Mechanical behavior of zirconia and titanium abutments before and after cyclic load application

Sergio Alexandre Gehrke, DDS, PhD,a Pablo Mateus Poncio da Silva, MS,b José Luiz Calvo Guirado, DDS, PhD,c Rafael Arcesio Delgado-Ruiz, DDS, PhD,d Berenice Anina Dedavid, PhD,e Magda Aline Nagasawa, DDS,f and Jamil Awad Shibli, DDS, PhDg

Demand for esthetically ideal results from implant-supported restorations have increased significantly. Titanium abutments are commonly used to restore implants because of their excellent biocompatibility and mechanical properties.1,2 However, the gray color of titanium may lead to esthetic problems.2,3 In some situations, soft tissue height above the implant level may be insufficient at the time of definitive restoration or may occur after marginal periimplant bone loss and soft tissue recession. The resulting display of metal components could be unesthetic.4

Just as titanium, zirconia is a biocompatible material that promotes the health of the surrounding soft tissues.5-7 Zirconia is radiopaque and clearly visible on radiographs. Its ivory color is similar to that of natural teeth.8 This factor is particularly critical for the esthetic nature of implants, especially in patients with high lip lines, as it allows for light transmission at the critical interfaces between the marginal gingival tissue and the prosthetic components.9,10 Mechanically, zirconia exhibits good properties, such as flexural strength and fracture toughness.11,12 In addition to these favorable properties, zirconia is believed to form less dental biofilm than does titanium.5,13,14

Statement of problem. Esthetic factors influence the decision to use titanium or zirconia abutments in anterior regions. Clinicians may have concerns about the durability and behavior of these zirconia abutments.

Purpose. The purpose of this in vitro study was to evaluate the longitudinal and transverse long axes of the implant-abutment interface before and after the cyclic loading of titanium and zirconia abutments with an external hexagon.

Material and methods. Forty dental implants with an external hexagon and 40 corresponding abutments made of titanium (Ti) and zirconia (Zr) were subjected to cyclic load (c1) versus no load (c2). The longitudinal and transverse axes of 4 experimental groups (Tic1, Tic2, Zrc1, and Zrc2) were analyzed (vertical/horizontal adjustment) using a scanning electron microscope at ×1000 magnification. The differences among the groups were determined by 1-way analysis of variance (ANOVA) and post hoc Tukey tests (α=.05). T tests were used to identify the statistically significant differences between each group and each condition (α=.05).

Results. Significant differences were found among the groups with respect to the misfits analyzed in the 2 sections (longitudinal and transverse) before and after load application (P<.05). The behaviors of the groups differed particularly with regard to the accommodation of sets (abutment/implant) after the application of cyclic loads (P<.05).

Conclusion. The use of zirconia abutments in titanium implants can cause changes to and/or permanent deformation of the implant hexagon. (J Prosthet Dent 2016;116:529-535)
Furthermore, a short-term clinical study observed that the biologic, esthetic, and mechanical properties of zirconia are favorable and that this material can be used in various prosthetic indications on the teeth or in implants.\textsuperscript{14}

The clinical consequences of poor fit between implants and prosthetic abutments has been reported extensively.\textsuperscript{15-19} Discrepancies greater than 10 $\mu$m can have biologic effects (bacterial microfiltration)\textsuperscript{15,16} and can produce inappropriate biomechanics (the loosening and rotation of screws),\textsuperscript{17} which may lead to complete treatment failure.

Values of 10 $\mu$m or less do not seem to have consequences for hard or soft periimplant tissues.\textsuperscript{19} The long-term success of implant-supported restorations is directly related to the precision of the fit of the prosthetic components with the material from which the prosthetic components are made.\textsuperscript{19} This factor dictates the stability of the implant-abutment interface and the strength of the interface when subjected to the loads produced by mastication.\textsuperscript{15,20} The micromotions between the pieces are always present in the application of the occlusal forces produced during clenching, mastication, and jiggling movements (intermittent forces in two different directions), which might originate wear and fracture.\textsuperscript{21-23}

The use of zirconia abutments in the esthetic region has increased significantly during the past 10 years.\textsuperscript{24} Therefore, different studies have been developed to compare zirconia abutments with conventional titanium abutments. These studies on the behaviors and wear of titanium implants with zirconia and titanium abutments have indicated greater wear at the implant interface after cyclic loading in implants connected to zirconia abutments.\textsuperscript{25-29} Similarly, the present study evaluated and compared the mechanical behaviors of titanium and zirconia abutments under different loading conditions using metallographic sections in 2 directions (longitudinal and transverse long axes).

