Short communication: In vitro pilot study: Are monolithic 3Y-TZP zirconia crowns too strong for titanium implants?

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Abstract

Purpose: To report on pilot tests for a planned study on single implant-supported crowns made from different restorative materials using finite element analysis (FEA) and in vitro load-to-failure testing. Materials and Methods: Within this pilot study, FEA was conducted
using Ansys 2019 R2 to simulate stress and deformation for implant-supported crowns made of lithium disilicate ceramic (LiS2) and zirconia (3Y-TZP). Additionally, an in vitro load to failure test was conducted using two specimens per group to evaluate the failure mode and to confirm the findings from the FEA. **Results/Conclusion:** FEA revealed stress areas at the palatal cervical areas of the crowns. In the load to failure test, both hybrid abutment crowns made of LiS2 fractured (410 N and 510 N) before plastic deformation of the metal implant components occurred. The monolithic hybrid abutment crowns made of 3Y-TZP did not fracture until tests were interrupted at 646-N and 690-N occlusal force, when plastic deformation of the metal implant components was visually observed. *Int J Prosthodont 2021.*
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**Introduction**
Against the strong trend towards monolithic restorations, hybrid abutment crowns on titanium bases are being used more frequently. The screw-retained restoration is milled from a ceramic material in full contour and then adhesively luted to a titanium meso-structure. This makes the approach fast and economical and the concept entails possible biological advantages, due to absence of a cement gap. However, the wide range of dental ceramics exhibit significantly different biomechanical properties and little is known about the possible risks associated in regards to the failure mode of the restoration and the supporting implant.

Hybrid abutments and hybrid abutment crowns made from monolithic zirconia have proven adequate and even superior mechanical stability, sometimes exceeding clinically relevant loading. However, one must note that the success of implant and crown is dependent on an optimized interaction of the characteristics of all parts of the reconstruction.
Clinical experience and first scientific evidence raise the question whether monolithic 3Y-TZP zirconia might - in case of occlusal overload - negatively influence the failure mode of hybrid abutment crowns and cause implant-associated complications. To the authors’ best knowledge, scarcely any investigation has addressed this issue.

This short communication reports on pilot tests for a planned study on single implant supported crowns made from different restorative materials using finite element analysis (FEA) and in vitro load-to-failure testing.

**Material and Methods**

The FEA analysis was conducted using Ansys 19.0 R2 software (Ansys, Canonsburg, USA). Stress and deformation analysis were performed for implant supported crowns from Lithium Disilicate Ceramic (LiS2) and zirconia (3Y-TZP) using material-specific parameters given in table 1. An occlusal force up to 800 N and a load angle of 30 degrees was assumed adequate and used for the FEA calculation.

For the confirmation of the FEA in vitro, four implants (PROGRESSIVE-LINE Implant, Promote® plus, Ø 3.8 mm / 13 mm length, CAMLOG Vertriebs GmbH, Wimsheim, Germany) were provided with single crowns in premolar form either from monolithic 3Y-TZP zirconum oxide (Prettau® Zirkon, Zirkonzahn GmbH, Gais, Italy) or from Lithium-Disilicate-Ceramic (IPS e.max CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein) on CAD/CAM titanium bases (CAMLOG® Titanium base CAD/CAM, Crown, Ø 3.8 mm, CAMLOG Vertriebs GmbH). and embedded in PMMA (PALAXPRESS®, Kulzer GmbH, Hanau, Germany) in accordance to ISO norm 14801. After sandblasting (aluminium oxide 110 µm, 1 bar, 10 mm, 10 s) of the titanium base the restorations were pre-conditioned and adhesively bonded with a self-curing luting composite (Multilink Hybrid Abutment H0, Ivoclar Vivadent AG). Specimens were tested for fracture strength in the universal testing machine (Zwick UPM 1445; Zwick GmbH & Co. KG, Ulm, Germany) under 30° angulation (10kN capsule; testing speed: 1mm/min).
Results

The FEA revealed stress and deformation areas at the palatal areas of the crown which further disseminated from the cervical area towards the palatal cusp of the crowns (Figure 1).

The load-to-failure-test confirmed these findings, however showed two different failure-modes:

1) Both hybrid abutment crowns out of LiS2 fractured before a plastic deformation of the metal implant components occurred (Fig 2; right) at forces of 410 N and 510 N.

