Debonding Forces for Two-Piece Zirconia Abutments with Implant Platforms of Different Diameter and Use of Different Luting Strategies

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Purpose: The forces needed to detach zirconia copings from titanium inserts of two-piece abutments were evaluated for implant platforms of different diameters (4.8 and 6.5 mm) and different luting strategies.

Materials and Methods: Eight specimens (four for each platform diameter) were prepared to simulate two-piece zirconia implant abutments with prefabricated titanium inserts and computer-aided design/computer-aided manufactured (CAD/CAM) zirconia copings. Half of the copings were luted to their titanium inserts by use of composite cement; the others were luted after additional bonding treatment of the titanium and zirconia surfaces. All specimens were subjected to tensile forces up to failure. Samples were used with or without artificial aging. Each specimen was luted and subsequently debonded 12 times; thus, a total of 96 tests were conducted. Results: All debonding forces exceeded approximately 600 N. Larger platform diameters (P < .001) and additional bonding treatment (P = .021) resulted in significantly better retention; artificial aging had no effect (P = .165). Conclusion: Forces for debonding of titanium bases from zirconia abutments were favorable. The use of these abutments might be a viable prosthetic treatment option in specific clinical cases. INT J ORAL MAXILLOFAC IMPLANTS 2018;33:1041–1046. doi: 10.11607/jomi.6300

Keywords: debonding forces, implant, titanium, zirconia abutment

The healing and survival of modern dental implants are encouraging and frequently increase the prosthetic treatment options if one or more missing teeth must be replaced.1–3 One can differentiate between one-piece (osseous anchorage and contiguous prosthetic component manufactured as one piece) and two-piece implants (separate osseous implant and additional transmucosal element); the latter enable more individual prosthetic treatment options. Prefabricated titanium abutments adjusted for accommodation of a single crown, or of an abutment for fixed dental prosthesis (FDP) or removable dental prosthesis (RDP), are well researched and can often fulfill standard prosthetic demands.1–4 The demand for tooth-colored prosthetic restorations has, however, increased use of ceramic abutment systems—which are especially suitable for patients with a thin soft tissue biotype.4,5 These abutments are frequently manufactured from zirconia because of its high fracture resistance.6 Although a low incidence of complications and favorable mid-term survival of single crowns attached to individual monolithic zirconia abutments screwed to the implants have been observed in some studies,7,8 others have identified a need for substantial aftercare because of screw loosening, marginal misfit, and abutment fracture9,10—primarily for FDPs in the posterior region.11 These complications have been attributed to unfavorable tensile forces in the screw channel, although systematic research on this issue with adequate sample sizes is sparse. Nevertheless, besides superior esthetic properties in the anterior region (no
Two-piece zirconia abutments (transmucosal element consisting of two separate parts, jointed, eg, by luting), theoretically, combine the advantages of prefabricated titanium and customized zirconia abutments. In this approach, prefabricated titanium inserts are attached to an individually milled zirconia coping (computer-aided design/computer-aided manufacturing [CAD/CAM] technique) by use of a composite cement. On the basis of materials science (fracture resistance of zirconia, screw connection between the titanium base and titanium implant), this type of abutment might be expected to have appropriate properties. However, evidence for the performance of customized two-piece zirconia abutments is sparse.

Previous research found that fracture loads of two-piece zirconia abutments were sufficient (approximately 400 N), and substantially larger than for one-piece ceramic abutments.14,15 Other research focused on the retention forces of customized two-piece zirconia abutments.16,17 Gehrke et al luted the zirconia copings by use of three different types of composite cements and reported retention forces exceeding 650 N but high variability among the samples.16 The observed retention values tended to be different among the used composite cements with the highest value (however, not statistically significant) for a material containing phosphate monomer (MDP).16 Ebert et al found that the pretreatment of the surfaces to be luted affected the retention between zirconia copings and titanium inserts. Here, the size of the gap for the composite influenced the debonding forces as well.17 In general, luting to zirconia is controversially discussed in the literature. Some authors suggest that one can rely on an adequate long-term bond between zirconia—especially when MDP containing composite cement is used—and the composite cement, while others suggest caution.19–21 With regard to pretreatment of the zirconia surfaces, either mechanical (eg, sandblasting) or mechano-chemical (silica coating, use of silane) conditioning is recommended.16–21 Debonding forces, however, substantially depend on the retentiveness of the preparation design. When a zirconia coping is luted to a titanium insert, a favorable case is present (closed ring). Nevertheless, it remains unclear which effects on the retention forces of two-piece zirconia abutments can be expected by choice of different implant platform diameters and additional chemical pretreatment strategies of the surfaces to be luted.

