Mechanical Stability of Zirconia Meso-abutments Bonded to Titanium Bases Restored with Different Monolithic All-Ceramic Crowns

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Purpose: To evaluate the bending moments and failure modes of zirconia meso-abutments bonded to titanium bases restored with different monolithic all-ceramic crowns after aging, and to compare them to titanium abutments restored with all-ceramic crowns. Materials and Methods: Forty-eight internal conical connection implants (CONELOG, Camlog Biotechnologies GmbH 4.3 mm diameter) were restored with four different computer-aided design/computer-aided manufacturing (CAD/CAM) abutment-crown combinations (n = 12). Thirty-six customized zirconia meso-abutments were bonded to titanium bases (CONELOG Titanium Base CAD/CAM crown, Camlog Biotechnologies GmbH) and divided into three groups according to the different crown materials: (T1) monolithic lithium disilicate (e.max CAD, Ivoclar), (T2) monolithic PICN (polymer-infiltrated ceramic network [Enamic, Vita]), and (T3) monolithic zirconia (Lava Plus, 3M ESPE). Twelve titanium customized abutments restored with monolithic lithium disilicate (e.max CAD, Ivoclar) crowns served as the control group (C). The crowns were equal maxillary central incisors and were adhesively bonded with a resin-based cement (Panavia 21, Kuraray). All samples were embedded in acrylic holders. After aging (1,200,000 cycles, 49 N, 1.67 Hz, 5°C to 50°C, 120 seconds), static load was applied until failure. Bending moments were calculated for comparison of the groups. Data were statistically treated with one-way analysis of variance (ANOVA) followed by Tukey post hoc test (P < .05). Failure modes were analyzed descriptively. Results: The means of the bending moments were 356.4 ± 20.8 Ncm (T1), 357.7 ± 26.3 Ncm (T2), 385.5 ± 21.2 Ncm (T3), and 358.8 ± 25.3 Ncm (C). Group T3 revealed significantly higher mean bending moments than the other groups (P < .05). No differences were found between zirconia meso-abutments supported by titanium bases and customized titanium abutments when lithium disilicate crowns were used (P > .05). No failures were identified during and after aging. After static load, failures occurred due to fracture of the abutment in the internal connection in all the groups. Conclusion: Zirconia meso-abutments bonded to titanium bases showed similar mechanical stability compared with customized titanium abutments. Regarding the crown material, all three tested ceramics (lithium disilicate, PICN, and zirconia) revealed very good stability when used in the monolithic state. Int J Oral Maxillofac Implants 2019;34:1091–1097. doi: 10.11607/jomi.7431

Keywords: aging, bending moments, CAD/CAM, monolithic crowns, titanium base, zirconia abutments

Titanium and zirconia are well-established materials for implant abutment reconstructions, with similar survival and success rates after 5 years.1-3 From a mechanical point of view, titanium abutments have proven to be efficient and durable due to their loading capacity.4 In contrast, zirconia abutments, which offer better optical properties than metal,5 might have some mechanical limitations.6-9 Taking the brittle nature of ceramics into account, one might expect fatigue fractures over time.10,11 Furthermore, the possible effect of wear and fretting at the implant-zirconia interface12,13 and low-temperature degradation should be considered as potential mechanical risk factors.14

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A possible alternative to solve this problem might be the choice of a hybrid abutment that consists of an all-ceramic customized meso-abutment, bonded to a standardized titanium base, to be screw-retained to the implant as one complex. This new hybrid concept encompasses the combination of the excellent mechanical stability of metals with the esthetic advantages of ceramic abutments. Moreover, the customization of the ceramic meso-abutment allows the placement of the crown margins at mucosal level, facilitating the removal of the excess cement after cementation.

The stability of the implant crowns is an additional factor influencing the clinical outcomes of implant-borne reconstructions. High fracture resistance of the prosthetic materials is important. Traditionally, a stable framework made out of metal gave the stability of the crown, and the esthetic was provided by the veneering ceramic. More recently, high-strength ceramic materials are used for the fabrication of implant-borne reconstructions, either covered by a veneering ceramic or in the monolithic state. The prevailing ceramics for monolithic crowns are lithium disilicate glass-ceramic and zirconia. More recently, computer-aided design/computer-aided manufacturing (CAD/CAM) blocks of a polymer-infiltrated ceramic network (PICN), also called hybrid ceramic, have been introduced. Due to its dual network, this material presents reduced brittleness, lower hardness, and lower elastic modulus, which can help to distribute stress more favorably. Moreover, this hybrid material provides a faster milling process with smoother margins and easier polishing properties than other ceramic materials.

