Pull-off Force of Four Different Implant Cements Between Zirconia Crowns and Titanium Implant Abutments in Two Different Abutment Heights

Hanna Volkmann, DMD¹
Angelika Rauch, Priv-Doz Dr Med Dent²
Andreas Koenig, Priv-Doz Dr Rer Nat³
Oliver Schierz, Priv-Doz Dr Med Dent³

This study evaluated the pull-off force between titanium abutments and zirconia crowns that were bonded using four different cements and two abutment heights (AHs). In total, 24 titanium abutments (3-mm AH: n = 12; 5-mm AH: n = 12; taper: 7.5 degrees) and 24 zirconia crowns were designed, manufactured, cemented with one of four dental cements (one temporary, two semi-permanent, one permanent), stored in water for 24 hours, and thermocycled (37,500 cycles, equal to ~4 years in vivo). The pull-off force needed to separate the abutment and crown in each combination was determined eight times per combination of cement type and abutment height. Statistical analysis was conducted at a significance level of P < .05. The permanent self-adhesive composite cement showed a high pull-off force with a risk for crown fracture (mean: 381 N for 3-mm AH; 617 N for 5-mm AH). In contrast, the temporary zinc-oxide cement showed frequent premature decementation after thermocycling (mean: 14 N with 3-mm AH; 28 N with 5-mm AH). Both semi-permanent methacrylate-based cements ranked between the other cements (mean: 31 N/37 N for 3-mm AH; 120 N/72 N for 5-mm AH). Statistically significant differences were found between all cements (ANOVA P < .001). The abutment heights differed significantly for all cements (P < .005) except for the temporary zinc-oxide cement. Methacrylate-based cements were the most reliable cements for semi-permanent mounting of zirconia crowns on titanium abutments. They provide sufficient retention to avoid unintended loosening and are weak enough to remove the crown without causing damage. Int J Periodontics Restorative Dent 2022;42:e67–e74. doi: 10.11607/prd.4926

1Private Practice, Weissenfels, Germany.
2Department of Prosthetic Dentistry, Regensburg University Medical Center, Regensburg, Germany.
3Department of Prosthodontics and Materials Science, University of Leipzig, Leipzig, Germany.

Correspondence to: Dr Oliver Schierz, Department of Prosthodontics and Materials Science, University of Leipzig, Liebigstrasse 12, D-04107 Leipzig, Germany.
Email: oliver.schierz@medizin.uni-leipzig.de

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pull-off force of semi-permanent implant cements in distinction to temporary and permanent luting agents to show a compromise between reliability and removability. As abutment heights between 3 and 4 mm are the most common in the premolar and molar regions, the secondary aim was to describe the influence of abutment height on pull-off force. To achieve this, the pull-off forces between zirconia crowns and titanium implant abutments of two different and clinically relevant abutment heights were determined after water storage and thermocycling that corresponded to a wearing period of approximately 4 years.

Materials and Methods

Universal titanium abutments (n = 24) with a diameter of 5.9 mm and a taper of 7.5 degrees (iSy, CAMLOG Vertriebs) were used. Every abutment was screwed to a corresponding laboratory implant analog. Using cutting discs (Dynex Titanium, Henry Schein Zahn) and titanium milling cutters (A.M. Edelingh Red Milling Cutter, M+W Dental), half of the abutments were milled to a height of 3 mm (n = 12) and the other half to a height of 5 mm (n = 12). The abutments had a manufacturer-designed cove and a natural gingival profile (Fig 1). To increase the reproducibility of the milling, a template of self-curing resin was used (Pattern Resin, GC). The screw access was closed after purification with isopropanol (70%) and inserting a foam pellet (Pele Tim, VOCO) with a light-curing composite (Telio CS Inlay, Ivoclar Vivadent).

The implant analogs were embedded two thirds of the way in a custom-made steel device using thermopolymerizable resin (Paladur, Kulzer). To ease the scanning process, a silicone gingiva mask was made (GumQuick, Dreve Dentamid). The abutments were scanned (CEREC Omnicam, Dentsply Sirona), and, for each abutment, a corresponding monolithic zirconia crown (VITA YZ HT, VITA Zahnfabrik) with a 120-µm spacer was designed (CEREC software 4.6.1) (Fig 2), milled (inLab MC XL, Dentsply Sirona), and sintered (HT Sintering Furnace, Mihm-Vogt). The crowns and abutments were blasted for 10 seconds with 50-µm Al₂O₃ particles (1 bar maximum) and cleaned with isopropanol. Every crown was cemented (n = 3 crowned abutments for each combination of abutment height and cement type) according to the product information of the respective cement (cement types and product details are listed in Table 1) under a 50-N load for 10 minutes under room conditions (approximately 21°C and 50% humidity). Excess cement was removed with an implant curette (Implant Deplaquer, KerrHawe). Subsequently, the samples were stored for 24 hours in demineralized water (37°C) and underwent 37,500 thermocycles (Haake DC10, 15W, Thermo Haake).

