where marginal adaptation decreased to 65.9±21.4%. Marginal adaptation decreased to 88.4±11.7% in group III (endo-crowns), to 95.9±4.8% in group IV (glass fiber posts), and to 77.0±12.2% in group VI. The percentage of continuous margin between the luting composite and the crown was significantly higher in groups III and IV than in groups V and VI ($p<0.01$), which did not differ statistically from each other (Fig. 2).

Table 1 Dye penetration.

Group	Number of teeth			
	Grade 0	Grade 1	Grade 2	Grade 3
III	3	0	2	3
IV	4	2	1	1
V	3	3	1	1
VI	5	2	0	1

Table 2 Loads to failure and failure characteristics.

Group	n	Mean ± SD	Load to failure (N)			Failure characteristics	
			Significance[a]	Minimum	Maximum	Reparable	Problematic
I	8	849.0 ± 194.0	AB	713.0	1037.0	8	0
II	8	1031.9 ± 266.0	A	500.0	1433.0	5	3
III	8	649.8 ± 161.2	BC	596.8	779.5	4	4
IV	8	672.6 ± 158.7	BC	446.2	868.8	4	4
V	8	481.6 ± 147.7	C	421.8	534.6	4	4
VI	8	450.9 ± 183.2	C	232.8	727.5	5	3

Groups with the same letter did not differ significantly statistically.
[a] One-way ANOVA with correction for multiple testing (Bonferroni/Dunn).

Dye penetration

The results for dye penetration are shown in Table 1.

Load to failure

In the untreated control group (group I), a mean load of 849.0 ± 94 N was necessary to cause a fracture. In group II, the mean load to failure was 1031.9 ± 266 N, which did not differ from that of group I. In groups III and IV, loads to failure did not differ significantly from that of the control, whereas in groups V and VI, significantly lower mean loads led to failure relative to that in the control (Table 2).

In the untreated control group, fractures occurred exclusively coronal to the cemento-enamel junction, i.e. the failure mode allowed for a clinical retreatment. In all other groups, about half of the teeth failed in such a way that clinical retreatment was difficult or impossible because of root fracture. However, no fracture was more than 3 mm below the original finish line. Crowns fractured and fell off the tooth without any damage to the tooth structure in group V (two crowns) and in group VI (three crowns). The different fracture modes observed in this study are shown in Fig. 3.

Discussion

Two main reasons for the failure of teeth restored after root canal treatment are coronal leakage and fractures of the remaining dental hard tissue. Therefore, in this study, marginal adaptation, failure loads, and failure type were analyzed for composite resin endo-crowns and composite resin crowns supported by different post-and-core systems on natural human premolar and canine roots of similar shapes. After standardized root canal treatment, a ferrule was prepared in all groups, root length was standardized, and a periodontal ligament was simulated. A computer-controlled masticator with simultaneous thermocycling was used to simulate the cyclic loading of restorations in the oral cavity before the specimens were loaded to failure in a universal testing machine. The load was applied in an oblique direction, which is more detrimental than an axial load.[11]

The results were compared with those for untreated premolars and premolars that had

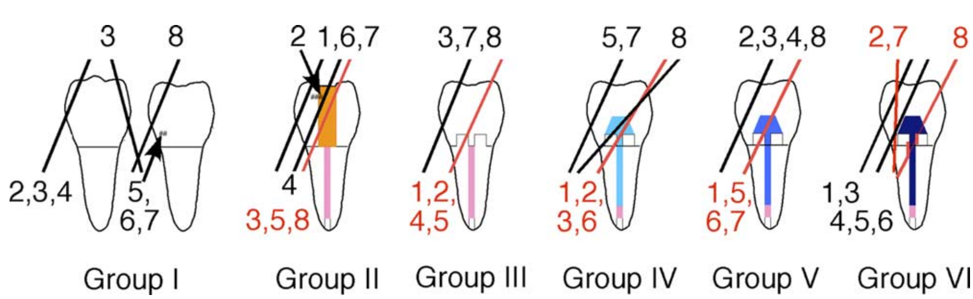

Figure 3 Fracture modes observed after static loading to failure. The numbers shown are the tooth numbers in the respective groups. Black numbers indicate uncritical fractures, red numbers indicate critical fractures, meaning that the tooth would be difficult to re-restore. Tooth 1 in group I, tooth 6 in group III, and tooth 4 in group IV showed no fragment dislocation.

received root canal treatment through a small access cavity, restored with incremental composite filling.

Besides the usual limitations of in vitro studies, one limitation of this study was the exclusive use of composite resin crowns for the final restoration of the root-canal-treated teeth. This only gives information about the tested combinations of posts, cores, and crowns, and the results cannot be generalized for other combinations, especially for other crowns made of metal, ceramic fused to metal, or high-strength ceramic.

