In vitro comparison of fracture load of implant-supported, zirconia-based, porcelain- and composite-layered restorations after artificial aging

Futoshi KOMINE, Kohei TAGUCHI, Ryosuke FUSHIKI, Shingo KAMIO, Taro IWASAKI and Hideo MATSUMURA

Department of Fixed Prosthodontics, Nihon University School of Dentistry, 1-8-13, Kanda-Surugadai, Chiyoda-Ku, Tokyo 101-8310, Japan

Corresponding author, Futoshi KOMINE; E-mail: komine.futoshi@nihon-u.ac.jp

This study evaluated fracture load of single-tooth, implant-supported, zirconia-based, porcelain- and indirect composite-layered restorations after artificial aging. Forty-four zirconia-based molar restorations were fabricated on implant abutments and divided into four groups, namely, zirconia-based all-ceramic restorations (ZAC group) and three types of zirconia-based composite-layered restorations (ZIC-P, ZIC-E, and ZIC groups). Before layering an indirect composite material, the zirconia copings in the ZIC-P and ZIC-E groups were primed with Clearfil Photo Bond and Estenia Opaque Primer, respectively. All restorations were cemented on the abutments with glass-ionomer cement and then subjected to thermal cycling and cyclic loading. All specimens survived thermal cycling and cyclic loading. The fracture load of the ZIC-P group (2.72 kN) was not significantly different from that of the ZAC group (3.05 kN). The fracture load of the zirconia-based composite-layered restoration primed with Clearfil Photo Bond (ZIC-P) was comparable to that of the zirconia-based all-ceramic restoration (ZAC) after artificial aging.

Keywords: Dental implant, Fracture load, Implant framework, Indirect composite material, Zirconia ceramics

INTRODUCTION

Due to its superior physical properties, excellent biocompatibility, and inherent esthetic properties1,2, zirconium dioxide (zirconia) is used as a coping material for tooth-supported and implant-supported all-ceramic restorations. The coping of zirconia-based all-ceramic restorations is machine-milled with a computer-aided design/computer-aided manufacturer (CAD/CAM) system. Zirconia-based restorations are usually bilayered with layering materials such as feldspathic porcelain and indirect composite materials. Although a number of clinical studies showed that zirconia frameworks of tooth-supported all-ceramic restorations seldom fracture, chopping of the layering porcelain was frequently reported3,5. The clinical outcomes for implant-supported, zirconia-based, all-ceramic restorations were equivalent to those of tooth-supported restorations6,8; however, the rate of chipping was higher than that for tooth-supported restorations6,8, perhaps because the absence of the periodontal ligament around the implants results in high occlusal stress on implant-supported restorations8,10.

Chipping of layering porcelain in zirconia-based restorations can be caused by limitations in the mechanical properties of the layering porcelain, inadequate coping design, inadequate bond strength between layering material and the coping, and thermal stress during porcelain firing4,10. Use of layered indirect composite materials in implant-supported, zirconia-based, fixed restorations might lessen chipping of layering materials. Dental composite materials increase creep and recovery, in addition to their plastic and viscoelastic effects1,2,13. These characteristics of composite materials could improve the functional aspects of restorations, especially under conditions of high occlusal stress, such as those associated with implant-supported fixed restorations10.

In vitro studies of bond performance between indirect composite materials and zirconia ceramics for zirconia-based composite-veneered restorations found that application of a hydrophobic phosphate monomer (MDP)/initiator combination resulted in satisfactory initial and durable bond strength between the two materials14,15. One study evaluated the fracture resistance of implant-supported, single-tooth, zirconia-based composite-layered molar restorations16, which have a potential fracture resistance comparable to that of porcelain-fused-to-metal and zirconia-based all-ceramic restorations. Furthermore, application of a primer containing MDP to zirconia ceramic copings enhanced initial fracture resistance of implant-supported, zirconia-based, composite-layered restorations. However, there are limited data on the fracture load of single-tooth, implant-supported, zirconia-based, composite-layered restorations after artificial aging. Therefore, the aim of the current in vitro study was to evaluate the fracture load of such restorations after thermal cycling and cyclic loading in an artificial oral environment. The null hypotheses were that the fracture load of zirconia-based restorations after artificial aging would be equal for all tested groups and that the two different surface treatments for zirconia copings would not affect the fracture load of zirconia-based composite-layered restorations.