Fig 1 A titanium abutment (5.9-mm diameter and 7.5-degree taper) was placed on an implant analog and milled to a height of 3 mm.

Fig 2 Design of a crown after abutment scanning (CEREC Omnicam, software version 4.6.1).
with a dwelling time of 30 seconds in 5°C and 55°C demineralized water.8

To test the retentive force, each crown was clamped into a custom-made device. The device generated the point of force for the universal testing machine (Z010, testXpert II, version 2.2, ZwickRoell), pulling the crowns apart from the abutments with a speed of 2 mm/minute and a preload of 4 N in an axial direction.8 After cementation, remaining cement remnants in the crowns and on the abutments were quantitatively coded to a modified Adhesive Remnant Index11 to differentiate affinities of the cement to the surfaces (Tables 2 and 3, Fig 3). The three abutment-crown units per combination of abutment height and cement type were tested up to three times (and were reset after every use by airborne-particle abrasion) so that there were eight measurements per cement, for a total of 64 measurements (4 cement types × 2 abutment heights × 8 tests). A flowchart of the abutment groups and number of tests is shown in Fig 4.

The data were statistically analyzed using STATA (version 15.1, StataCorp) at a significance level of $P < .05$ applying one-way analysis.
of variance (ANOVA) and Mann-Whitney U test. Cohen’s d was calculated and interpreted to determine the effect sizes for the cement comparisons.12

Results

TempBond NE (TB) showed the lowest mean pull-off force for both abutment heights (14 N for 3-mm; 28 N for 5-mm), followed by Harvard Implant (HI) (37 N for 3-mm; 72 N for 5-mm), Premier Implant Cement (PI) (31 N for 3-mm; 120 N for 5-mm), and SpeedCEM Plus (SC) (381 N for 3-mm; 617 N for 5-mm). Premature debonding of crowns without a directed force effect appeared in 6 of 64 samples (4 TB and 2 PI). PI achieved larger maximum pull-off forces than HI (also semi-permanent), and PI’s standard deviation was more than twice the size of HI. SC continuously achieved excessive pull-off forces, inducing one crown fracture during the removal trial (Table 4).

Differences Between Abutment Heights

Statistically significant differences in the pull-off forces were found between the abutment heights (ANOVA $P < .001$). Post hoc statistically significant differences between both abutment heights could be proven for PI, HI, and SC (all $P \leq .003$), but not for TB ($P = .091$) (Table 4). Accordingly, a small effect was seen between the abutment heights in the TB group, whereas the other cements showed huge effect sizes (Cohen’s d: TB = 0.2; PI = 2.2; HI = 2.2; SC = 2.4). For 3-mm abutments cemented with TB, HI, and SC, the pull-off force was ~50% of the force for the 5-mm abutments, while PI achieved only 25% in 3-mm abutments.

Differences Between Cements

Statistically significant differences in pull-off force were seen between all cements (ANOVA $P < .001$). The effect sizes were small between TB and PI, PI and HI, and HI and TB for the 3-mm abutment height. In contrast, for the 5-mm abutment height, huge effects were seen between all pairings.

The Surface Affinity of the Cements

The amounts of cement residue at the abutment and/or crown per cement type are presented in Table 3. After pulling the crown and abutment apart, TB was mainly located at the abutments, and the other cement remnants were primarily located in the crowns.

Discussion

In the present study, the influence of different luting agents on the pull-off force between zirconia crowns and titanium abutments of two different heights was examined. A quarter of the TB-mounted samples detached before finishing the 37,500 thermocycles. The flaw...
in the bond could be assumed at the zirconia surface (Code 2, see Table 2). This correlates with the findings of Rohr et al,\textsuperscript{13} ascribing the weak bonding with ceramics to the carboxyl groups. Al Hamad et al\textsuperscript{14} showed a standard deviation of pull-off force values of 10 N for the 4-mm abutments and 13 N for the 6-mm abutments. The standard deviation of pull-off force of TB cement in the present study is comparable with 13 N for the 3-mm short abutments and 19 N for the 5-mm abutment height. Every fourth evaluation

![Flowchart](image-url)
of PI on 3-mm abutments loosened prematurely, too.

In the studies of Pan et al,15 Sheets et al,16 Bulaqi et al,17 and Gultekin et al,18 PI achieved similar pull-off force results (64 N after 1,000 thermocycles15 and 32 to 171 N without thermocycling16,18). This justifies the assumption that PI has a low sensitivity for thermocycling. In the present study, the standard deviation for PI's pull-off force (26 N) in 3-mm abutments is similar to the mentioned studies (21 to 25 N15,16,18), but the 51-N standard deviation in the 5-mm abutments is nearly double the value of the 3-mm abutments. Consequently, the assumption can be made that surface treatment influences the standard deviation and becomes more apparent in 5-mm abutments. Gultekin et al18 used every abutment once, and Sheets et al16 renounced the application of airborne-particle abrasion. It is to consider that an inadequate removal of blasting powder residues can lead to a reduction of the pull-off force19,20 and decreases the reliability.