The cast all-ceramic and especially the cast metal post-and-core systems with a high modulus of elasticity exhibited better and more stress-resistant marginal adaptation at the tooth-to-luting-composite interface than the endo-crown or the glass-fiber-post-supported crown. The reason might be that the deformation of the root was limited by the stiff post-and-core systems, whereas the composite resin crown was proportionally more deformed than the root, leading to a slightly increased loss of marginal integrity at the luting-composite-to-crown interface. The relatively poor marginal adaptation of the composite resin endo-crowns after thermomechanical loading was supported by the highest degree of dye penetration, which may clinically indicate a higher incidence of coronal bacterial leakage or secondary caries. These findings are supported by clinical observations, where endo-crowns were frequently not retained on premolars.[8]

Only a few other studies have analyzed the marginal adaptation of postendodontic restorations after cyclic loading procedures.[12,13] In agreement with our study, good marginal adaptation was found for the all-ceramic-post-supported crowns at the tooth-to-luting-composite interface. The marginal adaptation of glass-fiber-post-supported crowns was acceptable. Krejci et al.[12] tested maxillary premolars with different restorations and found no differences in marginal adaptation for composite resin endo-crowns and glass-fiber-post-supported composite resin crowns after mechanical loading. Marginal adaptation was better than in our study, but their restorations were not simultaneously thermocycled during occlusal loading.

When loaded to failure, the highest values were obtained for untreated teeth or root-canal-treated teeth with small, adhesively restored access cavities, as expected. No significant differences were observed between these groups, which is in agreement with other studies.[14]

Teeth restored with composite resin endo-crowns or with glass-fiber-post-reinforced composite resin crowns exhibited similar failure loads, which did not differ from those of unrestored teeth. Although a tendency for higher loads to failure was observed compared with the composite resin crowns on cast-gold- or all-ceramic-post-supported teeth, these differences were not statistically significant. These lower values for cast-gold- and all-ceramic-post-supported teeth may be explained by the stiffer core material, which did not follow the deformation of the composite resin crowns under load. This may have led to critical strain on inner crown surfaces and to fractures of these crowns. The hypothesis was rejected that endo-crowns or crowns supported by glass fiber posts would lead to favorable, less dramatic failures without fractures of the root. In all groups except the unrestored control, approximately one half of the specimens exhibited partial fractures of the roots, leading to clinically subgingival fracture lines, which are rarely reparable. On the other hand, vertical root fractures, the most dramatic failure mode described for teeth restored with posts and cores, were not observed in any group in this study.

The use of composite crowns limited the load transfer to the root via the stiff post. With increasing pressure from the loading steel ball, the composite resin crown may have been elastically deformed, followed by a fracture of the crown before critical loads could be transferred to the root dentin. It is conceivable that a crown made of metal or high-strength ceramic may have led to other and more dramatic failure modes, as described in other studies.[2,13,15-17]

Studies in which the cemented posts were loaded directly onto the cores without a crown covering the restored system[3,4,9,18,19] were not compared with our study. The results of these studies may give better information about the effects of posts but may also be clinically misleading because the effects of crowns and ferrules are ignored, even though these have been shown to have a more significant effect on retention and fracture resistance than the length of the post. Clinically, a load exerted directly on the post seems to be the exception.

Among these studies using crowns over post-endodontic treatment variations, some used cyclic loading procedures.[2,12,13,16,18,20-22] In a study by Krejci et al., the load was applied to the center of the restoration of maxillary premolars in an axial direction. However, in agreement with the results of our study, the fracture patterns for composite resin endo-crowns and glass-fiber-post-supported composite resin crowns did not differ[12]

In most of these studies, root-canal-treated incisors were tested.[2,13,16,18,20–22] In three studies with a similar test set up, loads to failure were similar to those in our study.[2,16,18] The highest values were observed for teeth with closed access cavities; lower values were recorded for teeth with composite restorations 3 mm into the enlarged root canal.[16] For cast posts and cores, titanium posts with composite resin cores, or all-ceramic posts and cores, loads to failure were observed that were similar to those in our study.[18] However, in most other studies, more dramatic modes of failure with much more apical fracture lines were described. Rosentritt[13] described 50% root fractures with titanium posts, about 40% root fractures with all-ceramic posts, and 25% root fractures with glass fiber posts in incisors restored with all-ceramic crowns. However, the modulus of fracture of teeth without posts was similar to that in our results, but failures occurred at lower mean loads. This may be explained by the use of cast metal[16,18] or all-ceramic crowns.[13] In two other studies, extremely high loads to failure were recorded with Procera copings (Nobel Biocare, Gothenburg, Sweden). Fractures of the copings were described for most groups.[20,21] Only in the cast metal post and core group were vertical root fractures observed. Again, the highest load-to-failure values were obtained in the group with adhesively restored access cavities.[20] Sahafi et al. used higher cyclic loads than described in the latter studies and counted the loads which were necessary to induce failure. The best results were achieved without posts and cores. Ceramic posts were destroyed with about 50% of the loads that were necessary for the failure of a tooth without posts and cores. The more elastic glass-fiber-reinforced posts demonstrated an even poorer performance.[22] In contrast to other studies, the latter study was more focused on the performance and different surface treatments of the posts, and no ferrule was prepared to obscure this factor. With the preparation of a 2 mm high ferrule, as used in our study, the influence of the post and core material may be not as critical.

