Failure load of teeth restored by use of alumina copings: Influence of residual tooth structure and cementation

Marc SCHMITTER, Tomislav POSAVEC, Denise MUELLER, Katrin MUSSOTTER, Peter RAMMELSBERG and Stefan RUES

Department of Prosthodontics, University of Heidelberg, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany
Corresponding author, Marc SCHMITTER; E-mail: Marc_Schmitter@med.uni-heidelberg.de

To evaluate failure loads of teeth restored by use of alumina-coping, and to assess the effects of different amounts of residual tooth structure and different cements, standardized artificial alumina copings were fabricated on seventy-two molars. 24 of the copings were cemented by use of an adhesive resin cement (P-group), \( n = 24 \) by use of glass-ionomer cement (K-group), and \( n = 24 \) by use of a self-adhesive modified composite resin-cement (R-group). After artificial ageing (10,000 thermal-cycles between 6.5 and 60°C; 1,200,000 chewing cycles with \( F_{\text{max}} = 64 \) N), the specimens were loaded until failure (cross-head-speed: 0.5 mm/min). In the K-group 89% of the specimens failed during chewing simulation. Statistical analysis included chi-squared-test, unpaired-to-sample-t-test, and ANOVA. For severely damaged teeth, use of composite resin cement resulted in higher loads to failure than use of other cements.

**INTRODUCTION**

In the last decade, all-ceramic restorations have been introduced to replace metal-ceramic restorations of severely damaged teeth. Retention of the restoration can, however, be difficult if most of the coronal tooth structure is lost.

If a tooth is endodontically treated, post and core systems are used to anchor the core\(^5\). If, however, a tooth is vital, other techniques must be considered. In the past, pins in combination with different materials (e.g., amalgam) were used to anchor foundations\(^5\). With this technique there is a risk of damaging the pulp and/or perforating the periodontium. The introduction of adhesive composite core materials was a major advance in the restoration of damaged teeth. The mechanical properties of these foundations have been addressed in several studies demonstrating a high shear bond strength\(^5\). The fracture resistance of endodontically treated teeth restored by use of both posts and foundations has been assessed in several in-vitro and in-vivo studies\(^6\). In contrast, few studies have evaluated the fracture resistance of vital teeth prepared by use of adhesive foundations\(^5\) in combination with different amounts of residual tooth structure and different techniques for cementation of the artificial crown\(^6\). For unrestored teeth (without foundations), however, the technique used for cementation of alumina copings has a significant effect on fracture load\(^7,8\) and on the durability of the bond at the interface\(^9\). There might, therefore, also be an effect on the failure load of teeth with alumina coping and a foundation.

In the last two decades all-ceramic restorations have been used more frequently. Because the mechanical properties of alumina ceramic justify use of this material in dentistry\(^10\), it is often used beside zirconia ceramic, especially when single teeth are restored. Several cements are available to cement these all-ceramic restorations. Some of these cements do not require a pre-treatment of the tooth and are easy to handle (e.g., Ketac-Cem), whereas other cements require a pre-treatment (e.g., Panavia F2.0). The effect of the cement on the retention of alumina copings has been assessed\(^11\). In clinical practice decayed teeth receive an artificial crown. These teeth present different levels of hard tissue destruction. However, the effect of the amount of residual tooth structure on loads to failure of teeth restored by use of adhesive foundations and alumina copings has not yet been assessed. Thus, it would be helpful for the dental practitioner to know, which kind of cement is preferable in teeth presenting different levels of residual tooth structure. It might be, for example, useful to select an adhesive cementation technique in severely destroyed teeth.

The null-hypothesis of this study was that both the technique used for cementation of alumina copings and the amount of residual tooth structure would not have an effect on the fatigue behaviour and fracture resistance of the restoration.

