An in vitro comparison of cast metal dowel retention using various luting agents and tensile loading

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Statement of problem. No clear consensus exists regarding the choice of luting agents for the retention of cast metal dowels used as a treatment alternative for endodontically treated teeth with excessive loss of coronal tooth structure.

Purpose. The purpose of this in vitro study was to investigate the retention of the dowel/luting agent/tooth complex while applying different luting agents to cast metal dowels under vertical tensile loading.

Material and methods. Sixty extracted, noncarious mandibular premolars with roots of approximately 15-mm length were selected. For each tooth, a tapered root canal preparation was completed to a maximum diameter of 1.60 mm and a length of 11 mm, a common clinical configuration to accommodate cast metal dowels. Sixty cast metal dowels were fabricated for the tooth specimens and cemented with 1 of 3 luting agents (n = 20): zinc-phosphate cement (ZPC) as a control, phosphate-methacrylate resin luting agent (PMRL, Panavia F), and phosphate-methacrylate resin luting agent with metal dowel surfaces modified with a silane coating technique (PMRLS, Panavia F + Siloc). Tensile bond strength (TBS) of the specimens was measured with a universal testing machine at a crosshead speed of 0.5 mm/min. Data (kg) were statistically analyzed using a 1-way analysis of variance and a Scheffe multiple range test (α=.05). The homogeneity of variances was analyzed using the Levene test.

Results. The TBS values of ZPC (34.2 ± 10.54 kg) were significantly higher than PMRL (22 ± 9.57 kg) and PMRLS (21.7 ± 7.64 kg). There was no significant difference between the PMRL and PMRLS groups.

Conclusion. Within the limitations of this study, the use of zinc-phosphate cement provided greater TBS for cast metal dowels than the resin luting agent with and without the silane coating technique. The TBS values with and without the silane coating technique were not statistically different. (J Prosthet Dent 2005;93:446-52.)

CLINICAL IMPLICATIONS

The use of cast metal dowels is common in restorative dentistry. This study demonstrated that zinc-phosphate cement can provide superior retention for cast metal dowels relative to the phosphate-methacrylate resin luting agent with or without the silane coating technique. Consequently, practitioners may opt to choose zinc-phosphate cement over the other materials tested when providing this treatment.

The successful restoration of an endodontically treated tooth is an ongoing challenge for a restorative dentist.1-3 Cast metal dowels are used as a method for dowel-and-core fabrication, and have been used to provide long-term tooth structure replacement for endodontically treated teeth with moderate to severe damage.4,5 Cast dowels are best used for single-rooted teeth and may be fabricated directly or indirectly.4-6 The retention of a dowel in a root is critical for the longevity and success of this treatment. Studies have reported that design, length, and character of the surface of endodontic dowels have an influence on their retentive properties.2-4,7 Furthermore, the ability of a luting agent to retain a dowel can affect the prognosis of a restoration.4,7 All dowels gain their definitive retention by cementation into a prepared root.2,8-10 Currently, a large variety of luting agents are available for this purpose. Studies have provided conflicting results in regard to the performance of different types of luting agents in retaining dowels.1,2,7,8,10-14 The ability of different luting agents to retain dental dowels is related to the mechanical properties and durability of a luting agent, the bonding ability of a luting agent to the surfaces being joined, and the configuration of a dowel and prepared canal.2,15-17 The luting agents currently available for dental restoration are zinc-phosphate, polycarboxylate, glass ionomer, resin-modified glass ionomer, compomer, and adhesive resin cements.4,18 Morgano and Brackett4 showed that there are distinct advantages and inherent disadvantages for each material category.