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Dec 20, 2013: Accepted Jun 17, 2014
MATERIALS AND METHODS
Table 1 lists the materials used in the current study. Forty-four implants (OSSEOTITE Implant OSS511, Biomet 3i, Palm Beach Gardens, FL, USA; diameter, 5.0 mm; length, 11.5 mm) were used to simulate a replacement for a missing mandibular molar. All implants were embedded using a highly filled epoxy resin (Technovit 4000, Heraeus Kulzer, Wehrheim, Germany) in a special plastic specimen holder (Ring Forms, Lake Bluff, Buehler, IL, USA). The implants were embedded up to the first thread, perpendicular to the horizontal plane.

Identically shaped titanium abutments (GingiHue Post, WPP572G, Biomet 3i) were placed on the implants, and a torque control system (Torque driver HTD-C, Biomet 3i) was used to tighten the titanium screws (Titanium Square UniScrew UNIST, Biomet 3i) at 32 N of torque, according to the manufacturer’s recommendations. The abutments had standard measurements: a platform diameter of 5.0 mm, an abutment width of 7.5 mm, a height of 7.0 mm above the shoulder, and a circular shoulder width of 0.8 mm. The abutments were occlusally reduced by 1.5 mm (definitive total height, 5.5 mm) using a diamond bur (Bur No. 106RD, Shofu Inc., Kyoto, Japan) with diamond rotary cutting instruments and application of water spray (Presto Aqua, Nakanishi Inc., Kanuma, Japan) (Fig. 1). For this adjustment, a specific silicone index guide was used to obtain the standardized height of the abutment. Finally, the abutments were polished with silicone wheels (Silicone Wheel P Type, Shofu Inc.).

Zirconia copings were fabricated using a computer-aided design/computer-aided manufacturing (CAD/CAM) system (Katana, Kuraray Noritake Dental Inc., Tokyo, Japan). The abutment-implant complexes were scanned with a measurement apparatus (Dental Scanner SC-3, Kuraray Noritake Dental Inc.). CAD software (Dent MILL Comp Plus, Kuraray Noritake Dental Inc.) was used to design the copings for specimens with no cement space at the margin, a cement space of 40 μm for the axial and occlusal surfaces of the abutment, and a coping thickness of 0.5 mm. The design data were transmitted to a machine-milling device.

Table 1  Materials used in the current study

<table>
<thead>
<tr>
<th>Material</th>
<th>Manufacturer</th>
<th>Lot No.</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia ceramic material</td>
<td>Katana Zirconia</td>
<td></td>
<td>ZrO₂ 94.4%, Y₂O₃ 5.4%</td>
</tr>
<tr>
<td>Indirect composite material</td>
<td>Estenia C&amp;B</td>
<td>0048BA, 0050C</td>
<td>OA2, DA2</td>
</tr>
<tr>
<td>Feldspathic porcelain for zirconia</td>
<td>Cerabien ZR</td>
<td>019413, 029205</td>
<td>SBA2, A2B, E2</td>
</tr>
<tr>
<td>Priming agents</td>
<td>Estenia Opaque Primer</td>
<td>00172A</td>
<td>MDP, monomer solvent</td>
</tr>
<tr>
<td></td>
<td>Clearfil Photo Bond</td>
<td>0460BA, 0554CA</td>
<td>Catalyst: MDP, HEMA, Bis-GMA Universal: accelerators, ethanol</td>
</tr>
<tr>
<td>Implant</td>
<td>OSSEOTITE Implant; OSS511</td>
<td>849954</td>
<td>—</td>
</tr>
<tr>
<td>Abutment</td>
<td>GingiHue Post; WPP572G</td>
<td>846929</td>
<td>—</td>
</tr>
<tr>
<td>Abutment screw</td>
<td>Titanium Square UniScrew; UNIST</td>
<td>1096168</td>
<td>—</td>
</tr>
<tr>
<td>Glass-ionomer cement</td>
<td>Ketac Cem Easymix</td>
<td>469584</td>
<td>—</td>
</tr>
</tbody>
</table>

MDP, 10-methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethyl methacrylate; Bis-GMA, adduct of bisphenol A and glycidyl methacrylate.
Fig. 1 A schematic illustration of the specimen design.

