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ORIGINAL ARTICLE

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Resistance to cyclic loading of teeth restored with posts

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Abstract This in vitro study evaluated the effect of presence of post, presence of core, and of shape, type, and surface treatment of posts on resistance to cyclic loading of crowned human teeth. For all teeth, crowns designed without ferrule were cast in sterling silver and luted with resin cement (Panavia F). Each tooth underwent cyclic loading of 600 N at two loads per second until failure. Teeth that had only been crowned showed significantly higher resistance to cyclic loading than teeth with cores or with post and cores. No significant differences were found between teeth restored with cores only or with post and cores, irrespective of surface-treatment of the posts. Teeth restored with parallel-sided cast post (ParaPost XP) and cores showed significantly higher resistance to cyclic loading than teeth with either tapered cast posts or untreated prefabricated posts of titanium alloy (ParaPost XH) or glass fiber composite (ParaPost Fiber White). No significant difference was found between teeth restored with parallel-sided cast post and cores and teeth restored with untreated prefabricated posts of zirconia (Cerapost). Surface treatment of posts significantly increased the resistance to cyclic loading compared with untreated posts. When posts are used, surface treatment is recommended.

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Introduction

Post and cores are often used to provide retention and stability for final restorations of endodontically treated teeth [19, 31]. Generally, two types of post and core systems exist: custom-made post and cores and prefabricated posts with resin composite cores. Individually cast post and cores are normally cast from metal alloys. As for prefabricated posts, these are either metallic posts such as stainless steel, titanium alloy and noble metal posts, which traditionally have been luted with zinc phosphate cement, or non-metallic posts such as posts of zirconia and carbon fiber or glass fiber reinforced resin composite, which are intended to be adhesively bonded in the root canal.

The effect of type of post and core on resistance to loading of restored teeth has been investigated in several in vitro studies [1, 5, 12, 14, 21] and conflicting results have been reported. Isidor et al. [14] investigated the resistance to cyclic loading of teeth restored with either individually cast or prefabricated posts and found higher resistance to cyclic loading of the teeth restored with prefabricated posts. In another in vitro study, Butz et al. [5] compared the resistance to cyclic and static loading of teeth restored with either individually cast or prefabricated posts and found no differences in resistance to loading of the restored teeth.

Differences in resistance to cyclic loading have been shown for various types of prefabricated posts: the use of carbon, quartz, or carbon-quartz fiber posts has been found to result in lower failure rates than posts of zirconia or metal, most probably due to the bonding of the posts to the root canal [15, 20].

As regards the shape of posts, two fundamental shapes exist: tapered and parallel. A number of in vitro and in vivo studies have shown superior retention, higher resistance to cyclic loading, and higher success rate of teeth restored with parallel-sided posts compared to teeth restored with tapered posts [7, 14, 16, 25, 34, 36, 42].

The fracture resistance of endodontically treated teeth is largely dependent on the amount of remaining tooth structure [18, 43]. Preparation of the root canal reduces remaining tooth structure and the use of a post may weaken the tooth and increase the risk of root fracture by uneven stress distribution along the length of post. A number of in vitro studies have investigated the fracture strength of teeth restored with and without post and cores: either no effect or a positive effect on fracture strength of teeth was found as a consequence of omitting a post [3, 12, 43].

In attempts to maximize the retention of posts and the fracture strength of roots, luting of posts with resin cement as well as surface treatments of posts have been studied [10, 17, 22, 23, 26, 27, 32–34, 41, 44–46]. One surface treatment, the tribochemical silicate-coating system CoJet (3 M ESPE), has been found to create an effective bonding of resin cement to various types of prefabricated posts [32]. The system uses silicate-coated alumina particles to sandblast the surface prior to application of silane and resin cement. Sandblasting with the silicate-coated alumina particles produces a high spot heat, which together with the blasting pressure results in welding of the silicate layer onto the surface [9] and subsequent silanization enhances the bond strength of resin cement to the treated surface [6]. These studies have investigated the fracture strength of teeth restored with posts, the bond strength of resin cement to posts, or the retentive strength of posts luted in root canals. In an attempt to simulate the complex, clinical conditions more closely, in vitro studies of resistance to cyclic loading of teeth restored with post and cores with the use of covering crowns have been carried out [13–15]. However, these latter studies have not investigated the effect of surface treatment of posts.