**MATERIALS AND METHODS**

For this study 72 caries-free third molars (3 cements\(\times\)3 different amounts of residual tooth structure\(\times\)8 specimens per group) were collected and stored in 0.1% thymol solution (storage time between 3 and 12 weeks). The root surfaces were cleaned by use of scalers and isopropyl alcohol. All the teeth were decoronated down to the deepest point of the occlusal relief and were assigned to the test groups. All specimens were embedded in 2.8 cm\(^3\) PalaPress acrylic specimen holders (Heraeus Kulzer, Wehrheim, Germany), 4 mm below...
were then divided into three groups. Three different
a comparable surface structure for all specimens; they
34.5% phosphoric acid etching agent for 5 s to achieve
The ferrule design area of the teeth was etched with
(Stemi SR; Carl Zeiss, Oberkochen, Germany) and measurement software (AxioVision V 4.6.3.0, Zeiss Imaging Solutions, Oberkochen, Germany). The teeth were then treated with 34.5% phosphoric acid (Vococid; Voco, Cuxhaven, Germany), Solobond-Plus-primer, and Solobond-Plus-adhesive (Voco) and the cores were built up by use of a self-curing composite (Rebilda-SC-Blue, Voco, batch: 0809202). After complete polymerization of the foundations the teeth were prepared, under irrigation (50 mL/min), at an angle of 4°, by use of a high-speed turbine (Bien-air-dental-SA). All cores had a flat occlusal area and were 6 mm high, including the 2 mm ferrule height.

After preparation, silicone impressions (Adisil; Siladent, Munich, Germany) were prepared. Casts were made from stone gypsum (GC-Fujirock; GC-Europe, Leuven, Belgium). The casts were scanned by use of a tactile scanner (Procera Forte, Nobel Biocare, Gothenburg, Sweden). Standardized artificial copings were then waxed-up and scanned (Procera Forte). The data were submitted online to a milling centre and the copings were one-third filled with the cement and placed on the teeth. After auto-curing for 10 min, the cement, placed on the teeth, and excess cement was removed. For the last third (total n=24, n=8 of each residual tooth structure design), the copings were cemented by use of a self-adhesive resin composite cement (R-group, RelyX Unicem, batch: 363502). The copings were one-third filled with the cement, placed on the teeth, and excess cement was removed. For the last third (total n=24, n=8 of each residual tooth structure design), the copings were cemented by use of a self-adhesive resin composite cement (R-group, RelyX Unicem, batch: 376357). The copings were one-third filled with the cement and then placed on the teeth. After auto-curing for 10 min, excess cement was removed. All copings were cemented by use of an axial force of 60N. After cementation the specimens were stored at 36±2°C for 24 h. All teeth were exposed to 10,000 cycles from 6.5 to 60°C in a thermal cycling machine (dwell time 90 s, intermediate pause 4 s; Willytec, Graefelfing, Germany). The specimens

cements which are frequently used in the dental office were selected in the present study: a classical glass-ionomer cement (Ketac-Cem), a self-adhesive resin cement (RelyX Unicem) and a conventional resin cement (Panavia F2.0). For one third of the teeth (total n=24, n=8 of each residual tooth structure design) the copings were cemented on the foundations by use of an adhesive resin cement (P-group, Panavia F 2.0; Kuraray Medical Inc., Tokyo, Japan). The ferrule areas were primed (30 s, then dried by use of air-flow) with ED-primer (Kuraray) and the inner surfaces of the crowns were treated with Alloy Primer (Kuraray), as proposed by Hummel & Kern. After the crowns had been placed on the teeth, excess cement was removed and Oxyguard II (Kuraray) was applied to the margins of the restoration.

Auto-curing mode was used to place the copings. For another third (total n=24, n=8 of each residual tooth structure design), the copings were cemented by use of glass ionomer cement (K-group, Ketac-Cem; 3M-Espe; batch: 363502). The copings were one-third filled with the cement, placed on the teeth, and excess cement was removed. For the last third (total n=24, n=8 of each residual tooth structure design), the copings were cemented by use of a self-adhesive resin composite cement (R-group, RelyX Unicem, batch: 376357). The copings were one-third filled with the cement and then placed on the teeth. After auto-curing for 10 min, excess cement was removed. All copings were cemented by use of an axial force of 60N. After cementation the specimens were stored at 36±2°C for 24 h. All teeth were exposed to 10,000 cycles from 6.5 to 60°C in a thermal cycling machine (dwell time 90 s, intermediate pause 4 s; Willytec, Graefelfing, Germany). The specimens

the planed occlusal surface. Use of human teeth was permitted by the ethics committee of the local university (S-034/2010).