Crowns mounted by HI did not detach prematurely. In the present study, HI achieved results that were comparable to other studies, with a mean pull-off force of 37 N on 3-mm abutments and 72 N on 5-mm abutments (Rohr et al13 achieved a mean pull-off force of 43 N). Rohr et al13 attributed low pull-off forces to the absence of bonding agents such as phosphate groups. Furthermore, according to manufacturer information, HI adheres through expansion rather than chemically. With a code of 3.3/3.4 (Tables 2 and 3), more than 50% of HI adhered to the crown, but these results were not as distinct as PI (code 3.5/3.9). HI’s standard deviation in the present study was 12 N for 3-mm abutments and 18 N for 5-mm abutments; these findings are two to three times larger than the standard deviations reported by Rohr et al13. Consequently, it can be considered that thermocycling influences the reliability of HI and leads to higher standard deviations.

SC showed the largest pull-off forces (381 N for 3-mm abutments and 617 N for 5-mm abutments). These values are comparable to other studies using similar composites,8,13,21 and the standard deviations are also comparable.8,21 One crown on a 3-mm abutment fractured during removal (Table 4). According to Ozkir et al,22 there is a considerable risk of damaging the implant or corresponding components when removing the crown.

The abutment height also affects the pull-off force: The taller the abutment, the stronger the retention.7,8,14,23 It can be approximated that a 3-mm abutment has ~60% of the surface of a 5-mm abutment. This reflects the decreased pull-off forces (about 50% less) measured in

<table>
<thead>
<tr>
<th>Luting agent</th>
<th>3-mm abutment height</th>
<th>5-mm abutment height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD), N</td>
<td>Range, N</td>
</tr>
<tr>
<td></td>
<td>Crown fractures, n</td>
<td>Premature bonding, n</td>
</tr>
<tr>
<td>TempBond NE</td>
<td>14 (13) 0–38</td>
<td>0 2</td>
</tr>
<tr>
<td>Premier Implant Cement</td>
<td>31 (26) 0–64</td>
<td>0 2</td>
</tr>
<tr>
<td>Harvard Implant</td>
<td>37 (12) 15–52</td>
<td>0 0</td>
</tr>
<tr>
<td>Speed-CEM Plus</td>
<td>381 (116) 231–587</td>
<td>1 0</td>
</tr>
</tbody>
</table>

Values were calculated according to the means of eight measurements per combination of cement type and abutment height.

*Mann-Whitney U test.

*Statistically significant difference.
three of the tested cements. In the present study, there was a significant difference in the pull-off force between the abutment heights, with huge effect sizes (except for TB) coinciding with the results of other studies.\textsuperscript{7,14} Al Hamad et al\textsuperscript{14} also did not find a significant difference in pull-off forces between 4-mm and 6-mm abutment heights using TB.

The short abutment height that was chosen for the present study represented the common abutment height in the lateral tooth area (3 to 4 mm).\textsuperscript{8,14,24} To increase the retention between the abutment and cement, airborne-particle abrasion with aluminum oxide powder can be used.\textsuperscript{14,24,25} By using 50-µm Al\textsubscript{2}O\textsubscript{3} particles, it is assumed that the abrasion is very slight, resulting in no clinically relevant alteration of the cement gap.\textsuperscript{2} Further factors affecting the outcomes of the present study include the absence of patient factors, cementation occurring at room temperature, and the retention evaluation being implemented only in an axial direction and with tensile force, which differs greatly from the clinical situation.

A potential limitation of this study is the reuse of samples and its unknown influence on the pull-off force. On this account, the reuse was limited to a maximum of three times. The adjustments for abutment lengths and screw access obturation were performed manually, and as a consequence, the surface of every abutment is slightly different. The use of a template made the process mostly similar. Crown fractures reduced the potentially higher pull-off forces. These limitations could contribute to the high standard deviations seen in the present study. Nonetheless, the sample size for each combination proved to be sufficient for verification of clinically relevant differences.

Conclusions

Within the limitations of this in vitro study, the following assumptions can be made: (1) The temporary, zinc oxide–based cement (TB) cannot be recommended for semi-permanent mounting of implant crowns in the given setting; (2) the semi-permanent, methacrylate-based cement (PI) showed greater mean pull-off forces than the methacrylate-infiltrated zinc-oxide cement (HI) but proved to be less reliable, as even with longer abutments, the retention force was small enough to minimize the risk of damaging the crown or implant; and (3) the composite cement (SC) was not intended for semi-permanent luting: The excessive pull-off force and the crown fracture that occurred highlight the risk of damaging the restoration or bone structure while removing the mounted restoration.

The abutment height influenced the pull-off force significantly in the bonding of zirconia crowns, except for the temporary zinc-oxide cement (TB). In all, the methacrylate-infiltrated zinc-oxide cement (HI) can be recommended as the most reliable for semi-permanent cementation of zirconia crowns on titanium implant abutments 3 mm and 5 mm in height for iFDPs.

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References