Adaptation of Adhesive Posts and Cores to Dentin After Fatigue Testing

Didier Dietschi, DMD*
Massimo Romelli, DMDb
Alessandro Goretti, DMDc

An in vitro nondestructive fatigue test was applied to adhesive posts and cores made on endodontically treated human teeth. Five post-and-core systems were evaluated: one zircon oxide post, two titanium posts (with resinous or ceramic coating), and two resin-fiber posts. Each test specimen was intermittently loaded and thermocycled. The scanning electron microscope observation of sample sections showed that only the interfaces between restorative materials and dentin exhibited substantial deficiencies. The Komet ER (Brasseler) exhibited the greatest percentages of continuity at the coronal (83.88%) or the radicular (78.12%) dentin levels, while the Zircon experimental post presented insufficient adaptation to the radicular (21.25% continuity) and to the coronal (53.25% continuity) dentin. Seven of eight samples in the Komet group showed root fractures. The carbon-fiber post (Compospost) behaved satisfactorily (67.38% radicular continuity), in spite of the use of an older bonding agent formulation. Int J Prosthodont 1997;10:498–507.

Root and post fractures, recurrent caries, or post decementation have a significant influence on treatment success and longevity.1-4 An analysis of clinical studies on post-and-core systems published since 1970 has reported ranges of survival rates varying from 98.6% after a follow-up of more than 10 years, to 77.6% after a mean period of 5.2 years.5 This extreme variation in longevity may reflect variations in materials and techniques or may be related to limitations in clinical studies and the absence of well-standardized evaluation criteria.

Because such failures are catastrophic,2,6 the fracture potential of restored nonvital teeth has been widely evaluated in vitro by using destructive mechanical testing methods. Such tests have demonstrated the biomechanical advantages of adhesive posts and cores.7,8 Recent studies have confirmed the value of adhesive techniques in restoring endodontically treated teeth.9-11 The failure mode of one adhesive system prototype was shown to be more favorable than a conventional post-and-core system.9 The use of adhesives also proved to significantly increase pull-out forces of composite-luted posts.12,13 However, one aspect of adhesive posts and cores that requires additional improvement is their tendency to exhibit marginal leakage.14

An expected benefit of adhesive posts and cores is their ability to overcome the esthetic deficiencies of traditional cast gold or amalgam cores, especially when an all-ceramic crown is to be placed. This esthetic concern has led to exploration of the feasibility of new ceramic post-and-core designs.15-19 Some
Table 1 Experimental Groups and Post Systems Under Investigation

<table>
<thead>
<tr>
<th>Groups</th>
<th>Trade name</th>
<th>Material</th>
<th>Geometry</th>
<th>E modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Komet</td>
<td>Komet ER (Brasseler)</td>
<td>Head: Titanium (Ti6Al4V) coating (PCR); (1) SiO2-C [Silicoater]; (2) Silane (Silicoup); and (3) Opaque composite (DentaColor 123, Kulzer)</td>
<td>Conical, with flare and retentive ball-shaped head</td>
<td>110</td>
</tr>
<tr>
<td>Cera</td>
<td>Ceramic, prototype (Dentsply-Maillefer)</td>
<td>TiN (Ti6Al4V)</td>
<td>Conical</td>
<td>110</td>
</tr>
<tr>
<td>Zircon</td>
<td>Sintered zircon (ZrO2-TiZP), machined and airborne particle abraded</td>
<td>Cylindrical</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Compo</td>
<td>Compospost (RTD)</td>
<td>Carbon fibers embedded in epoxy resin</td>
<td>Parallel-sided stepped</td>
<td>80: tensile 8: flexural</td>
</tr>
<tr>
<td>Exp</td>
<td>Experimental</td>
<td>Fiber-reinforced epoxy resin</td>
<td>Parallel-sided stepped</td>
<td>60: tensile 8.9: flexural</td>
</tr>
</tbody>
</table>

Dentin elastic-modulus = 2.4–2.7 × 10⁶ PSI = 16.5–18.5 Gpa (Craig and Peyton); root dentine E-modulus = 18 Gpa (Duret et al).