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The authors reported that polycarboxylate and glass-ionomer cements provide a weak chemical bond to dentin. Polycarboxylate cements have been reported to undergo plastic deformation after cyclic loading and may be less retentive than zinc-phosphate and glass-ionomer cements. Glass-ionomer cements are known to require several days and even several weeks to reach maximum strength, making this choice unsuitable as a cement for dowels. Resin-modified glass-ionomer cements, although suggested for cementation of dowels, can imbibe water and expand with time. Zinc-phosphate cement has been the gold standard luting agent for decades. However, resin luting agents have also been studied extensively, and several investigations have evaluated the retention of interradicular dowels using adhesive resins. Some studies demonstrated that adhesive resin luting agents are more retentive than zinc-phosphate cement for dowels. However, other studies have demonstrated conflicting results based on shrinkage stress and the difficulty in manipulating a phosphate-methacrylate resin luting agent. Shrinkage stress results in debonding of the luting agent from dentin and a tendency of the bonding of phosphate-methacrylate resin cement to fail in the root canal. Additionally, difficulty in manipulation, which results in the premature polymerization of the phosphate-methacrylate resin luting agent, can prevent a complete seating of dowels into root canals.

In the dowel–luting agent–tooth complex, there are several regions that may be a weak link in the outcome of treatment, depending on the luting agent used. These regions include the luting agent–dentin interface, the dentin, and the luting agent–metal interface. With respect to the luting agent–metal interface, metal surfaces may be altered in a variety of ways to improve adhesion, including airborne-particle abrasion, etching, and silane coating. The silane coating technique has been used for both noble and base alloys and has also been proposed for use in combination with phosphate-methacrylate resin luting agents. This technique pyrolytically applies a silica bonding layer to the surface of a metal. A bifunctional silane-coupling agent, which bonds the silanol groups of a silica layer with the monomers of acrylic resin, is then added to enhance bonding between the resin and metal surface. It was reported that a strong chemical bond is produced between metal and resin as a result of the silica-silane bond that promotes adhesion. However, other studies indicate decreased or unchanged bond strengths of adhesive resin luting agents with base metal alloys when used with silane coating. A silane coating technique (Siloc) has been recently developed to simplify the regimen. It is also applicable to both noble and base alloys and is used to provide a chemical bond between the silica layers coated to an airborne-particle–abraded metal surface and a resin composite. Limited information is available about the bond strength of cast base metal dowels with a silane coating surface treatment. The objective of this in vitro study was to compare the retention of cast metal dowels when cemented with a zinc-phosphate, a phosphate-methacrylate, and a phosphate-methacrylate resin luting agent together with a recently developed silane coating metal surface treatment technique.

**MATERIAL AND METHODS**

Sixty mandibular, noncarious premolars with root lengths of approximately 15 mm were selected for this study. Specimens were extracted within the last 6 months due to periodontal involvement. Teeth were stored in a 0.1% M NaCl (0.9%) isotonic sodium chloride solution at 22°C. The crowns were separated from the roots 1 mm above the cementoenamel junction with a diamond-coated disk (Superflex; Edenta AG Dentalprodukte, Au/SG, Switzerland) under constant water spray. Root canals were widened using tapered burs (Lindemann; Edenta AG Dentalprodukte) with 11-mm-long cutting surfaces that provided a continuous, uninterrupted taper from the apical end of the preparation with a 0.5-mm diameter to the coronal 1.6-mm diameter opening. Root specimens were chosen from the set of 60, and the canals were lubricated with petrolatum. For a single specimen, a solid plastic sprue (Williams Sprues; Williams Dental, Amherst, NY) was trimmed so that it could easily slide into the canal. Blue inlay wax (Blue regular inlay wax; Heraeus Kulzer, Hanau, Germany) was introduced into the canal followed by the sprue to register the morphology of the root canal. A rubber loop was placed at the end of the sprue to allow attachment to the tensile testing apparatus. Another sprue was attached to the opposite side of the rubber loop so it was parallel to the sprue located in the root. These 2 sprues and the rubber loop were
aligned so that the sprues and the center of the loop were parallel. Finally, a pattern was obtained that was composed of a dowel and rubber loop. This pattern was duplicated with acrylic resin (Palavit G; Heraeus Kulzer) in a flask. After all specimens were fabricated, this procedure resulted in 60 dowel acrylic resin patterns, each with a loop and sprue. The dowels were evaluated for fit in all 60 prepared teeth. The canals were lubricated with petrolatum. The coronal aspects were reconstructed by applying the same acrylic resin with a brush. After the acrylic resin had polymerized, the patterns were removed from the roots. Blue inlay wax was placed in the voids, and the pattern was reinserted in the root. This procedure was repeated until the dowel pattern was satisfactory. Afterwards, the coronal foundation was shaped to a 4-mm height and a 3.7-mm diameter of acrylic resin. In consideration of the shrinkage of acrylic resin, the preparation depth was marked on the tapered bur (Lindemann; Edenta AG Dentalprodukte) to verify that the dowel was as long as the dowel space. This length was then compared with the length of the dowels to ensure that shrinkage was not a limitation of this study. The acrylic resin specimens, ready for casting, were placed into a metal casting ring (Whip Mix, Louisville, Ky). The investment (Bellavest T; BEGO, Bremen, Germany) was prepared using a vacuum mixer (Motava SL; BEGO) and poured into a casting ring. The specimens were cast using an induction casting machine (Fornax 35K-F; BEGO). A metal alloy composed of 61.3% Ni, 26% Cr, 11% Mo, 1.5% Si, 0.1% Mn, 0.03% C was prepared according to the manufacturer’s recommendations. Equal amounts of self-etching primer (Panavia F; Kuraray) liquids A (2-hydroxyethyl methacrylate [HEMA], N-methacryloyl
d