A 2 mm circular ferrule design with a 0.6 mm chamfer was prepared, under irrigation (50 mL/min), by use of a high-speed turbine (Bien-air-dental-SA, Sirius Dental Innovations, Bienne, Switzerland) mounted in a parallel milling machine (Fraesgeraet-F1, Degussa, Frankfurt, Germany) and fitted with special two-degree diamond burs (Sirius-Prothetik-Systems, no.6254; grid=40 μm; Hafner, Pforzheim, Germany). Subsequently, three different amounts of residual tooth structure were simulated (Fig. 1): mesial-occlusal-distal cavity (mod, n=24), mesial-occlusal-distal-palatinal cavity (modp, n=24), and mesial-occlusal-distal-buccal cavity (modb, n=24). The standardized 2-mm-deep cavities were prepared by use of standard diamond burs (#8856.314.014; Komet, Brasseler, Germany). Afterwards, the occlusal surface of the prepared teeth was measured using a microscope (Stemi SR; Carl Zeiss, Oberkochen, Germany) and measurement software (AxioVision V 4.6.3.0, Zeiss Imaging Solutions, Oberkochen, Germany). The teeth were then treated with 34.5% phosphoric acid (Vococid; Voco, Cuxhaven, Germany), Solobond-Plus-primer, and Solobond-Plus-adhesive (Voco) and the cores were built up by use of a self-curing composite (Rebilda-SC-Blue, Voco, batch: 0809202). After complete polymerization of the foundations the teeth were prepared, under irrigation (50 mL/min), at an angle of 4°, by use of a high-speed turbine (Bien-air-dental-SA). All cores had a flat occlusal area and were 6 mm high, including the 2 mm ferrule height.

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then underwent mechanical artificial ageing by use of a chewing simulator (1.2 million cycles, purely vertical movement with mass \( m = 5 \) kg, descending speed \( v = 30 \) mm/s, spring \( k = 43 \) N/mm, damper \( d = 135 \) Ns/m, leading to a maximum force magnitude \( F_{\text{max}} = 64 \) N; water storage; Willytec CS3 modified with spring-damper system for controlled force overshoot relative to the static load).

During all mechanical tests (i.e., chewing simulation and fracture tests), the loading area of the samples was oriented horizontally; this was achieved by tilting the samples at 45° (Fig. 2), and loading was applied perpendicular to this surface.

All specimens surviving both thermal cycling and chewing simulation were loaded to failure (e.g., debonding of the crowns) in a universal testing machine with a cross-head speed of 0.5 mm/min (Universal-Pruefmaschine-Z005; Zwick, Ulm, Germany). Loads were applied to the standardized occlusal area (2 mm high, 2 mm wide) at an angle of 45° toward the buccal side of the tooth. During chewing simulation, forces were applied to the centre of the occlusal area via steel posts of diameter 2 mm, whereas a prismatic steel antagonist with 0.3 mm tin foil was used to apply the test force to the complete occlusal area in fracture testing (Fig. 2). All fracture tests were performed with a constant cross-head speed, leading to a decrease of test force (less resistance for the same displacement) when damage of the structure occurred or a gradual decline of the slope in the force-displacement diagram if damage was related to a force interval.

**Statistical analysis**

Descriptive statistical analysis (mean, standard deviation) was conducted. The Kolmogorov-Smirnov test was used to test for normal distribution of the data.

The chi-squared test was used to analyze differences with regard to failure in the chewing simulator. Two-way analysis of variance (ANOVA) was also performed to assess the effects on failure load of cementation technique and the amount of residual coronal tooth structure. Differences between the cement groups were analyzed by use of an unpaired two sample \( t \)-test. All statistical analysis was performed by use of SPSS (SPSS Inc., Chicago, IL, USA).

**RESULTS**

**Bonding area**

In the Panavia F2.0 group, the bonding area was 81.9±10.2 mm², in the Ketac-Cem group 80.5±11.9 mm² and in the RelyX Unicem group 76.2±9.5 mm². Differences between the groups were not significant (\( t \)-tests, \( p > 0.1 \)).