The objective of this laboratory study was, therefore, to evaluate debonding forces for two-piece zirconia abutments with different platform diameters after use of different luting strategies.

MATERIALS AND METHODS

Sample Fabrication

To simulate two-piece zirconia abutments, eight specimens were fabricated, four with an implant platform diameter of 4.8 mm and four with a platform diameter of 6.5 mm (Straumann). These two-piece implants had a microrough surface, and the implant platform ended at tissue level. Implants were vertically embedded in a prefabricated alumina mold by use of acrylic resin (Technovit 4071, Heraeus Kulzer; Fig 1). Titanium inserts were 3.5 mm in height and had a cervically limiting platform to allow a defined finishing line for the zirconia coping. Depending on the implant platform diameter, the respective titanium insert diameters were used (N-Series, Medentika) and were digitized by use of a laboratory scanner (D800, 3Shape). Customized zirconia copings were designed by use of CAD software (Dental Designer, 3Shape). In a second step, the occlusal geometry was modified (Geomagic DesignX, 3D Systems) such that axial pull-off tests could be performed after applying eccentric cyclic loads with 30-degree tilt relative to the implant axis in some test groups. These copings were milled from zirconia blanks (CerconHT, Degudent) followed by a sintering process (Cercon Heat Plus, Degudent). If necessary, fit of the copings was adjusted by use of fine-grain diamond burs and silicon polishers at a maximum speed of 10,000 rpm and with permanent water cooling, eg, when a minimal (inner) imperfection hindered the border seal at the titanium insert (Komet).

Luting and Fixation of the Samples

Bonding surfaces of the copings and titanium inserts were sandblasted with 50-µm alumina at 1.0 bar pressure. Within each repetitive test series, each four customized zirconia copings and the respective titanium bases of each implant platform diameter were assembled by using two different luting approaches: (1) luting without further treatment, and (2) luting after application of an additional bonding, applied to both the titanium inserts (Signum metal bond 1 + 2, Kulzer) and the zirconia copings (Signum Ceramic Bond 1 + 2, Kulzer). In a final step, all crowns were attached to their respective titanium inserts by use of a composite cement (Panavia 2.0, Kuraray). Excess cement was gently removed by use of foam pellets. Samples were cleaned with ethanol and dried with oil-free air.
For the tests, implants were embedded in aluminum molds with retentive elements necessary for the debonding tests. The crowns were fixed on the implants by tightening the screw with 35-Ncm torque (an overview of the study groups is displayed in Fig 2).

**Artificial Aging**

Every second test series was subjected to artificial aging consisting of thermal cycling (10,000 cycles, 6.5°C to 60°C) and a subsequent chewing simulation (Willytec CS4, water storage, 1,200,000 cycles with 108-N force magnitude). One of the “cusps” of the crown was designed with a surface tilted by 60 degrees with regard to the implant axis. During chewing simulation, the samples were fixed with a tilt of 30 degrees such that the contact region was oriented horizontally.

**Debonding Tests**

Debonding tests were performed with a universal testing device (Zwick/Roell Z005, Zwick; crosshead speed 0.5 mm/min), with an arrangement (Fig 1) free from undesired transverse forces or torques. Failure was recorded when a drop in test force of at least 95% was detected. The first damage of the bonding, identified by monitoring (possible) gap formation corresponding to intermediate drops in test force, was also recorded. After each test series, samples were reused, in accordance with their respective luting strategy, to enable
12 independent tensile tests for each specimen (total of 96 tensile tests). After each test, residual cement was removed by sandblasting with 50-µm alumina at 1.0 bar pressure.

**Statistical Analysis**

For descriptive purposes, means (standard deviations [SD]) of the debonding forces were used. Debonding forces were analyzed by means of a linear mixed model, including platform diameter (4.8 mm/6.5 mm), additional bonding (yes/no), and artificial aging (yes/no) and the interactions between those parameters as fixed factors, while specimen was included as a random factor in order to model the hierarchical data structure (measurements clustered within the eight specimens). The restricted maximum likelihood method and an unstructured covariance matrix were used to fit the model. Effect estimates were calculated alongside 95% confidence intervals and P values, which were regarded as statistically significant if smaller than .05. All statistical analyses were performed using SAS v9.4 (SAS Institute).
RESULTS

In each experimental group, up to two debonding force values are missing (range: 0 to 2) because of screw breakage. These specimens were not subjected to further tensile tests, and debonding force values from the most recent test were also rejected (no adhesive failure). All tensile tests after use of different approaches (luting strategy/artificial aging/platform diameter) yielded debonding forces exceeding approximately 600 N. The highest debonding forces (mean [SD]: 1,121.5 [121.0] N) were observed for customized two-piece zirconia abutments with 6.5-mm platform diameter and additional bonding. For customized zirconia abutments luted to titanium bases with a diameter of 4.8 mm with no additional bonding, debonding forces (mean [SD]: 906.4 [144.1] N) were the lowest observed among all the tensile tests. Descriptive statistics for parameter groups are shown in Table 1 (for each of the eight subgroup combinations) and Table 2 (accumulated for each factor level).