<table>
<thead>
<tr>
<th>Composition</th>
<th>Brand name</th>
<th>Manufacturer</th>
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<tbody>
<tr>
<td>Zinc-phosphate cement</td>
<td>Harvard</td>
<td>Richter &amp; Hoffmann Harvard Dental, Berlin, Germany</td>
</tr>
<tr>
<td>Phosphate-methacrylate cement</td>
<td>Panavia F</td>
<td>Kuraray, Osaka, Japan</td>
</tr>
<tr>
<td>Silane metal surface conditioning system</td>
<td>Siloc</td>
<td>Heraeus Kulzer, Hanau, Germany</td>
</tr>
<tr>
<td>Dowel metal (61.3% Ni, 26% Cr, 11% Mo, 1.5% Si, 0.1% Mn, 0.03% C)</td>
<td>Kera N</td>
<td>Eisenacher Dentalwaren, Oben, Germany</td>
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For the control group (ZPC), a zinc-phosphate cement (Harvard; Herstellungs-und ertriebsgesellschaft Richter & Hoffmann Harvard Dental, Berlin, Germany), in the proportion 1.5/1 g/mL, was mixed on a clean glass slab for 1.3 minutes at 20°C. Then, zinc-phosphate cement was applied to the dowels with a plastic instrument, and the dowels were inserted into the roots. Next, a 5-kg constant load was applied to the specimens for 10 minutes until the cement set. After dowel cementation, the root canals were etched with 35% phosphoric acid gel (K Etchant; Kuraray) for 15 seconds, rinsed with water spray for 2 minutes, and dried with cotton paper points. The metal surfaces were rinsed with water and dried with compressed air before cementation.

In the second group (PMRL Group), a phosphate-methacrylate resin luting agent (Panavia F; Kuraray) was prepared according to the manufacturer’s recommendations. Equal amounts of self-etching primer (Panavia F ED primer; Kuraray) liquids A (2-hydroxyethyl methacrylate [HEMA], N-methacryloyl
d