The present study tested the following hypotheses: 1) teeth restored with only crowns have higher resistance to cyclic loading than teeth also restored with cores or with post and cores; 2) teeth restored with only cores have higher resistance to cyclic loading than teeth also restored with post and cores; 3) teeth restored with parallel-sided posts have higher resistance to cyclic loading than teeth restored with tapered posts; 4) teeth restored with surface-treated posts have higher resistance to cyclic loading than teeth restored with untreated posts; 5) teeth restored with prefabricated posts have higher resistance to cyclic loading than teeth restored with cast posts. Consequently, the aim of this in vitro study was to evaluate the effect of posts, of core, and of shape, type, and surface treatment of posts on the resistance to cyclic loading of crowned human teeth.

Material and methods

One hundred extracted, healthy human maxillary incisors and canines and mandibular canines with a root length of at least 10 mm were kept in an antimicrobial preservative (0.5% Chloramine T) after extraction. The root of each tooth was roughened by green grit (SiC) No. 48 (Hallvard Foss & Co., Fetsund, Norway) and following application of an adhesive system Optibond Solo Plus (Kerr, Orange, CA, USA), a ball of resin composite Flow line (Heraeus Kulzer, Inc., NY, USA) was applied to the apex and light cured for 30 s. The surface of the root and composite ball was roughened by green grit and coated with a layer of silicone rubber RTV 11 GE Silicones (GE Bayer Silicones, Bergen op zoom, The Netherlands). After drip drying and curing under humid conditions for 1 d, this artificial periodontal ligament had a thickness of approximately 60 µm [13]. The teeth were mounted in a cylindrically prepared cavity in a prefabricated acrylic block (d=10 mm, l=15 mm) and fixed with auto-curing acrylic resin Paladur (Heraeus Kulzer, Inc., NY, USA), which was left to cure for 60 min. The ball of resin composite helped secure retention of the tooth in the acrylic block. The teeth were randomly distributed into ten experimental groups, each consisting of ten teeth (Table 1).

Teeth planned to receive a crown (without post and core) were wet-sectioned horizontally in the coronal part and then prepared. The height of the preparation was 3 mm, the angle of convergence was approximately 15°, and the height of root outside the acrylic block to the crown margin was 5 mm.

Teeth planned to receive a core but no post were wet-sectioned to leave 5 mm of root outside the acrylic block. Cores of auto-curing resin composite Clearfil core (Kuraray, Osaka, Japan) were then bonded by the use of an adhesive system Clearfil LinerBond 2 V (Kuraray, Osaka, Japan). After a setting time of 20 min, the cores were prepared to receive a crown. The heights of prepared cores were 3 mm,

Table 1 Experimental groups (n =10)

Type of post and core restoration	Type, material, and shape of post	Surface treatment of post	Type of core
No post, no core	None	None	None
No post	None	None	Resin composite
Tapered post	Cast, sterling silver, tapered	None	Cast in sterling silver
ParaPost XP	Cast, sterling silver, parallel-sided	None	Cast in sterling silver
ParaPost XH	Prefabricated, titanium alloy, parallel-sided	None	Resin composite
ParaPost XH	Prefabricated, titanium alloy, parallel-sided	Cojet system	Resin composite
ParaPost Fiber White	Prefabricated, glass fiber, parallel-sided	None	Resin composite
ParaPost Fiber White	Prefabricated, glass fiber, parallel-sided	Cojet system	Resin composite
Cerapost	Prefabricated, zirconia, parallel-sided part	None	Resin composite
Cerapost	Prefabricated, zirconia, parallel-sided part	Cojet system	Resin composite