**Failures during chewing simulation**

During chewing simulation several specimens failed: in all cases the coping alone or the coping-foundation complex loosened. In the K-group, only four specimens were intact after chewing simulation; for eleven specimens the coping-foundation complex loosened and for nine specimens the coping alone loosened. In the P-group two specimens failed (coping-foundation complex loosened) and in the R-group four specimens failed (three coping-foundation complex loosened and one
Table 1  Loads to failure of the crown-core complex for samples surviving the aging procedure (n of 8 samples)

<table>
<thead>
<tr>
<th>cement / adhesive</th>
<th>design</th>
<th>n</th>
<th>mean value and standard deviation</th>
<th>95% confidence interval (based on a Gaussian distribution)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>[μ N]</td>
<td>[σ N]</td>
</tr>
<tr>
<td>Ketac-Cem mod</td>
<td>1</td>
<td>268.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>modp</td>
<td>0</td>
<td>244.3</td>
<td>27.6</td>
<td>—</td>
</tr>
<tr>
<td>modb</td>
<td>3</td>
<td>374.6</td>
<td>133.5</td>
<td>—*</td>
</tr>
<tr>
<td>RelyX Unicem mod</td>
<td>8</td>
<td>247.8</td>
<td>81.0</td>
<td>—</td>
</tr>
<tr>
<td>modp</td>
<td>4</td>
<td>355.9</td>
<td>109.2</td>
<td>—</td>
</tr>
<tr>
<td>modb</td>
<td>8</td>
<td>386.4</td>
<td>80.2</td>
<td>—</td>
</tr>
<tr>
<td>Panavia F2.0 mod</td>
<td>7</td>
<td>366.6</td>
<td>81.4</td>
<td>—</td>
</tr>
<tr>
<td>modp</td>
<td>8</td>
<td>445.7</td>
<td>89.4</td>
<td>—</td>
</tr>
</tbody>
</table>

* All samples failed during ageing.

Coping alone loosened. In the K-group, the specimens failed after 235,094 cycles (min: 140), in the R-group after 263,036 cycles (min: 31196) and in the P-group after 178,550 cycles (min: 169423). The difference between the K-group and the other groups with regard to failure during chewing simulation was significant (chi-squared test, p<0.001).

However, the residual tooth structure had no significant effect on failure during chewing simulation (p=0.124).

Load to failure
The results for the failures are shown in Fig. 3 and Table 1. In all cases the coping-foundation complex loosened. For Ketac-Cem, predominantly adhesive failure along the ceramic/cement interface at the finishing line was observed, see Fig. 4a. For Panavia F2.0, a mixed failure mode at the finishing line was observed, see Fig. 4b. For RelyX Unicem, predominantly adhesive failures along the ceramic/cement interface at the finishing line were seen, see Fig. 4c. Occasionally, abfraction in the region of the finishing line occurred in the P-group and R-group.

The Kolmogorov-Smirnov test showed the data were normally distributed. Loads to failure of teeth with a mod cavity were similar for both Panavia F2.0 and RelyX Unicem (unpaired two sample t-test p=0.638). For modp cavities Panavia F2.0 showed significantly higher loads to failure than RelyX Unicem (p<0.05). Loads to failure for Ketac-Cem must be interpreted with care, however, because only four specimens could be tested—the other 20 specimens failed during chewing simulation. Thus, no statistical analysis of load to failure was possible.

ANOVA was used to assess the effect of both cementation and amount of residual coronal tooth structure on load to failure. Cementation had a significant effect (p<0.001, F=5.901) whereas amount of residual coronal tooth structure as an isolated factor had no significant effect (p=0.07, F=2.9). However, analysis of the interaction of cementation and amount of residual coronal tooth structure revealed a significant effect (p=0.014, F=3.4). This shows that for some types of residual coronal tooth structure the type of cementation had a significant effect. Further analysis by use of the unpaired two sample t-test for modp showed that Panavia F2.0 outperformed RelyX Unicem (p=0.028).