Finally, excess cement was removed, and each specimen was cleaned with a moist cotton roll. After the casting was completed, all castings were allowed to cool to room temperature, and the investment material was removed from castings by airborne-particle abrasion with aluminum oxide (250 μm). The fit of the dowel cores in the teeth was evaluated with light finger pressure, and the cast metal dowel cores were airborne-particle abraded with 250-μm aluminum oxide for complete seating in the root canals (Fig. 1). The grain size of 250 μm was chosen because it has been found to produce an optimal surface for allowing a strong bond of the base metal alloy to the silane-coated layer.27,28 Retentive notches were placed on the outer surfaces of the roots with an inverted cone carbide bar (Lot 05151197; Diatech Dental, Heerbrugg, Switzerland). A mixture of autopolymerizing acrylic resin (Tru-Kit; Harry Bosworth, Skokie, Ill) was poured into rectangular boxes with dimensions of 3 × 2 × 2 cm to form a solid block to hold the roots during testing. Cast metal dowel and cores seated in the prepared canal were then embedded into the acrylic resin in the boxes at the level of a cementoenamel junction while the upper sprue was located in a surveyor (BEGO). The surveyor was used to embed the specimens perpendicular to the base of the boxes to ensure tensile loading occurred along the long axis of the root canal. These 60 standardized specimens were then assigned to 3 groups of 20 specimens each to accept a variable luting regimen. Before dowel cementation, the root canals were etched with 35% phosphoric acid gel (K Etchant; Kuraray) for 15 seconds, rinsed with water spray for 2 minutes, and dried with cotton paper points. The metal surfaces were rinsed with water and dried with compressed air before cementation.
5-aminosalicylic acid [5-NMSA], 10-methacryloxydecyl dihydrogen phosphate [MDP]) and B (5-NMSA) were mixed together in a mixing dish, applied with a brush inside the canal, and allowed to stand for 60 seconds. Excess liquid was eliminated with a paper point before completely drying the primer with a gentle air flow to delay the polymerization process. Equal amounts of the phosphate-methacrylate (Panavia F) paste A (MDP, bisphenol-A-glycidyldimethacrylate [Bis-GMA], filler, benzoyl peroxide, and photoinitiator) and B (Bis-GMA, filler, sodium fluoride, and amine) were then mixed for 20 seconds on the mixing plate and applied with a brush to the dowel. The dowel, covered with cement, was inserted into the root canal. A 5-kg constant load was applied to the specimens. The excess cement at the margins was light-polymerized for 2 seconds with conventional halogen by means of a light (Translux EC; Heraeus Kulzer) for easy cleanup, and removed with an explorer. The antioxidizing agent supplied with the material was applied to the margins of the specimens.

In the third group (PMRLS Group), a surface conditioning procedure involving the use of methacryloxypropyl trimethoxysilane (Siloc; Heraeus Kulzer) was used. This system was recently developed by the manufacturer from the classical Silicoater system. This procedure is recommended by the manufacturer for use with all metals and has also been investigated with adhesive luting agents such as phosphate-methacrylate monomers. Siloc Pre material, purported to be an SiO2-reinforced polymer bond layer by the manufacturer, was first applied uniformly with a disposable brush on the cast metal dowel surfaces and allowed to dry for 2 minutes. When the application of Siloc was completed, Panavia F primer and paste were applied as previously described for the PMRL Group. After allowing an hour for the cementation, the specimens were returned to the isotonic NaCl solution for 15 days at 22°C. The composition, brand name, and manufacturer for the 3 luting materials and casting alloy are listed in Table I.

Each acrylic resin block was mounted firmly to the lower jaw of a universal testing machine (Lloyd EZ50; Lloyd Instruments, Hampshire, England). The upper sprue portion of the casting was connected to the upper member of the testing machine. The prepared specimens were subjected to tensile forces along the long axes of the dowel and tooth at a crosshead speed of 0.5 mm per minute. The force required to dislodge each dowel was recorded in kilograms. For each of the groups, the mean, SD, SE, and minimum and maximum values were calculated according to the data output obtained from the universal testing machine.

Statistical analysis was performed using 1-way analysis of variance (ANOVA), the homogeneity of variances was evaluated using the Levene test, and paired comparisons of the groups were performed using the Scheffe test. Differences were considered significant at α = .05.