It has been emphasized that the necessity of using posts with biomechanical properties similar to those of natural tissues. Fatigue tests have been established as being an essential research tool for testing adhesive restorations, because they reproduce cyclic loading patterns comparable to physiologic function and therefore can simulate the results of time-consuming clinical trials. More recently such tests have been applied to posts and cores. The different materials used in posts and cores have fundamentally distinct physical properties, and it has been demonstrated that these materials can exhibit fundamentally different fatigue behavior. One shortcoming of testing protocols used for adhesive posts and cores is the destructive approach, which renders it difficult or impossible to characterize and localize the interfaces potentially responsible for the failure.

The purpose of this investigation was to study the different interfaces found in adhesive post-and-core restorations made with different post systems after a nondestructive in vitro fatigue test.

Methods and Materials

Sample Preparation

Forty human maxillary incisors and canines, extracted for periodontal or prosthetic reasons, were used for this study. The inclusion criteria were that the teeth were free of root carious lesions or fissures and had not been previously endodontically treated.

Teeth were stored in saline at 4°C prior to the experimental procedures and were arbitrarily assigned to one of the five experimental groups (Table 1).

Endodontic preparation was completed using a manual step-back technique to achieve an apical diameter of 0.30 mm. A single cone filling was placed using a eugenol-free root canal cement (Sealapex, Kerr) and gutta-percha (Standardized gutta-percha points, Dentsply-Maillefer). Crowns were then resected at the cementoenamel junction to provide only dentin surfaces for the adhesive procedures. The roots were prepared for post placement using an armamentarium and procedures specified in the information for use of each post system described (Table 1).

Restorative Procedures

Except for the specimens to be restored with the Compospost system, root canals were treated first with the self-etching ED Primer (Kuraray) before a passive placement of the posts into the canal filled with resin composite cement (Panavia 21 EX, Kuraray). A special isolating gel (Oxyguard, Kuraray), containing a polymerization catalyst was then applied to the preparation margins. After 5 minutes the isolating gel was washed away. All the resin deposits were removed from the dentin shoulder using rotating instruments without contacting the post. The remaining dentin surface was acid etched using a 37% H3PO4 gel (Ultraetch, Ultradent) for 10 seconds prior to the application of the Scotchbond multipurpose (SBMP, primer and adhesive (3M). The
bonding resin was light polymerized for 40 seconds. The coronal build-up was finally completed using an autopolymerizing hybrid resin composite (Ti-Core, Essential Dental Systems) inserted in an adjusted prefabricated plastic cap (Produits Dentaires SA).

For the Composipost samples, the root was first conditioned for 30 seconds using a 17% ethylenediaminetetraacetic acid (EDTA) dentin etchant, and a single layer of uncured resin was applied (Sealbond cement dentin etching and resin, RTD). The carbon posts were cemented with a proprietary composite cement (Sealbond cement, RTD). Excess material was removed using a brush before cement hardening, leaving a thin layer on the preparation shoulder to act as bonding agent for the further coronal restoration. The core was then developed using an autopolymerizing fiber-reinforced resin composite (Resilient, RTD).

The shaping of the core, the margin finishing, and polishing were performed under profuse water spray with diamond instruments (No. 8614 and 4062, Intensiv).