DISCUSSION
In the present study, the hypothesis had to be rejected: For teeth with severe coronal damage (modp and modb cavities), adhesive cementation of the alumina copings by use of an adhesive resin cement resulted in higher loads to failure.

In this study, because the fatigue behaviour and fracture resistance of ceramic coping-foundation complexes with different amounts of residual tooth structure and different cementation techniques was being assessed, no veneer was used, because cohesive and/or adhesive failure of the veneer was not the focus of the study.

When restoring damaged teeth it must be kept in mind that the restoration must withstand high intraoral forces. Natural molars, for example, must withstand extremely high maximum bite forces, which have been evaluated in several studies11-13). Although axial forces of approximately 850N14) seem to be the maximum central biting ability, forces during function are lower, because these forces are nonaxial15). Nonaxial loads, especially, however, result in stress in the cervical area along the outer root surface along the cement-enamel junction16). Because the change from artificial crown to tooth is in this region, it is the weak point of the tooth-crown complex. Simulation of nonaxial loads is, therefore, a...
more appropriate means of assessing the performance of a crown-core complex than central and axial loading, which give information about the fracture load of the crowns only. Thus, in this in-vitro study, nonaxial loads were used to simulate in-vivo conditions during, for example, mastication. Thermal cycling was also used, because this significantly reduces the bond strength of many adhesive systems. Adhesive cementation of the final restoration might protect the vulnerable cervical area, because nearly gap-free margins can be achieved. On teeth without a foundation, use of adhesive bonding significantly increased the fracture load and improved the marginal seal of alumina copings. Although zirconia restorations have replaced alumina restorations in some applications, because of the higher fracture loads of this material, the good translucency and good survival of alumina crowns justify use of the material. A recent study of technical failures revealed that 10-year survival for alumina crowns was 95%. For teeth with moderate damage (mod cavity), both Panavia F2.0 F and RelyX Unicem cementation resulted in similar loads to failure. For severely damaged teeth, however, the resin cement (Panavia F2.0) resulted in higher loads to failure than the other cements. It has been reported that resin-modified glass ionomer cements show lower strengths compared with resin cements, especially after thermal cycling. Panavia F2.0 contains phosphate monomer which has been described to be responsible for the higher extrusive shear bond strength compared to conventional composite resin cement. Additionally, a priming agent was used that can chemically bond to metal oxides, which has been described to be more important than the composition of the resin luting agent.

As microtensile bond strength is an important factor which might affect the failure load of the coping-foundation complex, this issue is relevant when the results of the present study are discussed. Microtensile bond strength for multistep luting agents is significantly higher than those observed for most self-adhesive cements; this might increase failure loads for the resin cement group in our study and might explain the finding that for copings cemented by use of the adhesive resin cement failure loads were similar in all three groups whereas for crowns cemented by use of the self-adhesive resin cement composite cement loads to failure were lower for the severely damaged teeth. Piwowarczyk et al. assessed the shear bond strength of different cementing agents and found the following mean shear-bond strengths after thermal cycling of cements to densely sintered, high-strength, pure aluminium oxide ceramic substrate: Ketac-Cem: 0 MPa (debonded); RelyX Unicem: 5.9±1.1 MPa; Panavia F: 8.0±1.5 MPa. In this context, it has to be mentioned that thermal cycling often increases the bond strength of resin cements due to a postpolymerizing of the resin-based agents. Furthermore, the mechanical properties (flexural and compressive strengths) of resin cements are better after water storage compared to resin-modified glass ionomer cements, and glass ionomer cements. The results of these studies correspond to the results found in the present study since a higher shear-bond strength of the cement leads to a higher the failure load of the restoration (as long as the failure occurs at the cement interface).

However, in this context, geometric effects (location of intact coronal walls) might also affect the occurrence of failure: e.g. the presence of the axial wall of the unloaded side seemed affecting the failure loads. This assumption is in agreement with the results of Salameh et al. who found that fracture of endodontically treated molars restored with composite resins is affected by the number of residual coronal walls.