**MATERIAL AND METHODS**

Forty dental implants (4.1 mm in diameter, external hexagon; Conexão Implants) and 40 prefabricated prosthetic abutments with external hexagon for cement-retained implant-supported restorations were used in the present study (Fig. 1). Twenty abutments were made of titanium, and another 20 were made of tetragonal zirconia polycrystal (Y-TZP). Two conditions were used in the test: the implants were (c2) or were not (c1) submitted to cyclic loads. Thus, the following experimental groups were examined: titanium (Ti) abutments (groups Tic1 and Tic2) and zirconia (Zr) abutments (groups Zrc1 and Zrc2).

The 40 specimens were exposed to 20 Ncm of torque on a computerized torque testing machine (CME 30 nm; Técnica Industrial Oswaldo) according to the manufacturer’s instructions. To limit the effect of settling of the screws, which could reduce the preload, the components were retightened to their respective torque values 10 minutes after the initial torque.\textsuperscript{30}

For cyclic load application, a cylindrical acrylic resin tube (20 mm in diameter) was used to prepare 20 blocks of 22 mm in height using an epoxy resin (GIV; Polipox) with a Young modulus similar to that of cortical bone. An appropriate drill sequence (recommended for the implant model) was used to insert the implant/abutment into the blocks. A semicircular metallic crown was cemented onto each set. The cyclic loading tests were performed following previous guidelines which recommend that the position of the sets (implant/abutment) should be at an angle of 30 ±2 degrees with respect to the applied load and that 3 mm of the implant should be exposed to reproduce bone loss.\textsuperscript{31} The 20 specimens from the c2 groups were placed on a mechanical cycler (Biopdi) for the application of 360,000 cycles with 150 N of controlled axial force at 4 Hz frequency. During mechanical cycling, the specimens were immersed in water at 37°C.

All of the 20 specimens in the c1 groups and all of the 20 specimens in the c2 groups were embedded in resin...
the groups before and after fatigue (to determine the significance of the differences among the groups, and subsequent analyses were performed with post hoc Tukey tests. The t test was applied to determine the significance of the differences between the groups before and after fatigue (α=.05). The statistical analysis was performed using software (SPSS Statistics v21.0; IBM Corp).

DISCUSSION

This in vitro study evaluated the fit accuracy between external hexagon implants and abutments made of titanium and zirconia before and after the application of cyclic loads. Sections were made in 2 directions (longitudinal and transverse) relative to the long axis of the set (abutment/implant) and contacts in different positions (Fig. 7). Comparisons of the data between the groups in the same condition with t tests (Tic1 versus Zrc1, P=.105 and Tic2 versus Zrc2, P=.098) revealed no significant differences.

Regarding the longitudinal sections, significant differences were observed among the 4 groups according to 1-way ANOVA (P<.001). Before cyclic loading, the groups had exhibited gaps between the sets (abutment/implant) and contacts in different positions (Fig. 7). However, after the application of cyclic loads, the interfaces in the Tic2 group were in full contact, with significantly lower values than those of the Tic1 group (P=.002). The zirconia abutment (Zrc2 group) specimens exhibited microfractures in the region between abutment and implant (Fig. 8), but no significant differences in misfit values were observed compared with the Zrc1 group (P=.479). The t tests used to compare the groups in the same condition revealed significant differences (Tic1 versus Zrc1, P=.002; Tic2 versus Zrc2, P<.001).

RESULTS

In all specimens, loosening of the sets (abutment/implant) occurred after the programmed cyclic loads. Table 1 shows the contact measurements between the walls before and after the mechanical loading cycles in the 2 directions (longitudinal and transverse). The 1-way ANOVA for the analysis of the transverse section did not reveal any significant differences (P=.479) among the 4 groups. Tic1 and Tic2 specimens showed no significant differences (P=.358) and exhibited gaps in positions p2 and p3 before and after load application to the sets (implant/abutment). Contact was present in all specimens in position p1 (Fig. 5). The Zrc1 and Zrc2 specimens did not exhibit any significant differences (P=.403); they had greater contact at the angle of each face of the hexagon, and none of the specimens demonstrated contact in any of the other areas before or after cyclic load application. The Zrc2 specimens exhibited rounding of the angles in the implant hexagon, which was probably caused by the micromotion of the sets during cyclic loading (Fig. 6). Comparisons of the data between the groups in the same condition with t tests (Tic1 versus Zrc1, P=.479) among the 4 groups did not reveal any significant differences.

The measurements of the connection (Fig. 2). Thereafter, the specimens were polished using a sequence of papers 240-, 320-, 400-, 600-, and 1200-grit abrasive (Polipox) plus a rag wheel to provide appropriate surface smoothness. Subsequently, the specimens were ultrasonically cleaned in 96% isopropanol, and a strong air jet was used. The specimens were analyzed by scanning electron microscopy (SE).


