The effective design of zirconia coping on titanium base in dental implant superstructure

Maiko MIEDA¹, Ikiru ATSUTA¹, Yasuyuki MATSUSHITA¹, Takehiro MORITA², Yasunori AYUKAWA¹, Yoshihiro TSUKIYAMA¹, Yoshinori SAWAE² and Kiyoshi KOYANO¹

¹ Section of Implant and Rehabilitative Dentistry, Division of Oral Rehabilitation, Faculty of Dental Science, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan
² Machine Elements and Design Engineering Laboratory, Department of Mechanical Engineering, Kyushu University, 744 Motomachi, Nishi-ku, Fukuoka 819-0395, Japan

Corresponding author, Ikiru ATSUTA; E-mail: atyuta@dent.kyushu-u.ac.jp

Zirconia exhibits good tissue compatibility and nontoxicity, making it a widely used esthetic replacement material for implant abutments. To avoid abutment-fracture, the parts composed of zirconia with a bonded metal component connected to the implant can be used. The purpose of this study was to design titanium and zirconia components with high fracture resistance at the zirconia component’s edge line. Three edge line designs of the titanium base and zirconia sleeve were made: chamfer, shoulder, and back-taper. To assess the strength of the abutment design, static loads were applied vertically and 30 degrees from the vertical axis. A test of tensile strength was also performed after chewing simulation. Conventional zirconia components mounted on a chamfer-type titanium base showed significantly lower fracture resistance than shoulder and back-taper types. This study suggests that to improve the durability of zirconia abutments with a titanium base, a back-tapered edge design is recommended.

Keywords: Dental implant, Zirconia sleeve, Titanium base, Structural durability, Chewing simulator
attachment between zirconia and titanium at the margin is essential.

In this study, we used a chewing simulator to compare three types of zirconia margin on a titanium base: back-taper, shoulder, and chamfer. The best margin shape for safe clinical application was determined.

MATERIALS AND METHODS

Experimental abutment with titanium base and zirconia sleeve

Thirty zirconia implant abutments with three different zirconia margins (n=10 each) were used. The different abutments, with back-taper, shoulder, and chamfer margins, are shown in Fig. 1B, C. All zirconia sleeve components were produced with identical dimensions, with a circumference of 0.4 mm and a height of 10 mm. In all groups, the zirconia sleeve consisted entirely of zirconia (Aadva CAD/CAM Zirconia Abutment, GC Advanced Technologies, Alsip, IL, USA) and the titanium base was pure titanium. Details of the implant blueprint are shown in Fig. 1B.

Pretreatment and bonding between titanium base and zirconia sleeve surface

To observe the surface of the zirconia margin after loading tests, the zirconia sleeve was bonded to the titanium base component. The surfaces of the titanium base and the zirconia sleeve were tribochemically treated (Rocatec, 3M ESPE, St. Paul, MN, USA), according to the manufacturer’s instructions. The titanium bases and the zirconia sleeves were bonded with dual-polymerizing composite resin cement (Multilink Hybrid, Ivoclar Vivadent, Schaan, Liechtenstein) after primer treatment (Monobond plus, Ivoclar Vivadent), according to the manufacturer’s instructions.

Fixation of sample on foundation

Thirty implants made of titanium with a standard diameter (NobelActive 13 mm, Nobel Biocare, Zurich, Switzerland) were used for this experiment. These were embedded in resin (Shade D3 JetTooth Shade Powder and Jet liquid, Lang Dental Manufacturing, Wheeling, IL, USA) with a custom-made positioning device to standardize the location of the implant within the steel holder. The platforms of the test implants were 3.0 mm from the steel holder to simulate 3.0 mm of bone loss, according to the ISO 14801 standard\(^\text{19}\). A 35-Ncm load was applied to all abutments to anchor them, according to the manufacturer’s instructions. As control, a group had no vertical or slanting load.