2) The hybrid abutment crowns out of 3Y-TZP did not fracture. The load-to-failure tests were interrupted at 646 N and 690 N occlusal force, because a massive plastic deformation of the metal implant components occurred. (Fig 2; left).

The fractures of the LiS2 crowns occurred a mean force of 460N, causing a maximum tension of 1159,8 MPa in the FEA for LiS2 crowns. Applying this force to the FEA of the monolithic zirconia crowns a maximum tension of 1220,4 MPa or 2211,1 MPa at a force of 460N and a force of 700N respectively could be observed.

Discussion

The limited results from the presented pilot-test based on theoretical considerations, FEA, and mechanical testing add fuel to the fire concerning the question of material choice for hybrid abutment crowns. Theoretical considerations lead to the conclusion that a flexural strength of the ceramic prosthodontic component larger than the yield strength of titanium implant components shifts the point of weakest resistance towards the latter one. The results from the preliminary FEA support that theory and revealed that the greatest tension and origin of stress is located at the transition zone between the implant and the full-ceramic components. It can be suggested, that a failure is initiated on the cervical palatal area of the hybrid abutment crowns. Also the further load-to-failure tests showed a fracture-pattern in accordance to the assumption and simulation – however only for the weaker lithium-disilicate ceramic. The
stronger 3Y-TCP zirconia did not fracture at all, but the occlusal load led to a plastic deformation of the implant shoulder, which must be considered a worst-case scenario. The applied forces might appear as high; however mean clenching forces in full-dentition subjects as high as 720N (+/- 162N) have been reported. Against that background, Menini et al. reported and discussed the shock absorbing capacity of different restorative materials for implants supported prostheses.

Bearing in mind the results of this pilot-testing, the prevalence of failures – and the respective failure modes - of hybrid abutment crowns need to be evaluated and discussed further. Short term clinical studies show good survival (success) rates for hybrid abutment crowns from Lithium Disilicate ceramic. Also the clinical experience with monolithic implant supported zirconia crowns is still limited to observation periods of two and three years. Despite the fact, that so far there is no clinical evidence for implant failures because of the hardness of zirconia-ceramic or other ceramic materials, clinicians should carefully consider the material choice when it comes to monolithic hybrid abutment crowns. Due to the limits of this pilot-tests, further in vitro research and especially further clinical research needs to be conducted to better understand the impact of the restorative material’s choice on the failure mode considering a worst-case-scenario.

Conclusion

Hybrid abutment crowns made from lithium disilicate ceramic seem to show a favorable failure mode in case of occlusal overload, protecting the osseointegrated implant from fatal damage.
References


7 De Angelis, P., Passarelli, P. C., Gasparini, G., Boniello, R., D'Amato, G., & De Angelis, S. (2020). Monolithic CAD-CAM lithium disilicate versus monolithic CAD-CAM zirconia for single implant-supported posterior crowns using a digital workflow:
A 3-year cross-sectional retrospective study. *J Prosthet Dent,* 123, 252-256.  
doi:10.1016/j.prosdent.2018.11.016

**Figures**

**Figure 1:** Finite-Element-Analysis: Stress-distribution and movement under different occlusal loads of a Zirconia crown. After trespassing the 0.2% yield strength of 640N/mm² for titanium plastic deformation of the implant shoulder occurs.
**Figure 2:** Implant supported full ceramic crowns after load to failure test: In both pilot tests hybrid abutment crowns from 3Y-TZP zirconia (right) showing a macroscopic deformation of the implant shoulder but no fracture of the ceramic component. In hybrid abutment crowns from lithium disilicate no macroscopic deformation of the implant shoulder was visible (each left side) however crowns fractured.
## Tables

**Table 1: Material specific assumptions as a basis for FEA**

<table>
<thead>
<tr>
<th>Material</th>
<th>E-Modulus [Gpa]</th>
<th>Flexural Strength [Mpa]</th>
<th>0.2% yield strength [MPa]</th>
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<tbody>
<tr>
<td>Lithium Disilicate Ceramic</td>
<td>95</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>3Y-TZP Zirconia Ceramic</td>
<td>210</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td>Titanium Grade 4</td>
<td>108</td>
<td></td>
<td>640</td>
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<tr>
<td>Luting Composite</td>
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