Fatigue Test

Each completed specimen was fitted into the test chamber of the mechanical fatigue device (Department of Restorative Dentistry and Endodontics and Laboratory of Electronics of the Medicine Faculty; University of Geneva) and fixed on a metallic holder (Al-Tec) with a small amount of light-activated resin composite before embedding the roots with an autopolymerizing acrylic resin (Technovit 4071, Kulzer). Sample holders mounted on an inclined rubber cylindrical base allowed the restored teeth to undergo motion along the 45-degree path of the experimental device (Fig 1). The construction and function of the apparatus used in this study closely resembled the device described by Krejci et al.24

All samples were submitted successively to 250,000 cycles of mechanical loading. The loading force was 70 N at a 1.5-Hz frequency following a one-half sine wave curve, and was produced by solenoids (Magnet AG). The restored teeth were contacted by an artificial tooth of simplistic design made of stainless steel having a hardness similar to natural enamel. The artificial tooth had a 45-degree angulated slot that guided the sample and maintained its spatial relationship with the device central axis (Fig 1). The maximum force was attained at the end of a 2.5-mm movement of the solenoid core in which the guide contacted the sample surface after a 1 mm displacement. The specimens remained immersed in saline at room temperature during the entire course of the test. Following the mechanical loading, the restored teeth were subjected to 5,000 thermal cycles of 1 minute each, with alternate immersion in water baths at 5°C and 55°C.

Sample Evaluation

After completion of the mechanical and thermal loading, samples were embedded in autopolymerizing epoxy resin. A slowly rotating saw (Isomet, Buehlers) was used to section samples into three segments with a central section of 800 µm. These sections were gently polished using a 600-grit glass paper and acid etched for 90 seconds with a H₃PO₄ gel (Ultratech). Polyvinyl siloxane impressions (President light body, Coltene) of the four observable surfaces were then made, and gold-sputtered epoxy resin models were prepared. These replicas were used for a semiquantitative analysis of the internal adhesive interfaces using scanning electron microscopy (SEM) at a standard × 250 magnification (Phillips XL 20i). The following interfaces were studied: (1) the coronal restorative material with the post head; (2) the coronal restorative material with the dentin; (3) the luting composite material with the post; and (4) the luting composite material with the dentin. Two evaluation parameters were considered: “continuity” and “internal gap” to characterize each portion of the interfaces.
The percentage of gap-free restoration-tooth interface (relative to the overall interface length) was then calculated. The occurrence of root fracture was also recorded and scored as present (P) or absent (A). The micromorphology of the interfaces with dentin was observed at a higher magnification (× 500 to × 1000) to determine, when present, the location of adhesive failures with respect to the dentin surface, the hybrid layer, and the luting or restorative composite layer.

The cement thickness was recorded at the middle post length on each side for all measurable sections. A mean for the interface integrity and cement thickness was calculated from the four sections of each sample; these values served for the calculation of each group mean. Nonparametric statistical analyses were performed for interface integrity evaluation by the Kruskall-Wallis and Nemenyi tests. Differences in the cement thickness were explored by analysis of variance (ANOVA) and the Scheffe F test. All tests were conducted at the 5% level of significance.

Results

The evaluation of the integrity of the core-dentin and cement-dentin interfaces, as measured in mean percentages of continuity, is presented in Figs 2 and 3. The detailed data and the results of the statistical analysis are presented in Tables 2 and 3.

Table 2 Percentages of Adhesive Interfaces in Continuity (± SD)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cement-dentin (%)</th>
<th>Core-dentin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zircon</td>
<td>21.25 ± 20.91</td>
<td>53.25 ± 26.33</td>
</tr>
<tr>
<td>Komet</td>
<td>78.12 ± 17.94</td>
<td>83.88 ± 15.33</td>
</tr>
<tr>
<td>Cera</td>
<td>59.50 ± 22.11</td>
<td>78.62 ± 16.61</td>
</tr>
<tr>
<td>Exp</td>
<td>54.12 ± 23.30</td>
<td>65.75 ± 22.21</td>
</tr>
<tr>
<td>Compo</td>
<td>67.38 ± 16.14</td>
<td>44.88 ± 15.77</td>
</tr>
</tbody>
</table>

Table 3 Statistical Analysis of the Influence of Restorative Materials on the Integrity of Cement-Dentin and Core-Dentin Interfaces as Related to Continuity Percentages

