Fracture resistance of implant-supported zirconia-based molar restorations layered with indirect composite material

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ABSTRACT

This study evaluated the fracture resistance of single-tooth implant-supported zirconia-based indirect composite-layered molar restorations. Sixty-six titanium abutments (GingiHue Post) were placed on dental implants (Osseotite Implant). Standardized single-tooth cement-retained implant-supported mandibular molar restorations were fabricated for each of six test groups \( (n = 11) \) as follows: porcelain-fused-to-metal crowns (PFM), zirconia-based all-ceramic crowns (ZAC), zirconia-based indirect composite-layered crowns primed with Estenia Opaque Primer for zirconia frameworks (ZIC-E), and zirconia-based indirect composite-layered crowns (ZIC); ZAC and ZIC after artificial aging. The crowns were luted with a glass-ionomer cement (Ketac Cem Easymix). The ZAC and ZIC groups were subjected to thermal cycling (10,000 cycles, 5–55°C, dwell time 1 min) and cyclic loading (1.2 million cycles, load 49 N). Fracture resistance (N) was determined by force application of a perpendicular load to the crowns with a universal testing machine. One-way analysis of variance (ANOVA) and the Tukey’s HSD test were used to assess differences in fracture resistance values \( (\alpha = 0.05) \) without the artificial aging. An independent t-test was used to determine differences in fracture resistance values of two groups after the artificial aging, and between each group of before and after the artificial aging. Mean fracture resistances (SD) of without the artificial aging were 3.09 (0.22) kN, 3.11 (0.34) kN, 2.84 (0.21) kN, and 2.50 (0.36) kN for the PFM, ZAC, ZIC-E, and ZIC groups, respectively. Fracture resistance in the ZIC specimens was significantly lower \( (P < 0.05) \) than that in the other groups, which did not significantly differ. Mean fracture resistances (SD) after the artificial aging were 3.05 (0.39) kN for ZAC group and 2.37 (0.29) kN for ZIC group. There was a significant difference between ZAC and ZIC groups after the artificial aging \( (P < 0.05) \). The ZAC and ZIC groups did not show a significant difference between before and after artificial aging \( (ZAC; P = 0.69. ZIC; P = 0.38) \). The fracture resistance of single-tooth implant-supported zirconia-based indirect composite-layered molar crowns primed with Estenia Opaque Primer for zirconia frameworks (ZIC-E) is comparable to that of porcelain-fused-to-metal (PFM) and zirconia-based all-ceramic (ZAC) restorations. Application of Estenia Opaque Primer to zirconia ceramic framework provides superior fracture resistance in implant-supported zirconia-based indirect composite-layered molar crowns. Artificial aging does not affect the fracture resistance of zirconia-based restorations layered with the
indirect composite material supported by the dental implants.

INTRODUCTION

Studies have demonstrated the clinical effectiveness of osseointegrated implants for single-tooth replacement (Engquist et al. 1995; Creugers et al. 2000; Pjetursson et al. 2007; Jung et al. 2008; Buser et al. 2012). A review article concluded that the cumulative survival rate for implant-supported single crowns was 97±1%, and that the cumulative survival rate for tooth-supported single crowns was 93±3%, after an observation period of 4 years (Creugers et al. 2000). The most common technical complication of implant-supported porcelain-fused-to-metal (PFM) single crowns is fracture of the layering material (Pjetursson et al. 2007; Jung et al. 2008). In addition, as compared to tooth-supported prostheses, layering porcelain fractures of PFM restorations were more frequent in implant-supported restorations (Brägger et al. 2001; Pjetursson et al. 2007), most likely due to the lack of periodontal ligaments around the osseointegrated implant, which contacts directly with bone (Hämmerle et al. 1995).