Considering the aforementioned advantages of the hybrid abutment concept with promising properties of the new all-ceramic CAD/CAM monolithic crowns, one might assume that a combination of both may lead to outcomes similar to or even better than the conventional concept of customized metallic abutments supporting esthetic implant crowns. However, the available literature evaluating this new hybrid abutment concept is limited, and it remains to be clarified whether or not there are differences in outcomes between all-ceramic and hybrid-ceramic crowns when supported by hybrid abutments.

The purpose of this in vitro study, therefore, was to assess the mechanical stability, ie, the bending moments and failure modes of zirconia meso-abutments bonded to titanium bases and restored with different crown materials after artificial aging. The tested null hypotheses were: (1) the abutment type does not influence the bending moments; and (2) the crown material does not affect the bending moments.

**MATERIALS AND METHODS**

Forty-eight implants with an internal conical connection (diameter 4.3 mm, length 13 mm; CONELOG, Camlog Biotechnologies GmbH) were included and divided into three test groups and one control group (n = 12) (Fig 1). The sample size was based on previous published studies with similar methodology. The groups were as follows:

- **Test group 1 (T1):** zirconia customized meso-abutment bonded to a titanium base (CONELOG Titanium Base CAD/CAM crown, gingival height 0.8 mm, Camlog Biotechnologies GmbH) and restored with a monolithic lithium disilicate crown (e.max CAD, Ivoclar Vivadent)
- **Test group 2 (T2):** zirconia customized meso-abutment bonded to titanium base (CONELOG Titanium Base CAD/CAM crown, gingival height 0.8 mm, Camlog Biotechnologies GmbH) and restored with a monolithic PICN crown (Enamic, VITA Zahnfabrik).
- **Test group 3 (T3):** zirconia customized meso-abutment bonded to titanium base (CONELOG Titanium Base CAD/CAM crown, gingival height 0.8 mm, Camlog Biotechnologies GmbH) and restored with a monolithic zirconia crown (Lava Plus, 3M ESPE).
- **Control group (C):** customized titanium abutment (DEDICAM, Camlog Biotechnologies GmbH) restored with a monolithic lithium disilicate crown (e.max CAD, Ivoclar Vivadent).

**Fabrication of the Abutments and Crowns**

Following the procedures described in previous publications, a master abutment was selected, and its outer shape was replicated for all the customized titanium abutments and zirconia meso-abutments used in the present study by a central milling center (DEDICAM, Camlog). This master abutment was scanned (inEos X5, Dentsply Sirona), and a maxillary central incisor crown was designed using dedicated
surface pretreatments (Table 1).

<table>
<thead>
<tr>
<th>Bonding surface</th>
<th>C</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium abutment/Ti base</td>
<td>50-µm aluminum oxide abrasion + Alloy Primer</td>
<td>50-µm aluminum oxide abrasion + Alloy Primer</td>
<td>50-µm aluminum oxide abrasion + Alloy Primer</td>
<td>50-µm aluminum oxide abrasion + Alloy Primer</td>
</tr>
<tr>
<td>Zirconia meso-abutment Inner surface</td>
<td>CoJet (30-µm) + Clearfil Ceramic Primer</td>
<td>CoJet (30-µm) + Clearfil Ceramic Primer</td>
<td>CoJet (30-µm) + Clearfil Ceramic Primer</td>
<td></td>
</tr>
<tr>
<td>Crown inner surface</td>
<td>IPS Ceramic Etching Gel (20s) + Clearfil Ceramic Primer</td>
<td>IPS Ceramic Etching Gel (20s) + Clearfil Ceramic Primer</td>
<td>IPS Ceramic Etching Gel (60s) + Clearfil Ceramic Primer</td>
<td>CoJet (30-µm) + Clearfil Ceramic Primer</td>
</tr>
</tbody>
</table>

Materials used for surface pretreatment and respective manufacturers: Alloy Primer (Kuraray); Clearfil Ceramic Primer (Kuraray); IPS Ceramic Etching Gel (Ivoclar Vivadent); CoJet (3M ESPE).