<table>
<thead>
<tr>
<th>Comparisons</th>
<th>Cement-dentin</th>
<th>Core-dentin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Komet vs Cera</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Komet vs Zircon</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Komet vs Compo</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Komet vs Exp</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Cera vs Zircon</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cera vs Compo</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cera vs Exp</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Zircon vs Compo</td>
<td>*</td>
<td>ns</td>
</tr>
<tr>
<td>Zircon vs Exp</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Compo Vs Exp</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

*P < 0.05
**P < 0.01
ns = not significant.
Post-Core Material and Post-Luting Cement Interfaces

The post-core material interface presented virtually no adhesion defect, while for the post-luting cement interface, 10.75% of debonding was observed in the Zircon group (Fig 4). The difference with other groups was significant.

Core-Dentin Interface

After the fatigue test, the percentages of adhesive interfaces in continuity varied from 44.88% (Compo) to 83.68% (Komet). The Komet and Cera samples (Fig 5) presented significantly less interfacial defects than the Compo samples. The Komet restorations also presented significantly higher values of interface continuity as compared to the Zircon and Exp restorations (Fig 6).

In samples made with the SBMP adhesive, a uniform acid-resistant layer was generally observed between the restoration and dentin that was likely a hybrid layer (Fig 5). This layer was not consistently and clearly present in the Compo samples, which used the sealbond adhesive (Fig 6). When debonding occurred in the groups using SBMP, the gap was mainly observed between the acid-resistant (hybrid) layer and the coronal restoration (Fig 7). In Compo samples, defects were also adhesive (Fig 6).
Fig 8. The carbon-epoxy posts (Composipost) (C) produced greater proportions of continuity with the dentin (D) at the radicular level of specimens, probably because of their favorable mechanical properties. (SEM, original magnification x 251.)

Fig 9. The zircon posts (ZR), which are highly rigid, had a detrimental effect on the radicular adaptation to dentin (D). (SEM, original magnification x 103.)

Fig 10. The use of the Panavia cement and its self-etching primer also produced an acid-resistant layer (HL) having a less regular structure and occurrence. No resin tags were found within the dentinal tubules. (SEM of a Zircon sample, original magnification x 500.)

Fig 11. With the Komet posts, numerous fissures were present, although great proportions of continuity were attained at both the coronal and radicular levels. (SEM, original magnification x 100.)

Cement-Dentin Interface

After the fatigue test, the percentages of adhesive interfaces in continuity ranged from 21.25% (Zircon) to 78.12% (Komet). The Komet and Complo restorations presented significantly fewer interfacial gaps than the Zircon and Exp restorations (Figs 8 and 9).

The acid-resistant (hybrid) layer was less consistently observed in the radicular portion of the preparations where ED-Primer and Panavia were applied. When present, the layer was found to be less regular and did not show tags within the underlying dentin (Fig 10). In the Complo samples, as in the coronal surfaces, no well-organized structure was observed between the luting composite and the dentin.

Radicular Fractures

In the Komet groups, seven of eight samples presented radicular fractures (Fig 11). Two fracture locations were generally observed next to the angle or under the level of the box. The first location of fracture, which was the less frequent, was mainly oblique. The other type of fracture ran parallel to the post, with some extensions perpendicular to the post and the external root surface (Fig 11). A few fractures in the radicular dentin, of which the extension was limited, were also observed in two samples of the Zircon group.
Table 4  Mean Cement Thicknesses

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cement thickness (± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zircon</td>
<td>115.48 ± 31.3 μm</td>
</tr>
<tr>
<td>Komet</td>
<td>98.26 ± 27.35 μm</td>
</tr>
<tr>
<td>Cera</td>
<td>96.53 ± 27.68 μm</td>
</tr>
<tr>
<td>Exp</td>
<td>71.71 ± 10.53 μm</td>
</tr>
<tr>
<td>Compo</td>
<td>55.22 ± 7.35 μm</td>
</tr>
</tbody>
</table>

Groups connected by the same line are not statistically different.