However, all teeth were stored in a thymol solution, and it has previously been shown that this method
of storage results in significantly lower shear-bond strengths and atypical shear-bond failure\textsuperscript{35}. Thus, the copings which were cemented by use of the adhesive resin cement could result in even higher failure loads for fresh teeth.

In general, the results observed in this study revealed a clear ranking. With regard to failures during artificial aging and the force corresponding to failure of the restoration, substantially better results were obtained for luted crowns than for conventionally cemented (glass ionomer cement) crowns. Among the luted crowns, failure loads for severely damaged teeth were higher for the Panavia F2.0 group, as shown by ANOVA and the unpaired two sample \textit{t}-test. This is in good agreement with studies investigating the bond strength between dentine and luting agents\textsuperscript{34}, microleakage\textsuperscript{30}, the load fatigue of compromised teeth after use of different luting cements\textsuperscript{36}, and the fracture resistance of alumina copings\textsuperscript{40}; in all of these, behaviour of composite resin cements was superior to that of modified resin cements. The catastrophic test results for the crowns fixed with glass ionomer cement, \textit{i.e.} sensitivity to artificial aging, were because this cement cannot transfer tensile stresses at the interface area (especially at the ferrule). Because of this, the loading chosen in the present experiments causes the formation of a (small) gap between crown and glass ionomer cement at the oral ferrule interface when (cyclic) of a (small) gap between crown and glass ionomer cement during artificial aging, and the corresponding degradation of failure loads for the cemented crowns. Among the luted crowns, failure loads for severely damaged teeth were higher for the Panavia F2.0 group, as shown by ANOVA and the unpaired two sample \textit{t}-test. This is in good agreement with studies investigating the bond strength between dentine and luting agents\textsuperscript{34}, microleakage\textsuperscript{30}, the load fatigue of compromised teeth after use of different luting cements\textsuperscript{36}, and the fracture resistance of alumina copings\textsuperscript{40}; in all of these, behaviour of composite resin cements was superior to that of modified resin cements. The catastrophic test results for the crowns fixed with glass ionomer cement, \textit{i.e.} sensitivity to artificial aging, were because this cement cannot transfer tensile stresses at the interface area (especially at the ferrule). Because of this, the loading chosen in the present experiments causes the formation of a (small) gap between crown and glass ionomer cement at the oral ferrule interface when (cyclic) of a (small) gap between crown and glass ionomer cement during artificial aging, and the corresponding degradation of failure loads for the cemented crowns (crows will fail during chewing simulation when the failure load decreases to the cyclic test force magnitude) has also been observed in many other studies\textsuperscript{38-41}. Use of glass ionomer cement for alumina copings seems, therefore, questionable. It has also been shown\textsuperscript{42} that failure loads are significantly lower for alumina copings cemented by use of glass ionomer cement than for alumina copings cemented with resin luting cement.

In this study the ferrule height was 2 mm, as recommended in a review\textsuperscript{4}. Thus, a 2-mm ferrule height seems appropriate for simulating the clinical situation. A lower ferrule height might result in lower loads to failure and lower failure loads.

The results of this study must, of course, be interpreted with some caution, because they are based on an \textit{in-vitro} study with a limited sample size. However, clinical assessment of the effects of coronal tooth destruction and cementation technique would be very challenging. Thus, the \textit{in-vitro} approach used in this study to obtain preliminary results seems justified. It must also be kept in mind that the dimensions of the teeth varied. However, before placing the cores and the copings, the bonding area was measured and the statistical assessment showed that there was no significant difference with respect to this variable between the groups. It must also be borne in mind that etching before use of Panavia F2.0 is not recommended. However, etching time was reduced to 5 s to avoid over-etching in the Panavia F2.0 group. For the Ketac-Cem group etching might increase the strength of the bond to dentine\textsuperscript{45}. Even if there was a negative effect of etching in the Panavia F2.0 group, the superiority of Panavia F2.0 in this study would have been even more pronounced without etching.

**CONCLUSION**

The results of this \textit{in-vitro} study indicate that, in severely damaged teeth, alumina copings should be luted with conventional resin cements containing phosphate monomer. The null-hypothesis of the present study has to be rejected.

**ACKNOWLEDGMENTS**

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**REFERENCES**