Fig. 2 A metal apparatus for fabrication of the zirconia-based restorations.

(Katana DWX-50N, Kuraray Noritake Dental Inc.). The copings were machine-milled from pre-sintered zirconia blanks (Katana Zirconia, Kuraray Noritake Dental Inc.) and sintered to full density in a special heat furnace (Katana F-1, Kuraray Noritake Dental Inc.) at 1,375°C for 90 min. After verifying the coping dimensions with calipers (Measuring Device 2, YDM, Tokyo, Japan), the specimens were seated onto the implant abutments and an examiner inspected the adaptation with a sharp probe (Single-end Explore, YDM) and silicone disclosing medium (Fit Checker, GC Corp., Tokyo, Japan). The surface of the coping was airborne-particle-abraded with 50-μm aluminum oxide particles (Hi-Aluminas, Shofu Inc.) at 0.2 MPa pressure for 20 s.

A total of 44 implant-abutment complexes were randomly divided into four groups (n=11 each), namely, zirconia-based all-ceramic crown restorations (ZAC) and three types of zirconia-based composite-layered crown restorations (ZIC-P, ZIC-E, and ZIC). The zirconia copings of the zirconia-based composite-layered restorations were treated with different priming agents, ie, either Clearfil Photo Bond (CPB, Kuraray Noritake Dental Inc.) (ZIC-P) or Estenia Opaque Primer (EOP, Kuraray Noritake Dental Inc.) (ZIC-E), before layering the indirect composite material. The zirconia coping of another group (ZIC) was not treated with a primer.

**ZAC group**

All copings were veneered with feldspathic porcelain (Cerabien ZR, Kuraray Noritake Dental Inc.) using a specific metal apparatus (K554-02-000E, Tokyo Giken Inc., Tokyo, Japan) (Fig. 2), to standardize the configuration of the specimens (Fig. 1). Two layers of opaque (SBA2), two layers of dentin (A2B), and enamel (E2) porcelain were sequentially applied to all specimens. Layering porcelain powder was mixed with the corresponding manufacturer’s liquid (Meister Liquid, Kuraray Noritake Dental Inc.) and layered on the copings. Vibration with an ultrasonic vibrator (Ceracon II, Shofu Inc.) was performed at each layering step. Excess water on the surface of specimens was blotted with a tissue paper. The specimens were fired in a furnace (SingleMat Porcelain Furnace, Shofu Inc.), using the exact procedure specified by the manufacturer. A second firing under the same conditions was required to compensate for porcelain shrinkage during sintering. After verifying the thickness of the layering porcelain with the calipers and silicone index, all specimens were glazed. The finalized restorations were placed on the abutments to again verify adaptation, as described above.

**ZIC-P Group**

The surface of zirconia copings was first treated with Clearfil Photo Bond (CPB) according to the manufacturer’s recommendations. A layer of opaque material (Estenia C&B Body Opaque OA2, Kuraray Noritake Dental Inc.) was applied and polymerized in a laboratory light-polymerization unit (α-light II, J. Morita Corp., Suita, Japan) for 90 s. An additional layer was layered on the initial opaque material in the same manner. A dentin shade of composite material (Estenia C&B Dentin DA2, Kuraray Noritake Dental Inc.) and an enamel shade of composite material (Estenia C&B Enamel E1, Kuraray Noritake Dental Inc.) were sequentially layered on all specimens, using the same apparatus used for the ZAC group. Additional composite material was applied to areas with insufficient composite material. The specimen was then light-polymerized in the polymerization unit for 5 min and polymerized in a heat oven (KL-310, J. Morita Corp.) at 110°C for 15 min. After verifying the thickness of the layering composite material using calipers and silicone index, all specimens were finished with the companion polishing accessory (Polishing Instrument Kit, Kuraray Noritake Dental Inc.). Adaptation of all completed specimens was verified with the same procedure used for the ZAC group.
Table 2 Results of fracture load (kN) testing