Cement Thickness

The cement thickness was significantly greater for the Zircon samples compared to that of the Compo and Exp groups (Table 4). Among all groups the Compo samples presented the thinnest layer of composite cement.

Discussion

Materials and Methods

Covering the post-and-core restoration with a crown was shown to negate its influence on the mechanical resistance of the endodontically treated tooth.29-31 Clinical studies have demonstrated the importance of having a crown with a circular collar around endodontically treated teeth to improve long-term clinical success.32-33 In vitro tests have confirmed the importance of intact coronal tooth substance on the mechanical resistance of the restored nonvital tooth.26,29,36 In the present study, samples had only a shoulder finishing line for the core and no crown placement; therefore the interfaces to be studied sustained maximal stress during fatigue testing.

The artificial chewing cycle was designed to correspond as closely as possible to physiologic conditions. The magnitude, duration, and frequency of the force applied lay within values reported in vivo, and the shape of the force curve also resembled the orally generated forces.37-44 The force was applied with a 45-degree angle to the tooth's long axis, in accordance with most of the published reports on post-and-core fracture and fatigue tests.11,45,46 This configuration provided an even distribution of the force along and perpendicular to the root, and replicated flexion stresses resulting from protrusive movements.

Different material and design variables must be considered in the data analysis. There are variables inherent to human tooth anatomy and dentin quality that could account for some deviation in the results. The differences related to post design simply reflect the absence of a consensus treatment philosophy for the endodontically treated tooth.47 Composipost is a complete restorative system developed in accordance with the special characteristics of the carbon fiber post. Another selection of adhesive, luting cement, and core material was made for all other post systems that lacked specific manufacturer's recommendations.

Post-Core, Luting Cement–Post Interfaces

The micromechanical retention provided by the aluminum oxide plasma of Ceramic post prototype posts, the sites available for a chemical adhesion on the resin-coated Komet post, and the resinous matrix of Composiposts and experimental posts allowed the interface with the core material to satisfactorily withstand the fatigue test. Only samples in the Zircon group exhibited defects at the interface between the restorative materials and posts. It is unlikely that the 10-META cement developed an adhesion with the ceramic or that the microretention provided in densely sintered zircon oxide by airborne particle abrading was fully efficient, although this conditioning procedure proved to be the most efficient one.48

Core Build-up–Dentin Interface

Defects essentially developed within the interfaces with tooth substrate at the level of the coronal or radicular portions of the restoration. The relatively unsuccessful adhesion of the restoration to dentin in the Compo group is likely attributable to the adhesive used. The Sealbond adhesive, which is part of the Composipost original kit, did not formerly provide a hydrophilic primer, which has been proven to be essential in dentin bonding and hybrid layer formation.49,50 This component was only recently added to the Composipost system. This interpretation is corroborated by the absence of an acid-resistant zone underneath the coronal build-up in Compo samples, which could be clearly identified in the other groups that used the more recent and effective SBMP adhesive system (Figs 6 and 7). However, because dentin tubules are mainly cut parallel to their long axis, no tags were found at the coronal level of the preparations.

The elastic modulus of Resilient, a moderately filled composite material, used in the Compo group, was only 8.3 GPa, but it was 22 GPa for the Ti-Core, the highly filled material used in all other samples. A reduced rigidity favors stress absorption but increases deformation. It was not possible to ascertain which phenomenon predominated.
Luting Composite–Dentin Interface