The mixed-model analysis (Table 3) showed that the larger platform diameter ($P < .001$) and use of additional bonding resulted in significantly ($P = .021$) larger debonding forces. For specimens with and without artificial aging, debonding forces were similar ($P = .274$). Although slightly larger debonding forces were associated with artificial aging ($P = .165$), the confounder artificial aging did not reach the level of significance. The minimum test force associated with a first damaging of the adhesive bond was 217 N. Mean test forces causing first damage ranged between 500 N and 730 N for the four test groups and were significantly lower than the corresponding failure loads ($P < .001$ in mixed-model analysis).

DISCUSSION

Customized two-piece zirconia abutments are a promising prosthetic treatment option, because of the favorable esthetics and high fracture resistance of zirconia. In contrast with one-piece zirconia abutments, marginal misfit or screw loosening are less likely with the prefabricated titanium implant–abutment interface. This recent laboratory research was conducted to evaluate the debonding forces of customized zirconia copings luted to titanium inserts. The results indicated that all debonding forces for customized two-piece zirconia abutments exceeded approximately 600 N, substantially higher than tensile forces occurring clinically with the exception of cantilever prostheses. An interesting finding is that artificial aging does not result in a reduction of the debonding forces, quite the contrary, albeit not significant. One might have expected a negative effect of hydrolysis and thermal stress on the adhesive bond. It is possible that these effects were compensated as a result of complete polymerization during the prolonged service time, however. The effect of increasing retention forces after up to 60 days of water storage was described by Ebert et al; after 150 days, however, they observed a decrease in retention. Another study with a similar aging procedure reported comparable debonding forces after artificial aging, although these authors observed substantially larger standard deviations for individual samples, and retention values with and without artificial aging were not compared. On the other hand, with closed ring structures, mechanical retention has to be overcome as well. Since most samples showed a first partwise debonding for subcritical tensile forces, it can be assumed that maximum retention is based to a great extent on mechanical retention. The debonding forces observed are substantially larger than maximum retentive forces of zirconia restorations luted to dental hard tissues—especially after artificial aging. The results of this recent study also suggest that preparation of bonding surfaces with an additional bonding resulted in significantly improved retention forces. This finding is reasonable; it has been widely reported that the use of a coupling agent can improve bonding properties. Further, the unfilled methacrylate of the additional bonding moistens the microrough inner surfaces because of its low viscosity. However, it is worth discussing pretreatment strategies for zirconia to be luted; albeit, the debonding behavior of two-piece zirconia abutments is different from what is expected on the basis of less-retentive designs. Here, different pretreatment regimes combining mechanical and chemical conditioning are discussed and recommended. One approach is sandblasting in combination with a phosphate monomer (MDP) containing composite; others recommended sandblasting or silica coating in combination with a coupling agent. However, in this study, sandblasting in combination with a coupling agent (without MDP) was used, leading to higher retention values than without the use of additional bonding. This finding is new and cannot be compared with previous literature focusing on two-piece zirconia abutments.

One issue requiring discussion is the reuse of the eight customized abutments after tensile tests. It might be assumed that multiple sandblasting and re-luting of the specimens, even if performed carefully, affected the retention forces, because of possible enlargement of the luting gap. Significantly different retention forces for zirconia copings, which depended on the luting gap, were reported after one laboratory study. In the present work, however, significantly different debonding forces were not observed among...
the different tensile tests of specimens used several times (Kruskal-Wallis test; \( P = .379 \)).

**Study Limitations**

In general, a laboratory study design cannot fully reproduce clinical conditions, even if samples are artificially aged by chewing simulation and thermocycling. The results of the present study should, hence, be interpreted with caution. Albeit, with no significant effect, reuse of specimens has to be seen critically. Another limitation is that a bonding agent outside the product family of the respective composite cement was used; however, one is free to combine both materials.

**CONCLUSIONS**

Within the limitations of this laboratory study, customized two-piece zirconia abutments show promise, because debonding forces exceed the largest forces expected clinically. Larger debonding forces are associated with a larger implant platform diameter and with additional use of coupling agents. Clinical studies are encouraged to confirm the favorable performance with a higher level of evidence.

**ACKNOWLEDGMENTS**

The authors reported no conflicts of interest related to this study.

**REFERENCES**