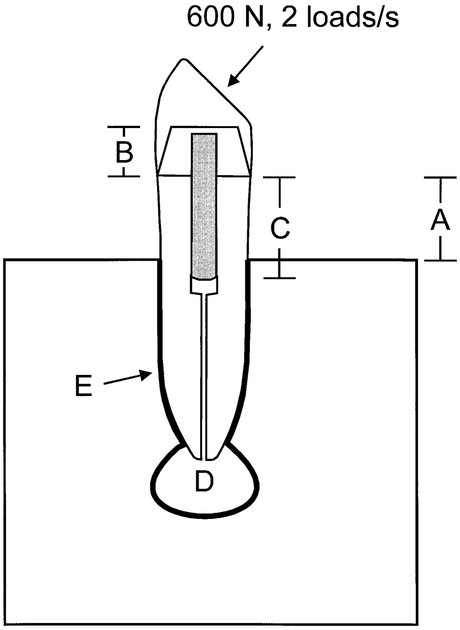

Fig. 1 Schematic drawing of root restored with prefabricated, parallel-sided post and resin composite core. A = 5 mm; length of root protruding from acrylic block; B = 3 mm; height of resin composite core; C = 6 mm; length of post luted in the root canal. D = ball of resin composite. E = artificial periodontal membrane of silicone

the angle of convergence was 15°, and the height of the ferrule (i.e. the vertical dentinal overlap of the crown) was 0 mm, i.e. the crowns were without ferrules.

Teeth planned to receive a post and core were wet-sectioned to leave 5 mm of root outside the acrylic block and restored with post and cores as described below and shown in Fig. 1.

Three types of prefabricated posts (a titanium alloy post ParaPost XH (Coltène/Whaledent, Mahwah, NJ, USA), a glass fiber reinforced resin composite post ParaPost Fiber White (Coltène/Whaledent, Mahwah, NJ, USA), and a zirconia post Cerapost (Gebr. Brasseler, Lemgo, Germany)) and two shapes of cast post and cores (parallel-sided posts ParaPost XP (Coltène/Whaledent, Mahwah, NJ, USA) and tapered posts) were studied. The composition and manufacturers of the investigated prefabricated posts and the cement are listed in Table 2.

Teeth assigned to receive ParaPost XP, ParaPost XH, ParaPost Fiber White, or Cerapost (Ceraposts were used "upside-down" in order for the Cerapost to be parallel-sided as are ParaPost XH and ParaPost Fiber White) were prepared with the calibrated ParaPost drill system to a final diameter of 1.4 mm. Teeth planned to receive a cast tapered post were prepared by a tapered drill Gerlach (Gebr. Brasseler, Lemgo, Germany) to a final coronal diameter of 1.5 mm. The length of the prepared root canal was 7 mm. After preparation, the canals were rinsed with deionized water for 2 min.

For fabrication of the cast post and cores, polyether impressions in Impregum Penta (3 M ESPE, Seefeld, Germany) were made following post preparation. For teeth planned to receive ParaPost XP posts, the corresponding impression plastic posts were placed in the post preparations, and for teeth planned to receive tapered posts, loose-fitting plastic pins were used to stabilize the impression material in the post preparations. The impressions were poured with Vel-Mix stone, ISO type IV (Kerr, Orange, CA, USA). Following the use of either ParaPost XP plastic burnout posts or waxed plastic pins, cores with the height of 3 mm and the angle of convergence of 15° were waxed on the dies and cast in sterling silver.

The effect of the surface treatment CoJet (3 M ESPE, Seefeld, Germany) was tested by the use of prefabricated posts. CoJet treatment consisted in air abrasion with an intraoral sandblasting device Dento-prep (Rønvig, Daugaard, Denmark) at 4 bar for 15 s using 30-µm silicate-coated particles followed by silane coating with ESPE-sil (3 M ESPE, Seefeld, Germany) according to the manufacturer's instructions.