The high elastic modulus of a ceramic material (see Table 1) could account for the high incidence of debonding measured in the Zircon, because forces are likely to be transmitted directly to the post-tooth interface without stress absorption. The shape of the post is another consideration, and in this study only the Zircon post was perfectly cylindrical. Parallel-sided posts, particularly those serrated and passively inserted, exhibit better stress distribution in photoelastic analysis.31-33 They show a reduced potential to fracture,34 and seem to have a higher clinical success rate.3 No advantage of the parallel-sided design was demonstrated in this study. The Composiposts and the experimental resin-fiber posts are also parallel-sided, but have steps, which undoubtedly improve their adaptation to natural tooth and root canal anatomy.20,21 The elastic moduli of these posts (see Table 1) are much closer to the natural tissue properties20,28 than the ceramic or titanium posts. Although a less effective adhesive was used for the Composipost samples, they did not show higher proportions of debonding at the cement-dentin interface, which suggests the favorable influence of the carbon fiber–epoxy post elasticity. This confirms the results of a previous fatigue study.11 The experimental posts, which were composed of different mineral fibers embedded in an epoxy resin, had a lower elastic modulus than the Composiposts (see Table 1). Because these were luted using the ED primer–Panavia combination, one may suspect that the reduced rigidity of this experimental post accounted for the absence of improvement and the reduction in the continuity score when compared to the Composipost group.

When adhesive failures occurred, they were systematically observed between the surface of the acid-resistant (hybrid) layer at the top of dentin and the luting cement (see Figs 9 and 10). The ED primer, a so-called self-etching primer, effectively made possible a modification of the smear layer and a dentin hybridization, but of somewhat irregular appearance and without tag formation (see Fig 10). The difficulty in adhering the luting composite to this hybrid layer is not yet clearly understood. It can be hypothesized that the pressure exerted during post placement on the demineralized dentin surface could compact or disturb the superficial collagen meshwork, and thus reduce its potential for adhesion. A similar phenomena is thought to occur with other types of bonded restorations when the bonding resin is not polymerized prior to restoration placement.35,36 An excess of water within the tissue, an insufficient penetration of the products through the smear layer, and, in the dentin, imperfect chemical reactions and resin polymerization are other hypotheses for explaining the bond deficiency between the luting agent and the treated dentin.

Komet presented the best results overall in coronal and radicular adaptation to dentin. However, significant radicular fractures were found in seven of eight samples. The reason for this remains unclear. The Komet post body taper approximates that of Cerametric and should therefore not be a factor. Whether the existence of a flange and a larger post head could have influenced stress distribution and development remains to be evaluated.

Cement Thicknesses

The Young’s modulus of luting cements is thought to be a significant parameter in crown fracture resistance when thick layers are considered.37 The cement deformation under loading is the important factor. In the present study configuration, the luting cement should also have deformed and therefore should have acted as a stress absorber between the post and the tissues, and the efficacy would be proportional to cement thickness. Although some significant differences were detected among groups, especially the Zircon group which exhibited the thicker mean cement layer, this parameter failed to demonstrate its influence on the development of adhesive failures.

General Considerations

The experimental protocol applied for this fatigue test proved to have the potential to identify the weak interfaces in post-and-core restorations, and made possible the localization of adhesion failures by a nondestructive approach. The sensitivity threshold of the sample evaluation method also appears to have adapted to the evaluation of modern adhesive post-and-core restorations. The standardization of post design and the use of similar restorative components is recommended for future research applying this testing method.
Conclusions

Five post systems were tested under fatigue loading to evaluate adhesive post-and-core system interfaces. Within the parameters of the study design and the materials tested, the following conclusions may be made:

1. Only the interfaces between restorative materials and dentin showed significant defects.
2. Among the five adhesive post systems tested (Komet ER, Ceramic prototype, Composipost, Zircon experimental post, and a resin-fiber experimental post), the Komet ER post exhibited the greatest continuity between coronal and radicular interfaces, although samples in this group presented root fractures.
3. The ceramic post (Zircon experimental post) had an adverse influence on post-and-core adaptation to dentin, probably as a result of its high rigidity.
4. The Composipost mechanical properties, which are close to those of natural dentin, appeared to be beneficial.
5. The use of a modern dentin bonding agent with a comprehensive adhesive system appeared to be mandatory for improving dentin adhesion.

Acknowledgments

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References