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software (CEREC inLab 16.1, Dentsply Sirona). The crowns were milled (CEREC MC XL, Dentsply Sirona) out of the corresponding ceramic block for the groups with lithium disilicate and PICN (T1, T2, and C). Then, lithium disilicate crowns were polished, crystallized, and glazed, while PICN crowns were just polished. For the production of the zirconia crowns (T3), the STL file was transferred to another milling machine (Zenotec Select Hybrid, Wieland Dental). After milling and sintering, the zirconia crowns were high gloss polished.

**Preparation of Specimens**

All implants were embedded into custom-made acrylic resin holders using a self-curing acrylic (Technovit 4071, Heraeus Kulzer) according to the recommendations of the ISO-Norm 14801 (“Dentistry-Implants-Dynamic fatigue test for endosseous dental implants,” International Organization for Standardization 2007). A vertical distance of 3 mm was left from the implant shoulder to the top of the acrylic holder in order to simulate vertical bone loss (ISO 14801). The excesses of resin were carefully removed from the top of the acrylic resin holders.

According to each group, the titanium abutments (C) and the titanium bases (T1, T2, and T3) were mounted to their corresponding implants and fixed with the respective abutment screw with a torque of 20 Ncm, as recommended by the manufacturer. In this study, titanium bases with a prosthetic height of 5.5 mm and a gingival height of 0.8 mm were selected. The respective bonding surfaces were mechanically and/or chemically treated (Table 1), and the zirconia meso-abutments were bonded to the titanium bases using resin cement (Panavia 21, Kuraray). The abutment-screw access holes were closed with Teflon and a resin-based composite filling material (Tetric EvoCeram, Ivoclar Vivadent). Finally, the crowns were adhesively cemented on the abutments with an MDP-containing resin cement (Panavia 21, Kuraray), after the respective surface pretreatments (Table 1).

**Aging**

The samples were aged by means of simultaneous thermal cycles (5°C to 50°C, dwelling time 120 seconds) and chewing simulation (1,200,000 cycles, 49 N, 1.67 Hz, chewing simulator CS-4.9, SD Mechatroniс). A steatite ball (≤ 6 mm), with similar hardness to enamel was used as an antagonist indenter. The specimens were loaded 2 mm below the incisal edge at a 30-degree angle of the indenter to the implant axis. The vertical indenter movement for each chewing act was 2 mm.

**Fracture Load Test**

After aging, a static load was applied in a 30-degree angle to the implant axis (ISO 14801) using a universal testing machine (Shimadzu AGS-X series, Shimadzu) until failure. To ensure even force distribution to the crown/abutment during loading, a 0.5-mm-thick tin foil (Dentaurum) was used in between the specimens and the indenter.6,9 Failure was defined either as visible fracture of the abutment/crown, or after a 20% decrease of the maximum load during the fracture strength test if no obvious fracture was observed. For each group, the fracture load was recorded using specific software (TRAPEZIUM X, V.1.4.4, Shimadzu).

For comparison of the groups, the bending moments (M) were calculated in Ncm according to the formula $M = 0.5 \times F \times l$ (ISO Norm 14801, 2007), with “F” corresponding to the maximum load (N) and “l” corresponding to the vertical distance from the simulated bone level to the center of load (cm).

**Analysis of Failure**

After aging and fracture load test, all samples were analyzed for determining the mode of failure. Failures at implant, abutment, and/or crown level were documented, including fractures, visible crack lines, plastic deformation, or debonding of components (Olympus SZX9, Olympus). To be able to visualize the patterns of the abutment/crown failures after loading, one
A specimen of each abutment type (titanium abutment or titanium base) was embedded and sectioned with a diamond saw in the bucco-oral direction through the center of the sample (Well Diamond Wire Saws). The embedded cross sections were examined by means of a microscope (Leica DM LM, Leica Microsystems) for further visualization of failure origin.

Statistical Analysis

Bending moments data were statistically analyzed with software (IBM SPSS Statistics v20, IBM Corp). A one-way analysis of variance (ANOVA) was performed, and multiple comparisons between groups were made using Tukey HSD post hoc tests ($\alpha = .05$). Failure modes were analyzed descriptively.