Prior to luting of the posts, the root canals were dried with paper points Top Dent No. 45 (Svenska Dental Instrument, Upplands Väsby, Sweden) and treated with ED primer (Kuraray, Osaka, Japan) according to the manufacturer's

Table 2 List of investigated prefabricatedposts and cement

Post	Composition according to manufacturer	Manufacturer
ParaPost XH	90% titanium, 6% aluminum, 4% vanadium	Coltène/Whaledent, USA
ParaPost Fiber White	42% glass fiber, 29% resin, 29% filler	Coltène/Whaledent, USA
Cerapost	94.9% ZrO_2, 5.1% Y_2O_3	Gebr. Brasseler, Germany
Cement		
Panavia F	Silanated barium glass, silanated silica, sodium fluoride, BPO, photosensitizer, 10-methacryloyloxydecyl dihydrogen phosphate (MDP), dimethacrylate, hydrophobic and hydrophilic dimethacrylate, Bis-phenol A polyethoxy dimethacrylate	Kuraray, Japan
ED primer	10-methacryloyloxydecyl dihydrogen phosphate (MDP), HEMA, N-methacryl 5-aminosalicylic acid, sodium benzene sulfinate, N, N-diethanol p-toluidine, water	Kuraray, Japan

directions. The cement Panavia F (Kuraray, Osaka, Japan) was mixed according to the manufacturer's recommended procedure and applied in the root canal, and the post was luted to a length of 6 mm. The dual-curing Panavia F was light-cured for 20 s with a conventional quartz tungsten halogen curing unit XL 3000 (3 M ESPE, Seefeld, Germany). All specimens were allowed to set for 15 min. In the case of roots restored with prefabricated posts and resin composite cores, these were produced and prepared as previously described.

Crowns of sterling silver, which had occlusal surfaces with a 45° angle to the long axis of the teeth and a maximum height of approximately 7.5 mm, were cast. In the case of a crown without post and core, crowns were luted with Panavia F following application of ED Primer. In the case of a core only (no post) or a post and core, crowns were luted with Panavia F without application of ED Primer. The restored teeth were stored in water at 37°C for at least 1 d.

The resistance to cyclic loading of the restored teeth was tested at 37°C using two loads of 600 N/s until failure. The teeth were kept humid during testing by means of wet cotton cloth covering the exposed roots. The force was generated by an air cylinder at a pressure of 5.25 bar. The loading was perpendicular to the occlusal surface of the crown (i.e. 45° angle to the long axis of the tooth) as described by Isidor et al. [13]. The test machine recorded the number of loads, and the testing was automatically discontinued when the system failed by loss of retention or fracture of the root and/or the post.

Because of the non-normal distribution of the results, the median values were calculated for all experimental groups, and Mann-Whitney U-tests were used to analyze the results with corrections for multiple comparisons by the Bonferroni method [2]. The level of significance was set to α=0.05.

Results

The results of the cyclic loading tests are presented in Table 3. Teeth restored with a crown without post and core gave significantly higher resistance to cyclic loading than teeth restored with cores only (no post) or with post and cores. There were no significant differences in resistance to cyclic loading between teeth restored with cores only (no post) and teeth restored with post and cores, irrespective of surface treatment of posts.

Post shape had a significant effect in that teeth restored with parallel-sided cast post and cores (ParaPost XP) showed significantly higher resistance to cyclic loading than did teeth restored with tapered cast post and cores. Teeth restored with parallel-sided cast post and cores were also significantly more resistant to cyclic loading than teeth restored with untreated prefabricated ParaPost XH or ParaPost Fiber White posts and resin composite cores. However, no significant difference was found between teeth restored with parallel-sided cast post and cores and teeth restored with prefabricated Cerapost posts.