RESULTS

According to the test results (Tables II and III), the difference between the second and third groups was not significant. Although the retentive strength of the phosphate-methacrylate resin luting agent (Panavia F) was found not to be significantly different than that of phosphate-methacrylate resin luting agent with metal dowel surfaces modified by silane coating.
(Siloc + Panavia F), the latter resulted in a slightly lower mean value. However, the tensile bond strength of zinc-phosphate cement was found to be significantly higher than the specimens cemented with phosphate-methacrylate resin luting agent \((P<.05)\).

**DISCUSSION**

Although the mode of failure measured in this investigation may not directly correspond to the clinical scenario, standardized tensile strength tests are an accepted measure of retentive values for luting agents used with a cement-root-dowel interface.\(^1,2,7,11,14,15,20\) For this reason, tensile strength testing was used in this study. The phosphate-methacrylate resin luting agent (Panavia F), which was also used as an adhesive resin luting agent in the present study, is commonly used for bonding cast alloys to tooth structure and has been shown to bond to both airborne-particle abraded base metal alloys and noble alloys.

In the studies concerning the bond strength of this luting agent, higher bond strengths were observed for base metal alloys than for noble metal alloys.\(^1,2,22,33\) This luting agent differs from existing resin composites, such as conventional resin luting agents, in that a phosphate ester has been added to the monomer to create a dental adhesive using both mechanical and chemical bonding.\(^12,18,19,24\) This phosphoric-acid type of monomer is adhesive to the oxide layer of base metals and plays an important role in the metal-resin bond.\(^22,23\) The phosphate-methacrylate luting agent is also recommended for use with silane-coated base metal alloys.\(^22,32\)

Contrary to the present study, some studies have reported significantly greater retention for cast metal dowels cemented with phosphate-methacrylate luting agents\(^2,8,9,11\) as opposed to zinc-phosphate cement when comparing tensile forces. For example, Chan et al\(^2\) compared the vertical retention of various luting agents, including zinc-phosphate and phosphate-methacrylate monomer luting agents, with stainless steel dowels and obtained higher resistance to dislodgement by vertical tensile forces for Panavia than for zinc-phosphate cement.

However, there are also studies that concur with the results of the present study.\(^4,10,13\) In an in vitro study of phosphate-methacrylate monomer luting agents, Tjan and Nemetz\(^13\) demonstrated that substantial voids were present with an adhesive resin luting agent and suggested that these voids were responsible for the unexpectedly low retentive values for dowels luted with resin luting agents. Additionally, Bouillaguet et al\(^10\) investigated microtensile bond strength between adhesive luting agents and root canal dentin. These authors indicated that bonding for some materials, such as dual-polymerized Panavia F, tends to fail in the intact root canal. The polymerization shrinkage stress in the confinement of the intact root canal is reported to exceed the bond strength, causing the bond of the luting agent in the root canals to fail\(^10,12\) Adhesive resin luting agents are also technique-sensitive, and there have been reported difficulties in manipulating resin luting agents in vitro.\(^4,7,8,10,13,14\) In a study of the retention of dowels under tensile forces, Mendoza and Eakle\(^9\) observed no significant difference between a non-resin-containing luting agent and an adhesive resin luting agent (Panavia) but mentioned difficulties in manipulating the resin luting agent. Because of premature polymerization of the resin, some dowels did not seat in the root canals. Although a premature polymerization was not observed in the present study, this should be considered as a factor in evaluating bond strengths.

Some studies of microleakage indicate that zinc-phosphate cement caused more microleakage of dowels and cores and other restorations than resin luting agents.\(^17,18\) These authors report that this was due to the greater solubility of zinc-phosphate cement.\(^16,18\) Although in the present study, higher retention values were observed with zinc-phosphate cement, dissolution of this type of cement should also be considered, as it may negatively affect retention over time.

