Fracture Strength Study of Internally Connected Zirconia Abutments Reinforced with Titanium Inserts

Hyo-Jung Chun, DDS, MSD1/In-Sung Yeo, DDS, MSD, PhD2/Joo-Hee Lee, DDS, MSD, PhD2/Seong-Kyun Kim, DDS, MSD, PhD4/Seong-Joo Heo, DDS, MSD, PhD4/Jai-Young Koak, DDS, MSD, PhD4/Jung-Suk Han, DDS, MSD, PhD4/Shin-Jae Lee, DDS, MSD, PhD5

Purpose: The implant-abutment connection area is known to be the weakest part of an internal-connection zirconia abutment and therefore the most likely to fracture. The aim of this study was to evaluate the complementary effect of a titanium insert on the fracture strength of a zirconia abutment.

Materials and Methods: Three types of abutments with internal connection structures were selected and assembled: titanium abutment-titanium abutment screw (Ti-Ti), zirconia abutment-titanium abutment screw (Zr-Ti), and zirconia abutment-titanium insert-titanium abutment screw (Zr+Ti-Ti). Fifteen abutments and 15 implants were used and divided into three groups of five specimens each. Compressive loading was applied to the specimens at 30 degrees off-axis with dislocation speed of 1 mm/min and was increased until deformation occurred. Results: The Ti-Ti specimens showed the highest maximum fracture load, followed by the Zr+Ti-Ti specimens; the Zr-Ti assemblies were the weakest. Significant differences in fracture strength were found between the groups. All of the investigated Zr abutments fractured. However, in the Zr+Ti-Ti specimens, 60% of the Ti abutment screws fractured and 40% bent, whereas all of the abutment screws in the Zr-Ti group were only bent. Conclusion: The Ti insert, as a substitute for the weakest part of a Zr abutment in an implant with an internal friction connection, can reinforce the fracture strength of a Zr abutment.

Key words: dental implant abutment, fracture strength, internal connection, titanium insert, zirconia

As esthetic demands in dentistry increase, the substitution of metal with ceramics has increased, not only in prosthetic restorations such as crowns and fixed partial dentures, but also in implant components.

Ceramic implant abutments prevent the appearance of an unnatural metallic color through the covering gingiva when planning implant treatment, especially in the anterior region.1 However, the application of ceramics has been limited because of brittleness of these materials. Zirconia ceramic has high resistance to fracture and fatigue as well as an esthetic advantage, which has recently led to fabrication of zirconia implant abutments.2–4 The mechanical and biomechanical success of zirconia abutments clinically has been reported, but with limited sample sizes and follow-up periods.5–8 Zirconia has also shown comparable biologic properties, and showed lower bacterial adhesion than titanium or gold.9,10

An internal friction connection connects an implant with an abutment by means of screw tightening and friction occurring at the contact between the implant and the abutment. This internal friction connection is known to provide more intimate contact with implants and more favorable force distribution than an external connection.11,12 When an implant abutment is made of zirconia and is connected to the implant by means of an internal friction connection, the implant-abutment connection area is vulnerable to crack or fracture, although force distribution is advantageous.13 Most clinical studies of successful zirconia abutments used...
an external-connection implant system. However, it was reported that the incidence of fracture of metal-based and zirconia-based abutments does not seem to be influenced by the type of connection.

A secondary metal component or a titanium insert can be used to replace the point of contact between an abutment and an implant in an internally connected zirconia abutment. The titanium insert allows the zirconia abutment to be connected with an implant similar to an external connection. Such an assembly avoids the weakest (and most fracture prone) point of the zirconia abutment connection—at the implant-abutment contact area in the internal friction connection—while the assembly maintains the advantages in force distribution of the internal friction connection.

This study evaluated the effect of a titanium insert on the fracture strength of a zirconia abutment under static compressive loading within the internal friction connection; a titanium abutment, a zirconia abutment, and another zirconia abutment that incorporated a titanium insert were compared.