Figure 2.
titanium abutments accommodated to the implant without changing their structure. Unlike zirconia abutments, in which structural changes were found in both the abutment and implant, a previous study found that the implants with zirconia abutments showed a greater initial rate of wear and more total wear than the implants with titanium abutments after cyclic loading.26

Although in vitro testing has limitations because of the difficulty in simulating all the clinical variables, an ISO standard was created in order to standardize dental implants assays using mechanical cycling.31 However, the results produced by such a method should be interpreted with caution. A wide range of testing parameters is specified in ISO 14801:2007, including testing frequency (2 to 15 Hz), environment (water or dry when testing above 15 Hz), and number of cycles (2 or 5 million, depending on the chosen frequency). The present study used low frequency (4 Hz) in water at 37°C, and there may be differences in the results when testing at the highest end of the speed scale allowed by the standard. Further investigation is needed.

Based on the results obtained in this study, titanium abutments performed better, especially with regard to damage to the implants. Regarding the adjustment of both implant abutments tested, the values were within the range reported in the literature; however, higher precision was found in the titanium abutments. This probably results from the difficulties in the production process (machining) of zirconia, which quickly wears the cutting tools used.

Zirconia-based ceramic is a high-strength material.11,12 The strength and toughness of zirconia are attributable to its toughening mechanisms, which include crack deflection, zone shielding, contact shielding, and crack bridging.12 The prevention of crack propagation is critically important in high fatigue situations, such as those encountered during mastication and parafunction.4 However, in this study, after the application of cyclic loading at a low frequency (4 Hz) and of a relatively low force (150 N), zirconia abutments exhibited cracks and microfractures that most likely occurred during the shift of the abutment accommodation against the implant platform. Nevertheless, titanium abutments allow for easier accommodation because of their excellent mechanical properties.

The occlusal forces produced during clenching, mastication, and jiggling movements (intermittent

### Table 1. Contact measurements (mean ±SD) between walls of sets (abutment/implant) before and after mechanical load cycles in 2 sections (longitudinal and transverse)

<table>
<thead>
<tr>
<th>Group</th>
<th>Longitudinal Section (μm)</th>
<th>Transverse Section (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tic1</td>
<td>3.8 ±1.9</td>
<td>13.4 ±7.0</td>
</tr>
<tr>
<td>Tic2</td>
<td>0</td>
<td>13.5 ±7.3</td>
</tr>
<tr>
<td>Zrc1</td>
<td>8.2 ±3.3</td>
<td>21.1 ±14.5</td>
</tr>
<tr>
<td>Zrc2</td>
<td>9.1 ±3.5</td>
<td>22.1 ±17.4</td>
</tr>
</tbody>
</table>

![Figure 3.](image1.png) A, Longitudinal section with landmarks p1 (most external area), p2 (central region), and p3 (internal region) used for evaluation of misfit. B, Horizontal section showing 1 side of hexagon with landmarks p1, p2, and p3 used to misfit measurement (×500 magnification).

![Figure 4.](image2.png) Image of measurement performed with software (yellow line).
forces in two different directions) are typically transferred through dental implant systems, causing movement between implants and abutments.\textsuperscript{21,22} The positional stability of the mated surfaces has been found to be inversely proportional to rotational freedom.\textsuperscript{23} In the present study, zirconia abutments exhibited the greatest contact between the parts (abutment and implant) against the angle of the hexagon. This contact produced micromotion during the application of cyclic loads, and, because the zirconia abutments were harder than the titanium implants, the angles of the implant hexagon were rounded, but there was no loosening of the abutment screws. However, this deformation can derail the use of this implant especially in single crowns.

Statistically significant results were obtained from this study. A possible limitation of the results, however, is related to the number of specimens included, the load value used, and the number of tests for each abutment. Including different load values and other evaluation methods, such as with regard to loosening of the abutment screws, would be important. Although studies have
shown no statistical or clinically relevant differences between survival rates and the technical and biologic complication rates of zirconia and titanium abutments,\textsuperscript{24} other clinical trials could assess possible damage to the implants after loosening of the abutment.

**CONCLUSION**

Despite the limitations of this in vitro study, it was concluded that the use of zirconia abutments in titanium implants can cause changes and/or permanent deformations of the implant hexagon. Furthermore, the stress that tended to accumulate at the vertices of the abutments led to microfractures and subsequent micro-gap formation in zirconia abutments.

**REFERENCES**


**Corresponding author:**
Dr Sergio Alexandre Gehrke
Rua Dr Bozano, 571-97015-001
Santa Maria, RS
BRAZIL
Email: sergio.gehrke@hotmail.com

Copyright © 2016 by the Editorial Council for The Journal of Prosthetic Dentistry.