<table>
<thead>
<tr>
<th>Group</th>
<th>After artificial aging</th>
<th>Before artificial aging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>ZAC</td>
<td>3.05</td>
<td>0.39</td>
</tr>
<tr>
<td>ZIC-P</td>
<td>2.72</td>
<td>0.32</td>
</tr>
<tr>
<td>ZIC-E</td>
<td>2.43</td>
<td>0.26</td>
</tr>
<tr>
<td>ZIC</td>
<td>2.37</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*Data are quoted from Taguchi et al.16.
Different lowercase letters indicate a significant difference between means (Tukey’s HSD test, p<0.05).
ZAC: zirconia-based all-ceramic restorations,
ZIC-P: zirconia-based composite-layered restorations with copings primed with CPB;
ZIC-E: zirconia-based composite-layered restorations with copings primed with EOP;
ZIC: zirconia-based composite-layered restorations with unprimed copings.
Fig. 3  Representative fractured specimens after fracture resistance testing.
(a) zirconia-based all-ceramic restoration (ZAC)
(b) zirconia-based composite-layered restoration with coping primed with CPB (ZIC-P)
(c) zirconia-based composite-layered restoration with coping primed with EOP (ZIC-E)
(d) zirconia-based composite-layered restoration with unprimed coping (ZIC).

Fig. 4  Representative SEM images of fractured surface.
(a) zirconia-based all-ceramic restoration (ZAC)
(b) zirconia-based composite-layered restoration with coping primed with CPB (ZIC-P)
(c) zirconia-based composite-layered restoration with coping primed with EOP (ZIC-E)
(d) zirconia-based composite-layered restoration with unprimed coping (ZIC)
Z; zirconia ceramics, P; layering porcelain, and I; indirect composite material. (Original magnification ×1,000).
groups. There was no significant difference among the ZIC-P, ZIC-E, and ZIC groups (p>0.69).

Total fracture of the restorations was frequently observed in all groups, namely, in 8 of 11 specimens in both the ZAC and ZIC groups and in 9 of 11 specimens in both the ZIC-P and ZIC-E groups. The ZAC, ZIC-P, and ZIC-E groups had a similar fracture pattern, i.e., mixed cohesive fracture of the indirect composite material and zirconia coping (Figs. 3a–c). ZIC group specimens showed a different fracture pattern, i.e., failure of both the layering material and zirconia coping (Fig. 3d).

Figure 4 show representative SEM images after fracture resistance testing. The surfaces of ZAC, ZIC-P, and ZIC-E specimens were mostly covered with layering materials such as feldspathic porcelain or indirect composite material (Figs. 4a–c). Conversely, little indirect composite remained on the fractured surface of a ZIC group specimen (Fig. 4d).

**DISCUSSION**

The current study compared the fracture load of zirconia-based all-ceramic restorations (ZAC group) and three types of zirconia-based composite-layered restorations (ZIC-P, ZIC-E, and ZIC groups) after artificial aging with thermal cycling and cyclic loading. The first null hypothesis—that the fracture load of zirconia-based restorations after fatigue testing would be equal in all tested groups—was partially confirmed, as the results of the current study showed no significant difference in fracture load between the ZAC and ZIC-P groups. No statistical difference in fracture load was found among the three types of zirconia-based composite-layered restorations (the ZIC-P, ZIC-E, and ZIC groups) after artificial aging; therefore, the second null hypothesis was confirmed.