**MATERIALS AND METHODS**

Three types of internal friction connection implant abutments with an antirotational hex structure were selected for this study and were divided into three groups. Titanium abutments (Dual Abutment [Hex], Dentium) and titanium abutment screws were used for the Ti-Ti group; zirconia abutments (ZirAce Internal, Acucera) and titanium abutment screws were used for the Zr-Ti group; and zirconia abutments (ZirAce External, Acucera) with titanium inserts (Z socket Dentium Regular, Osung MND) and titanium abutment screws were used for the Zr+Ti-Ti group (Table 1, Fig 1).

Fifteen screw-shaped titanium implants (Implantium, Dentium), which were 4.5 mm in platform diameter, 4.3 mm in body diameter, and 10.0 mm in length, were used in this study. The sample size of the abutments was five for each group. All the abutments were adjusted to the same length (8 mm) from the implant-abutment junction to the top of the abutments and assembled onto the implants through the titanium abutment screws. Using a torque wrench, the tightening torque to connect the abutment with the implant was 30 Ncm for the Ti-Ti group and 32 Ncm for the Zr-Ti and Zr+Ti-Ti groups according to the manufacturers’ instructions.

Preparation of specimens and setting of compressive loading were based on ISO Standard 14801:2007. The hemispheric metal caps were cast and placed on the abutments (Fig 2). The implant-abutment assemblies were embedded in a metal holder, which was inclined by 30 degrees off-axis relative to the compressive force (Fig 2). Compressive loading was applied by a hydraulic fatigue test machine (858 Mini Bionix II, MTS Systems Corporation) with dislocation speed of 1 mm/min and increased from 0 N until fracture or deformation occurred. The maximum compressive load was recorded in each test. The fractured area was observed with field emission scanning electron microscopy (FE-SEM) (Hitachi S-4700, Hitachi).

The statistical data analysis was performed with Language R software (R Foundation for Statistical Computing). The statistical power was close to 1.0, showing that the sample size used in this study was appropriate. The nonparametric Kruskal-Wallis and Wilcoxon tests were performed to analyze the data. To control for the multiplicity problem, the Bonferroni correction of α was applied.

**Figs 1a to 1c** Three types of implant-abutment systems. All groups had internal connections between the implants and the abutments.

**Fig 1a** Ti-Ti group: a titanium abutment with a titanium abutment screw and a titanium implant, which were connected by screw tightening and frictional forces.

**Fig 1b** Zr-Ti group: a zirconia abutment with a titanium screw and a titanium implant.

**Fig 1c** Zr+Ti-Ti group: a titanium implant and a zirconia abutment insert and a titanium screw. The titanium insert had both internal-hex (red arrowhead) and external-hex (white arrowhead) structures to connect the external zirconia abutment into the implant.

**Table 1 Abutment Specimens Used in the Study**

<table>
<thead>
<tr>
<th>Group</th>
<th>Items</th>
<th>Product name (product code)</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-Ti</td>
<td>Titanium abutment</td>
<td>Dual abutment hex (DAB5535HL)</td>
<td>Width: 5.5 mm Height: 5.5 mm Collar height: 3.5 mm</td>
</tr>
<tr>
<td>Zr-Ti</td>
<td>Zirconia abutment</td>
<td>ZirAce internal (ZIA5535)</td>
<td>Width: 5.5 mm Height: 9.7 mm Collar height: 3.3 mm</td>
</tr>
<tr>
<td>Zr+Ti-Ti</td>
<td>Zirconia external</td>
<td>ZirAce external (ZAR535)</td>
<td>Width: 5.0 mm Height: 5.5 mm Collar height: 3.0 mm</td>
</tr>
<tr>
<td></td>
<td>Titanium insert</td>
<td>Z socket Dentium Regular</td>
<td>Insert width: 4.1 mm</td>
</tr>
</tbody>
</table>

The International Journal of Oral & Maxillofacial Implants 347
RESULTS

The medians and interquartile ranges of the maximum compressive load values for each group are shown in Table 2. A global test revealed a significant difference between the groups ($P = .0019$). The Ti-Ti assemblies showed the highest load value, while the Zr-Ti group assemblies showed the lowest value. The maximum load for the Zr+Ti-Ti group was significantly higher than that for the Zr-Ti group and significantly lower than that for the Ti-Ti group.