Studies have shown that the bond between resin-based luting agents and metal alloys is made considerably stronger with the use of a surface modification procedure of metal alloys, such as silane coating.\(^22,25,26,28,31\) Silica coating not only promotes adhesion but also reduces gap formation at the resin and metal interface.\(^28,30\) The silane coating procedure resulted in higher bond strengths with base metal alloys than noble alloys in some studies, and using this procedure was suggested for the treatment of base metal alloys to improve bond strengths with adhesive luting agents.\(^22,26,29\) However, there are also some studies that observed decreased bond strength of base metal alloys with silane coating.\(^12,23\) Bahannan and Lacefield\(^12\) concluded that the bond strengths between phosphate-methacrylate resin luting agents and base metal alloys were significantly more effective compared to the bond strengths of silane coating. Furthermore, the phosphate-methacrylate resin luting agents alone appeared to be easier to use. In another investigation conducted by O’Keefe et al,\(^11\) the silica coating treatment of Ni-Cr cast dowels and cores apparently interfered somewhat with the tensile bond strength of phosphate-methacrylate resin luting agents. Both of these conclusions support the findings of the present study, as Panavia F showed slightly higher tensile bond strength values than Panavia F with the Siloc surface-conditioning technique. This may be the result of the Siloc surface-conditioning technique covering the oxide layer and decreasing the bond strength of functional monomers, such as Panavia F, which have a high affinity for metal oxides such as chromium, tin, and copper.\(^25,24,34\)
Although clinical recommendations can be made, there are certain limitations to the present study that must be considered. Complicating variables were eliminated to help simplify the analysis of data. Variables such as temperature changes, which are common in an oral environment, may also affect the properties of luting agents. Additionally, the occlusal forces are much more complex than forces applied using a simple tensile test. Shearing, rotational, and cyclical forces are also placed on teeth and restorations. Future research should consist of in vitro tests that more accurately replicate the clinical condition.

CONCLUSION

This in vitro study used tensile testing to allow for dowel retention comparisons of a conventional zinc-phosphate, a phosphate-methacrylate resin, and a phosphate-methacrylate resin luting agent with the metal dowel surfaces modified by a silane coating. Within the limitations of this study, the tensile strength of zinc-phosphate cement was significantly higher than that of the phosphate-methacrylate resin luting agent when used with and without the silane coating treatment of cast metal dowel surfaces. There was no significant difference observed between the tensile bond strengths of the phosphate-methacrylate resin luting agent when used with and without the silane coating treatment. The cast metal dowels without silane coating surface treatment showed slightly higher mean retentive values.

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REFERENCES

A 10-year randomized clinical trial on the influence of splinted and unsplinted oral implants retaining mandibular overdentures: Peri-implant outcome


**Purpose:** This randomized controlled clinical trial aimed to evaluate the efficacy of splinted implants versus unsplinted implants in overdenture therapy over a 10-year period.

**Materials and Methods:** The study sample comprised 36 completely edentulous patients, 17 men and 19 women (mean age 63.7 years). In each patient, 2 implants (Bränemark System, Nobel Biocare, Göteborg, Sweden) were placed in the interforaminal area. Three to 5 months after placement, they were connected to standard abutments. The patients were then rehabilitated with ball-retained overdentures, magnet-retained overdentures, or bar-retained overdentures (the control group). Patients were followed for 4, 12, 60, and 120 months post–abutment connection. Group means as well as linear regression models were fitted with attachment type and time as classification variables and corrected for simultaneous testing (Tukey).

**Results:** After 10 years, 9 patients had died and 1 was severely ill. Over 10 years, no implants failed. Mean Plaque Index, Bleeding Index, change in attachment level, Periotest values, and marginal bone level at the end of the follow-up period were not significantly different among the groups.

**Discussion:** The annual marginal bone loss, excluding the first months of remodeling, was comparable with that found around healthy natural teeth.

**Conclusion:** The fact that no implants failed and that overall marginal bone loss after the first year of bone remodeling was limited suggested that implants in a 2-implant mandibular overdenture concept have an excellent prognosis in this patient population, irrespective of the attachment system used.—Reprinted with permission of Quintessence Publishing.