Table 3 Median and range of load units of 2× 600 N/suntil failure of the experimental groups (n =10)

Type of post restoration	Median	Range
No post, no core	1.009.525	689.771–1.726.399
No post	367.922	6.752–690.514
Cast tapered post	140.280	1.670–346.725
Cast parallel-sided post (ParaPost XP)	418.933	114.760–1.180.971
ParaPost XH, untreated	190.524	1.517–708.662
ParaPost XH, Cojet-treated	542.707	298.540–1.033.161
ParaPost Fiber White, untreated	169.837	845–497.218
ParaPost Fiber White, Cojet-treated	322.948	8.946–758.216
Cerapost, untreated	435.520	485–689.260
Cerapost, Cojet-treated	495.806	178.342–797.674

No differences were found in resistance to cyclic loading between the three types of prefabricated posts. This held true when the posts remained untreated as well as when the posts had been surface-treated. Consequently, all results obtained with untreated and with surface-treated posts, respectively, were pooled. Statistical analysis showed that surface treatment significantly increased the resistance to cyclic loading of teeth restored with prefabricated posts.

The vast majority of the restored teeth failed due to root fracture (94%). Fracture of post was observed for 3% of the restored teeth while loss of retention of post or core was responsible for the remaining 3% of the failures.

Discussion

This study found that teeth with a moderate reduction of tooth structure, i.e. teeth restored with crowns without post and cores, had higher resistance to cyclic loading than had teeth with a pronounced reduction of tooth structure, i.e. teeth restored with either a core or a post and core, and that the use of a post did not improve the resistance to cyclic loading. It was also found that the resistance to cyclic loading of teeth restored with post and cores was influenced by the shape, type (cast versus prefabricated), and surface treatment of the post.

Regarding the influence of the amount of remaining tooth structure, the difference found between teeth with a moderate reduction of tooth structure and teeth with a pronounced reduction of tooth structure, is in agreement with a number of other studies [8, 29, 36–38, 43]. Post and cores are usually inserted before the final restoration of destructed, endodontically treated teeth. The function of the post in the root canal is to improve the retention of the core. However, the preparation of the root canal for the post weakens the root and thereby increases the risk of root fracture. In vitro and in vivo studies of fracture strength and failure mode of teeth restored with various post systems (individually cast post and cores and prefabricated metallic or zirconia posts with resin composites cores) showed that the use of posts not only decreased the fracture strength or success rate of the teeth as compared to no post but also resulted in unrestorable fracture of the teeth [3, 12, 37, 43]. In the present study, in which the crowns had no ferrule, no differences were found in resistance to cyclic loading between teeth restored with a core only (no post) and teeth restored with a post and core. The explanation for this finding may be an effective adhesion between the resin composite cores and dentin combined with no weakening effect of root canal preparation.

Significantly higher resistance to cyclic loading was found for teeth restored with parallel-sided cast post and cores than for teeth restored with tapered cast post and cores. This finding supports the in vitro cyclic loading study of Isidor et al. [15], who found teeth restored with prefabricated parallel-sided post and cores to have higher resistance to cyclic loading than teeth restored with tapered cast post and cores. The authors suggested that the higher resistance of teeth restored with parallel-sided posts is due to a more even stress distribution of parallel-sided versus tapered post and cores. The even stress distribution of parallel-sided posts has also been confirmed by a number of photoelastic stress analyses [4, 11, 39]. The fact that higher resistance to cyclic loading was obtained when parallel-sided posts were used is also supported by two in vivo studies in which the survival rate of teeth restored with parallel-sided post and cores was higher than that of teeth restored with tapered post and cores [36, 42].