Conclusions

Within the limitations of this in vitro study, it can be concluded that deeply destroyed single rooted teeth with composite premolar-shaped crowns show less dramatic failure modes than those described for metal or all-ceramic crowns, irrespective of the substructure used.

Glass fiber, all-ceramic, and cast gold posts had a positive effect on marginal adaptation, but not on loads to and modes of failure in composite resin crowns.

In future studies, our results should be verified with crowns made of high-strength lithium-disilicate or zirconia ceramic. As an alternative approach, studies with shorter glass fiber posts should be conducted to reduce the loss of hard tissue after root canal treatment of highly damaged premolars.

References

1. Leary JM, Aquilino SA, Svare CW. An evaluation of post length within the elastic limits of dentin. *Journal of Prosthetic Dentistry* 1987;**57**:277–81.
2. Heydecke G, Butz F, Strub JR. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. *Journal of Dentistry* 2001;**29**:427–33.
3. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. *Journal of Prosthetic Dentistry* 1990;**63**:529–36.
4. Isidor F, Brondum K, Ravnholt G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. *International Journal of Prosthodontics* 1999;**12**:78–82.
5. Christensen GJ. Post concepts are changing. *Journal of the American Dental Association* 2004;**135**:1308–10.
6. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years—preliminary results. *Journal of Adhesive Dentistry* 1999;**1**:255–65.
7. Göhring TN, Peters OA. Restoration of endodontically treated teeth without posts. *American Journal of Dentistry* 2003;**16**:313–7.
8. Bindl A, Björn R, Mörmann WH. Survival of ceramic CAD/CAM crowns bonded to preparations with reduced macroretention geometry. *International Journal of Prosthodontics* 2005;**18**: 219–24.
9. Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. *Journal of Prosthetic Dentistry* 1993;**69**: 36–40.
10. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. *Endodontics and Dental Traumatology* 1985;**1**:108–11.
11. Loney RW, Moulding MB, Ritsco RG. The effect of load angulation on fracture resistance of teeth restored with cast post and cores and crowns. *International Journal of Prosthodontics* 1995;**8**:247–51.
12. Krejci I, Duc O, Dietschi D, de Campos E. Marginal adaptation, retention and fracture resistance of adhesive composite restorations on devital teeth with and without posts. *Operative Dentistry* 2003;**28**:127–35.
13. Rosentritt M, Sikora M, Behr M, Handel G. In vitro fracture resistance and marginal adaptation of metallic and tooth-coloured post systems. *Journal of Oral Rehabilitation* 2004; **31**:675–81.
14. Steele A, Johnson BR. In vitro fracture strength of endodontically treated premolars. *Journal of Endodontics* 1999;**25**:6–8.

15. Mannocci F, Ferrari M, Watson TF. Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. *Journal of Adhesive Dentistry* 1999;**1**:153–8.
16. Heydecke G, Butz F, Hussein A, Strub JR. Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems. *Journal of Prosthetic Dentistry* 2002;**87**:438–45.
17. Pilo R, Cardash HS, Levin E, Assif D. Effect of core stiffness on the in vitro fracture of crowned, endodontically treated teeth. *Journal of Prosthetic Dentistry* 2002;**88**:302–6.
18. Butz F, Lennon AM, Heydecke G, Strub JR. Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post-and-core systems: an in vitro study. *International Journal of Prosthodontics* 2001;**14**:58–64.
19. Akkayan B. An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. *Journal of Prosthetic Dentistry* 2004;**92**:155–62.
20. Pontius O, Hutter JW. Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement. *Journal of Endodontics* 2002;**28**: 710–5.
21. Strub JR, Pontius O, Koutayas S. Survival rate and fracture strength of incisors restored with different post and core systems after exposure in the artificial mouth. *Journal of Oral Rehabilitation* 2001;**28**:120–4.
22. Sahafi A, Peutzfeldt A, Ravnholt G, Asmussen E, Gotfredsen K. Resistance to cyclic loading of teeth restored with posts. *Clinical Oral Investigations* 2005;**9**:84–90.

Available online at www.sciencedirect.com
SCIENCE DIRECT®