Thermocycling

After 24 h of storage in water at room temperature, all 30 zirconia-titanium abutments were thermocycled (v2.1a, Proto-tech, Portland, OR, USA) between 5 and 55°C for 20,000 cycles, with a dwell time of 20 s. The specimens were then kept in tap water at room temperature for at least 24 h before loading.

Finite element method (FEM) analysis

Two-dimensional FEM of zirconia sleeve and titanium base with chamfer, shoulder, and back-taper were created. All FEMs were created using a software program named ANSYS classic, version 11.

Static load tests

The universal testing machine (AG-10kNXplus, Shimadzu, Kyoto, Japan) made contact with the upper
corner at a 30° angle (Fig. 2), as modified from the ISO 14801 standard\textsuperscript{19}. The load was also applied at the center of the occlusal surface along the long axis (Fig. 3). Static loading was performed at a crosshead speed of 1.0 mm/min. The crosshead motion was stopped at 2 kN and this position was maintained for 30 s.

**Scanning electron microscopy (SEM)**

After the loading tests the specimens were gold sputtered with MSP-1S Magnetron Sputter (vacuum device, Ibaraki, Japan) and examined with a SEM (S-3000N, Hitachi Science System, Tokyo, Japan) at original magnification to analyze the fracture pattern (Fig. 3) and the separation between the zirconia sleeve and titanium base component (Fig. 2). These interfacial gaps were measured at three randomly chosen sites using SEM image data, and the results defined as graph (Fig. 2B).

**Chewing simulation and tensile test**

Chewing simulation testing was performed according to previously reported methods\textsuperscript{20}. In this testing condition, the samples had fatigue loading of 2-Hz frequency at room temperature and an upper cycle limit of $1.2\times10^6$ cycles. A 49-N test load was applied vertically to the long axis of the sample. After chewing simulation, the tensile strength along the long axis of all samples was tested with the universal testing machine (AG-10kNXplus, Shimadzu).
Statistical analysis
Data were processed with Sigma Stat 3.0 (Systat Software, London, UK); means±SD were calculated for each group. One-way analysis of variance with Fisher’s least significant difference test was performed. *p*-Values of less than 0.05 were considered significant. Experiments were performed using triplicate samples and were repeated three or more times to verify their reproducibility.

RESULTS
As shown in the implant cross sections, this study used three types at zirconia sleeve margin (back-taper, shoulder, and chamfer) made of zirconia that interfaced with a titanium base component (Fig. 1). First, the marginal fit between the zirconia sleeve and titanium base was investigated in each group. After the zirconia sleeve was cemented to the titanium base with general resin cement, the distance between the components was measured on SEM images. These showed that the zirconia sleeve was pushed upwards by the cement.

The second characteristic to be evaluated was the resistance strength of the zirconia sleeves with each marginal shape (Fig. 3A). FEM data showed that the zirconia margin with a back-taper shape transferred the stress to inside the component (Fig. 3C). In contrast, the chamfer margin released the stress outside of the experimental implant. After the test, the zirconia sleeve margin, which was marked with a red circle, was observed with SEM. Only the back-taper group had no fracture of the zirconia sleeve margin. The other groups had a few small fissures (white arrows).

The slanting load test at an angle of 30° resulted in separation of the zirconia sleeve from the titanium base component (Fig. 2A). Graph showed the separation distance between titanium base and zirconia sleeve in loading and un-loading sides (Fig. 2B). Only the shoulder group had marked separation in both sides. These results were supported by the SEM images of the interface separation between the titanium base and the zirconia sleeve (Fig. 2C, D). FEM data showed that the zirconia margin of all groups had the stress to inside the
Fig. 4 Tensile strength test after chewing simulation. (A) Experimental protocol for this study. (B) Simplified blueprint and illustration of chewing simulation system. After thermocycling, the samples were placed vertically on a chewing simulator using a customized jig. Chewing simulation was performed (1,200,000 cycles at 1.67 Hz and 49 N), simulating 5 years of aging. (C) Graph of adhesive strength of zirconia to titanium base component. The special loading effects were analyzed with the tensile test. The back-taper group maintained its adhesive strength, while strength in the other groups had decreased by half.