Teeth restored with parallel-sided cast post and cores were also more resistant to cyclic loading than teeth restored with parallel-sided untreated prefabricated posts of titanium alloy or glass fiber reinforced resin composite but equally resistant to cyclic loading as teeth restored with prefabricated zirconia posts. This finding is partially in contrast to that of a number of studies of static or cyclic loading as these studies found either no difference or higher resistance to loading of teeth restored with prefabricated post and cores as compared with cast post and cores [1, 14, 15, 30]. One explanation may be differences in the methods used. In some studies static loading, and not cyclic loading, was used to determine the fracture strength of the restored teeth [1, 30]. Another explanation may be differences in the shape or type of posts, in the load applied, and in the use/non-use of a ferrule. Isidor et al. [14, 15] compared the resistance to cyclic loading of teeth restored with tapered individually cast post and cores to that of teeth restored with parallel-sided prefabricated posts of titanium (ParaPost) or stepped (different coronal and apical diameter) parallel-sided carbon fiber posts (Composipost). Teeth were loaded using a force of 250 N. Crowns in these studies had a ferrule of 2 mm. However, in the present study, the teeth were loaded using a force of 600 N and the crowns had no ferrule. As no ferrule was used, the resistance to cyclic loading primarily depended on the stiffness of the core and of the post and on the bonding of the core to the dentin and to the post.

As regards the resistance to cyclic loading of teeth restored with prefabricated posts, no significant differences were found between the posts. According to the manufacturers, the prefabricated posts have the following values of modulus of elasticity: ParaPost XH = 112 GPa, ParaPost Fiber White = 29.2 GPa, and Cerapost = 200 GPa. A regression analysis performed on number of cyclic loadings until failure for the three posts (n =30) showed a significant influence of the modulus of elasticity of the prefabricated posts (p <0.01): the stiffer the post, the more resistant to cyclic loading. The positive influence of high modulus of elasticity of the post on resistance to loading is supported by previous studies [12, 24, 40].

The bond strength between various posts and luting agents, as well as the effect of post surface treatments on bond strength and retention of posts in the root canals have been investigated extensively [10, 17, 22, 23, 26, 27, 32–34, 41, 44–46]. The tribochemical silicate-coating system (CoJet) has been found to create an effective bonding of resin cement to various types of prefabricated posts [32–34], which is in line with the positive effect of tribochemical silicate-coating on resistance to cyclic loading found in the present study. The positive effect of surface treatment on resistance to cyclic loading may be assumed to derive from an effective bonding of resin cement to the posts with a reinforcing effect on the teeth [28].

Relatively large variations in resistance to cyclic loading were obtained within each experimental group. This is an inherent drawback associated with the use of human teeth. Although only maxillary incisors and maxillary and mandibular canines were used, variation occurred in the size of the roots. However, despite these variations, meaningful results and significant differences were found.

A load of 600 N was utilized in the present study because pilot tests had shown this load to result in failure of most teeth within a few days. Although this load seldom occurs clinically, it may be assumed that the mechanisms at play are identical for different loads and that the results of the present study apply also for lower levels of loading.

Generally, higher resistance to cyclic loading was obtained when the results of the present study are compared with the results of Isidor et al. [13]. In that study, the median number of loads of teeth restored without a ferrule was between 1 and 1.342. The discrepancy between the results of the two studies may be explained by differences in the teeth used (bovine versus human) in the post diameter, in the adhesive system used to bond the resin composite cores to dentin, and in the test conditions (dry versus humid).

The positive effect of a ferrule design on resistance to fracture has been demonstrated by a number of studies [3, 13, 35]. Because the present study focused on factors related to the posts, the weakest model, i.e. a no-ferrule design, was chosen. The use of ferrule may be anticipated to have resulted in higher resistance to cyclic loading for all teeth restored with cores or with post and cores, and possibly to have overshadowed the effect of post-related factors.

In the present study certain restorative methods proved to have a positive effect on resistance to cyclic loading of restored teeth. However, considering that failures related to teeth restored with post and cores do occur clinically, it is also important to study the failure mode of the restored teeth, i.e. whether some treatments lead to more favorable (restorable) failures than others. Therefore, the fracture modes that occur in the present study are currently being analyzed and will be presented in a separate paper.

Conclusions

Under the conditions of the present study, it may be concluded that the use of a post did not increase the resistance to cyclic loading compared with a resin composite core only. In the cases when posts were used, the resistance to cyclic loading was higher for parallel-sided posts than for tapered posts and for surface-treated posts as compared with untreated posts.

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