Clinically, all-ceramic restorations typically fail due to slow crack growth caused by fatigue from masticatory stresses. To ensure long-term stability of restorations, restoration designs should undergo in vitro evaluation before being recommended for clinical use. Resistance of restorations in the oral environment should be tested by thermal cycling and dynamic cyclic loading as well as by testing of static failure load. In this study we simulated clinical conditions by using 10,000 thermal cycles and dynamic cyclic loading of 1.2 million cycles to induce stress in crown specimens. These artificial aging were previously shown to be valid in evaluating the clinical performance of restorations after nearly 5 years of use.

The mean fracture loads for all tested zirconia-based restorations exceeded 2.3 kN after the artificial aging, which is higher than the reported physiologic maximum posterior masticatory force of approximately 900 N. In addition, all zirconia-based restorations survived artificial aging with thermal cycling and cyclic loading. Thus, all the present zirconia-based restorations have the potential to withstand physiologic masticatory forces. The fracture loads obtained in the current study might not differ from those of the previous study without fatigue testing (Table 2). This finding indicates that the zirconia-based porcelain- and composite-layered restorations presently tested can tolerate long-term masticatory stresses in the posterior region.

Although the results of the current study cannot be directly compared with those of previous studies, the present zirconia-based restorations had fracture loads similar to those of porcelain-fused-to-metal (PFM) restorations. The success of framework/veneer bilayered restorations depends on the satisfactory bonding between the two materials. Sufficient bond strength of feldspathic porcelain to zirconia could result in the durable fracture strengths of ZAC group. It also should be noted that ZIC-P and ZAC group specimens had comparable fracture resistance. This finding can be attributed to the characteristics that the composite materials have the plastic and viscoelastic effect as well as durable bond strength of indirect composite to zirconia treated with Clearfil Photo Bond (CPB). These findings suggest that zirconia-based composite-layered restorations with a CPB-primed coping are an alternative to zirconia-based all-ceramic supported by dental implants.

In the current study, the use of different primers for surface treatment of zirconia copings did not show statistically significant improvement in the fracture load values of zirconia-based composite-layered restorations. However, Taguchi et al. reported that application of primer containing MDP to zirconia ceramic copings enhanced fracture loads of implant-supported, zirconia-based, composite-layered restorations. These conflicting findings may be attributable to the bond strength between zirconia ceramics and indirect composite material. A previous study demonstrated that thermal cycling did not decrease bond strength between zirconia and indirect composite material, due to the ongoing polymerization of composite material with thermal stress at 55°C. However, SEM observation of the current study suggests that surface treatment with primers has a positive effect. Representative SEM images of ZIC-P and ZIC-E group specimens showed a similar fracture pattern, i.e., mixed cohesive failure of the indirect composite material on the surface of specimens (Figs. 4b and 4c). In contrast, ZIC specimens showed adhesive failure (Fig. 4d). The difference of the fracture patterns might be due to the bond strength between layering materials and zirconia frameworks. Surface treatment of zirconia with a primer containing a hydrophobic phosphate monomer (MDP) enhanced the bond strength of indirect composite to zirconia copings to a certain extent. Moreover, the limitation of the current study was the relatively small sample size of 11 specimens in each group. Increasing the sample size would increase the power of analysis and probably provide more reliable results. Thus, future studies must clarify the relationship between fracture load and bond strength. Moreover, controlled clinical trials are necessary to determine the final evaluation of material performance. In conclusion, the current study demonstrated that...
the fracture load of zirconia-based composite-layered restorations primed with Clearfil Photo Bond (ZIC-P) was comparable to that of zirconia-based all-ceramic restorations (ZAC) after fatigue testing. The use of primers for surface treatment of zirconia copings did not increase fracture loads of zirconia-based composite-layered restorations after artificial aging.

ACKNOWLEDGMENTS

This study was supported in part by JSPS KAKENHI Grant Number 24592933, a Grant from the Sato Fund, Nihon University School of Dentistry (2013 and 2014), Grant Number 24592933, a Grant from the Promotion and Mutual Aid Corporation for Private Schools of Japan (2013 and 2014).

REFERENCES