In the Ti-Ti and Zr-Ti groups, the failure occurred at the implant-abutment junction (Figs 3a and 3b). In the Zr+Ti-Ti group, however, the failure occurred at the junction between the abutment and the titanium insert, which was above the level of connection between the titanium insert and the implant (Fig 3c). Only deformation was found in the Ti-Ti group; no fractures were observed (Fig 3a, Table 2). In the Zr-Ti group, all the zirconia abutments fractured, and all the abutment screws bent during testing (Fig 3b, Table 2).

All the abutments in the Zr+Ti-Ti group also fractured, which was similar to the results of the Zr-Ti group. Because of the effect of the titanium insert, three titanium abutment screws fractured during the test, which was different from the results of the Ti-Ti and Zr-Ti groups (Table 2).

Figure 4 shows SEM images of the zirconia abutments in the Zr-Ti and Zr+Ti-Ti groups after fracture. No structural or material defects were found, while minimal scattered debris was observed on the fractured surfaces.

Table 2  Median Load Values Leading to Deformation or Fracture and Modes of Failure

<table>
<thead>
<tr>
<th>Specimen type</th>
<th>Maximum load (N, median ± IQR)</th>
<th>Failure mode</th>
<th>Abutment screw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fracture</td>
<td>Deformation</td>
<td>Fracture</td>
</tr>
<tr>
<td>Ti-Ti group</td>
<td>1,404.7 ± 19.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Zr-Ti group</td>
<td>1,119.5 ± 4.8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Zr+Ti-Ti group</td>
<td>1,216.8 ± 41.2</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

IQR = interquartile range.

© 2015 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
DISCUSSION

This study showed that the internal friction connection that used a titanium insert with a zirconia abutment was more resistant to loading than the internally connected zirconia abutment alone. This result is similar to that of a previous study.16 All the abutments tested in this study resisted loads of at least 1,100 N before failure, meaning that all will be clinically functional, since the reported maximum bite force in human ranges from approximately 100 to 300 N in the anterior region and from approximately 200 to 900 N in the posterior jaw.17–22 This evaluation corresponds with a previous study estimating that the initial fracture resistance before cyclic loading should be approximately 1,000 N for all-ceramic restorations.23 Furthermore, fracture occurred at the interface between the zirconia abutment and the titanium insert when the titanium insert was used. Removal and replacement of the fractured zirconia abutment are considered to be clinically easier should the zirconia abutment of the abutment-insert-implant assembly fracture in the patient’s mouth.

The maximum fracture loads measured in this study were higher than those observed in other studies. Previous studies reported mean fracture loads of 783 to 821 N for titanium abutments and 292 to 725 N for zirconia abutments.16,24,25 However, the previous studies tested internal-hex or tri-channel connections, which featured a butt-joint structure, whereas the current study tested an internal friction connection, which had an inclined plane.16,24,25 The butt-joint structure is usually considered to be less resistant to fracture than the inclined plane because of less favorable stress distribution.26 Differences in grades of titanium and the constituents of zirconia are another possible reason for the differences between studies.

The dissimilarity in fracture mode between the Zr-Ti and Zr+Ti-Ti groups was notable. Fractures in the zirconia abutments used in this study were considered to be caused purely by the compressive load, because neither structural nor material defects were observed on the FE-SEM images. Fracture of the zirconia abutment in the Zr-Ti group occurred after or in combination with bending of the titanium abutment screw, since the stress was concentrated on the coronal portion of the implant at the implant-abutment interface.16 The zirconia abutment in the Zr+Ti-Ti group fractured with and without abutment screw fracture above the implant level because of the titanium insert, which meant that the stress reached the fracture strength of the zirconia abutment before it became concentrated at the implant-insert interface. A remnant of a fractured abutment screw is easily removed without damage to the implant because the fractured remnant is surrounded by the titanium insert. Additional studies are required to compare data concerning the fatigue resistance of zirconia abutments with or without a titanium insert when cyclic loading is applied.

CONCLUSION

From the results of this study, the use of the titanium insert as a substitute for the weakest part of a zirconia abutment within the internal friction connection can be an alternative method to complement the low fracture strength of a zirconia abutment while still taking advantage of the esthetic superiority of zirconia.
ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) via a grant funded by the Korean government (MEST) (no. 2011-0028067). The authors reported no conflicts of interest related to this study.

REFERENCES