RESULTS

The means of the bending moments were $356.4 \pm 20.8$ Ncm (T1), $357.7 \pm 26.3$ Ncm (T2), $385.5 \pm 21.2$ Ncm (T3), and $358.8 \pm 25.3$ Ncm (C). Group T3 exhibited significantly higher mean bending moments than all the other groups ($P < .05$). No differences were found between zirconia meso-abutments bonded to titanium bases and the customized titanium abutments when lithium disilicate crowns were used (T1 and C) ($P > .05$) (Fig 2).

No failures were detected during and consequently to the aging procedure (Fig 3). In all groups, failures occurred due to fracture of the abutment screw in the internal connection (Fig 4). A plastic deformation of the abutment and implant head was visible in all the samples. Under the microscopic analysis, incomplete crack lines in the crowns were detected in four samples of group C, four samples of group T1, and seven samples of group T2. All of these crack lines followed a similar pattern distribution in the palatal aspect of the crown (Table 2).
a clinical situation. In incisor regions, masticatory force may range between 90 and 270 N. In the present investigation, all the specimens resisted higher forces, even after being subjected to artificial aging. If posterior regions are considered, higher masticatory forces can be expected. However, the direction of these forces are more axial and, therefore, more favorable for the implant and the prosthetic components. This results in very high fracture strength values, which have been reported in previous investigations using a posterior tooth-like shape. The use of a titanium base appears to be a very promising alternative, which offers the possibility to combine an all-ceramic superstructure with a metallic connection to the implant. In the present study, zirconia was successfully used as a meso-structure material, with 100% survival integrity from the mechanical and bonding point of view. Some authors also reported lithium disilicate as possible material for this purpose, showing similar stability. In another study, zirconia showed better reliability when compared with lithium disilicate or CAD/CAM resin-based composite. Different methodologies used might explain the differences found between studies.

The second variable analyzed in this in vitro study was the crown material. As the chewing simulation did not visibly affect the structural integrity of the reconstruction and bonding interface, it may be presumed that the complex of abutment and crown would behave as a solid one-piece during static load testing. Hence, the bending moment values would be expected to be similar, independently of the crown materials. Surprisingly, the zirconia group revealed significantly higher bending moment values than the lithium disilicate (P = .025) and PICN (P = .04) groups. A possible explanation might be related to the crack lines observed under the microscope after fracture load, for some lithium disilicate and PICN samples, but not at all for the zirconia ones. Even if these crack lines were not detected after chewing simulation, they could already be present at that time, and under the increasing static load, they might have propagated on the surface and became more visible. This explanation was also suggested in a previous investigation, and can be linked to the higher initial failure load of zirconia. Even though these differences were very small (less than 30 Ncm), and although they were statistically significant (P < .05), the P values were close to .05. Hence, a statistical error type I cannot be discarded.

Concerning the bonding aspect, no failures were registered. This finding is in agreement with previous studies. A recent investigation on narrow implant connections did not find any debonding on titanium resin bases after an identical aging simulation.
Despite limited evidence concerning the bonding stability on titanium bases after chewing simulation, these outcomes appear to be promising for this concept, as the fixation is merely based on the adhesive cementation.

The methodology used in this study is mostly adequate to test the whole implant-abutment-crown complex. The selection of different crown materials aimed to validate their respective use applied to the titanium base abutment concept, and not to test the fracture strength of the materials per se. Although fracture tests may contribute to assess the durability of prosthetic components, continuous fatigue is often one of the main causes that leads to a structural failure of the reconstructions. In that respect, dynamic loading might be considered a more clinically relevant testing approach. However, clinical extrapolation of the results must be done carefully, as it is not possible to fully replicate the oral cavity conditions through an in vitro study.

In this study, all tested samples based on the titanium base concept survived the dynamic loading. No mechanical failures were registered, either at abutment or at crown level. Moreover, titanium bases revealed a similar stability and mechanical behavior of titanium abutments, which is still considered the “golden standard” for implant-supported single reconstructions. The outcomes of this study demonstrate very good perspectives for application in an oral environment; yet, they must be confirmed in long-term clinical trials to prove the predictability of this concept over time.

CONCLUSIONS

Zirconia meso-abutments bonded to titanium bases were demonstrated to be a stable combination when compared with customized titanium abutments, which are still considered the golden standard. With respect to the crown material, all three tested ceramics (lithium disilicate, zirconia, and PICN) revealed very good stability when used in its monolithic form.

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