Porcelain-fused-to-metal restorations are considered the gold standard in implant-supported prosthetic treatments (Hofstede et al. 1999). Although such restorations typically have stable outcomes and excellent esthetics, they do have disadvantages, including high cost, grayish discoloration of the cervical area, distortion of the framework during fabrication, and possible metal allergies. The excellent esthetics and biocompatibility of all-ceramic (AC) crowns has led to their increasing use for implant-supported restorations (Andersson et al. 1998). Due to its high strength and biocompatibility, zirconium dioxide (zirconia) ceramic was introduced as an alternative material for implant abutments and as a framework material for implant superstructures (Piconi & Maccario 1999; Manicone et al. 2007). However, only a few studies have assessed clinical outcomes of implant-supported zirconia-based AC restorations (Larsson et al. 2006, 2010; Nothdurft & Pospiech 2009; Larsson & Vult von Steyern 2010). Such restorations are considered a valid treatment alternative, as no catastrophic fractures of these restorations have been reported in clinical studies (Larsson et al. 2006, 2010; Nothdurft & Pospiech 2009; Larsson & Vult von Steyern 2010), although reports indicate that the chipping rate for the layering porcelain is very high (10–40%) for implant-supported zirconia-based AC restorations.

Chipping or cracking of the porcelain veneer of toothsupported zirconia-based AC restorations has
been noted in clinical studies (Komine et al. 2010; Larsson 2011). Several techniques have been developed to overcome this complication, including overpressing the ceramic onto the zirconia framework (Beuer et al. 2009, 2010), using a supporting configuration of layering porcelain (Marchack et al. 2008), and layering an indirect composite material to the zirconia framework (Kobayashi et al. 2009; Komine et al. 2013). An in vitro study evaluated the effects of different layering materials on stress distribution in implant-supported restorations and found that stress reduction was 15% greater with the composite material as compared to feldspathic porcelain or gold alloy (Çiftçi & Canay 2000). Moreover, the failure rate of composite-layered implant-supported restorations did not significantly differ from that of PFM restorations (Takahashi et al. 2002).

Durability of bond strength was compared for an indirect composite material and a zirconia framework. The findings indicated that sufficient durable bond strength could be achieved by priming the zirconia surface with a specific functional monomer (Komine et al. 2013). Thus, indirect composite material might be a promising alternative layering material for implant-supported zirconia-based restorations (Kobayashi et al. 2009; Komine et al. 2013). However, to our knowledge, few studies have investigated fracture resistance of zirconia-based indirect composite-layered (IC) molar restorations supported with dental implants.

The purpose of this study was to evaluate fracture resistance of single-tooth implant-supported zirconia-based IC molar restorations. The null hypotheses were that the fracture strength of such restorations would be equal to that of zirconia-based AC molar restorations, that fracture strength would not be affected by priming the zirconia framework surface with a specific functional monomer, and that artificial aging would not influence the fracture strength.

**MATERIAL AND METHODS**

The materials assessed in this study are listed in Table 1. Sixty-six implants with a diameter of 5.0 mm and length of 11.5 mm (Osseotite Implant OSS511; Biomet 3i, Palm Beach Gardens, FL, USA) to simulate a replacement for a missing mandibular molar were studied. Using an autopolymerizing acrylic resin (Technovit 4000; Heraeus Kulzer, Wehrheim, Germany), the implants were embedded in a special plastic specimen holder (Ring Forms; Buehler, IL, USA) and positioned perpendicularly to
the horizontal plane to simulate clinical conditions. The resin covered the implant bodies up to the first thread. The modulus of elasticity of the resin (12 GPa) approximated that of human bone (14 GPa) (Dechow et al. 1993), thereby ensuring that the elastic response at the implant site was similar to that of human bone.

Titanium screws (Titanium Square UniScrew UNIST; Biomet 3i) were used to secure identically shaped titanium abutments (GingiHue Post WPP572G; Biomet 3i) to the implants. Using a torque control system (Torque Driver HTD-C; Biomet 3i), the abutment-implant complexes were tightened to 32 N, according to the manufacturer’s recommendations. The standard dimensions of the abutments were a platform diameter of 5.0 mm, an abutment width of 7.5 mm, a height of 7.0 mm above the shoulder, and circular shoulder width of 0.8 mm. With the guide of a silicone index (Lab Silicone; Shofu Inc., Kyoto, Japan) an occlusal reduction of 1.5 mm (definitive total height of 5.5 mm) was made for all abutments with diamond rotary cutting instruments (Bur No. 106RD; Shofu Inc.) and application of water spray (Presto Aqua; Nakanishi Inc., Kanuma, Japan). After adjustment, the abutments were polished with silicone wheels (Silicone Wheel P Type; Shofu Inc.).