**DISCUSSION**

Because the border of the zirconia sleeve over a titanium base is located in the subgingival portion of the dental implant, the adhesion between the zirconia sleeve and the titanium base component is much more important than adhesion of the general prosthesis, including crown and inlay. If the sleeve is detached, it is very difficult or impossible to refit to the base component. Moreover, desorption and floating of the zirconia sleeve from the titanium base can result in peri-implantitis. Therefore, this bonding should be strong and stable for a long term.

In the static load test, vertical load testing showed that both the chamfer and shoulder models had damage at the zirconia margin, while no marginal damage was seen in any group with the slanting load test at an angle of 30°. However, the slanting load caused separation at the border between the zirconia sleeve and the titanium base in the samples with the shoulder margin. In short, the back-taper samples maintained their shape without any damage or any separation between titanium and zirconia. Therefore, the back-taper margin seems to be the most stable formation.

How can we explain these results? In this study, a 2-kN static load was maintained for 30 s, according to the methods of a previous study, which reported that the load level could cause problems with the abutment. Such high loads are rare in the oral cavity, but we chose this load to estimate the long-term durability of implant superstructures that are subject to repetitive loading from occlusion.

Vertical loading did not cause fissure in the back-taper zirconia margin on the titanium base component. A possible reason for this finding is that the chamfer group had tensile stress, whereas the back-taper group had compression stress on the zirconia at the margin, as FEM data showed (Fig. 3C). First and foremost,
a material characteristic of zirconia is its poor tensile strength and good compression strength (Fig. 1C)\textsuperscript{25}. The above data showing that zirconia in the back-taper design is intact and complete as presented in Fig. 3.

As seen in Fig. 2, the slanting load test did not cause any damage in any of the zirconia margin types. In all groups, FEM data showed strong stress not on the edge of the margin, but along the long axis between the zirconia and titanium. The insertion force in the shoulder margin group seems to be weaker than that in the other groups. As a result, the zirconia sleeve with the shoulder margin exhibited floating from the titanium base.

The tensile test after chewing simulation showed the excellent efficacy of the back-taper margin, with high longevity for adhesive performance between zirconia sleeve and titanium base component. In this study, the samples were subjected to vertical and horizontal loads of 49 N at frequency of 2 Hz and an upper cycle limit of $1.2 \times 10^6$ cycles to the long axis of the sample. Such a series of loading mimics occlusal impact over 5 years. The above data showing that zirconia in the back-taper form had compression stress under the test conditions, minor damage to the cement layer between the titanium and zirconia might occur with the back-taper margin.

In our study model, the zirconia abutment was directly fixed to the implant fixture with a screw, but this structure can be applied with cement fixation. Originally, zirconia abutments with titanium base components were used in the esthetic zone, including anterior restorations, in which exposure of the access hole is not acceptable. However, because most abutments with narrow body implants or with angular compensation cannot avoid a thin zirconia margin, the use a zirconia abutment with titanium base component was limited in some cases. In this study, we showed the efficacy of a zirconia sleeve with back-taper margin, and we hope to see the use of this form increase in dental treatment.

The back-taper form is well known as the wrong margin form for crowns, because the dental structure is very thin and cannot support the compression stress of occlusal force. However, because the target of our study is the titanium base, we need not hesitate to apply this design in clinical practice\textsuperscript{26}. Moreover, it is said that the back-taper shape is hard to carve out with CAD/CAM systems, but it is easy to produce in commercial production.

**CONCLUSION**

The back-taper margin prevented desorption and damage, suggesting that a back-taper zirconia abutment with titanium base has long-term stability and protects against peri-implantitis in clinical use.

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**REFERENCES**