A total of 66 single-tooth cement-retained implant-supported molar crowns were divided into six groups (n = 11) : PFM, zirconia-based all-ceramic crowns (ZAC) for before and after artificial aging, zirconia-based composite crowns with an indirect composite material layered onto a zirconia framework primed with Estenia Opaque Primer (EOP; Kuraray Noritake Dental Inc., Tokyo, Japan) (ZIC-E), and zirconia-based composite crowns with an indirect composite material layered onto a zirconia framework without any other treatment (ZIC) for before and after artificial aging.

**PFM Group**

Eleven wax patterns were made by adding wax (Inlay Wax Medium; GC Corp., Tokyo, Japan) to the abutments with a silicone mold to ensure consistent thickness (0.5 mm) of the restorations. The patterns were sprued and invested in phosphate-bonded investment material (Velvety Superquick; Shofu Inc.), according to the manufacturer’s recommendations. The investment was allowed to heat-soak in a furnace (Auto Furnace QM-1; GC Corp.) for 30 min at 800°C. Gold alloy (G-96 h, Kuraray Noritake Dental Inc.) was melted in an argon atmosphere, and the investment pattern was cast
using a casting apparatus (Argoncaster AE; Shofu Inc.). After divesting, the sprues were cut using a diamond disk (SummaDisk No. 0690; Shofu Inc.), and castings were cleaned of remnant investment, oxidized, and abraded with airborne 50-μm aluminum oxide particles (Hi-Aluminas; Shofu Inc.) at a pressure of 0.2 MPa. After confirming the framework dimensions with a caliper (Measuring Device 2; YDM, Tokyo, Japan), the specimens were seated onto the implant abutments to allow visual inspection of the adaptation with a sharp probe (Single-end Explorer; YDM) and a silicone disclosing medium (Fit Checker; GC Corp.) by a dentist.

All copings were then layered with feldspathic porcelain (Super porcelain AAA; Kuraray Noritake Dental Inc.) with a specific index (K854-02-000E; Tokyo Giken Inc., Tokyo, Japan) to standardize the thickness of the layering porcelain (Fig. 1). Two layers of opaque porcelain (POA2), two layers of dentin porcelain (A2B), and enamel porcelain (E2) were sequentially applied to all specimens. Each layering porcelain powder was mixed with the corresponding manufacturer’s liquid (Meister Liquid; Kuraray Noritake Dental Inc.). The porcelain slurry was layered on the specimens with the specific index, after which the specimens underwent vibration with an ultrasonic vibrator (Ceracon II; Shofu Inc.) and excess water that rose to the surface of the specimens was blotted with a tissue. The specimens were then fired in a furnace (SingleMat Porcelain Furnace; Shofu Inc.) according to the manufacturer (Table 2). To compensate for porcelain shrinkage during sintering, a second firing under the same conditions was required. After using the caliper and silicone index to confirm the thickness of the layering porcelain, all specimens were glazed. Finally, the completed restorations were seated on the abutments to check the adaptation again in the same manner previously described.

_ZAC Group_

A commercial dental computer-aided design and computer-aided manufacturing (CAD/CAM) system (Katana; Kuraray Noritake Dental Inc.) was used to fabricate the zirconia frameworks. The abutment-implant complexes were scanned using the measurement apparatus (Dental Scanner SC-3; Kuraray Noritake Dental Inc.), and the scan data were then converted into CAD data. The frameworks for single-tooth crowns were designed with CAD software (Dent MILL Comp Plus; Kuraray Noritake Dental Inc.). No cement space was included for the finish line, and a cement space of 40 μm was
defined for the axial and occlusal surfaces of the abutment. Thickness of the frameworks was fixed at 0.5 mm, and all points were designed to be of the same dimensions. The design data were then converted into processing data and transferred to the processing machine. The frameworks were milled with a milling machine (Katana DWX-50N; Kuraray Noritake Dental Inc.) from presintered zirconia blanks (Katana Zirconia; Kuraray Noritake Dental Inc.) (KZR) and sintered to full density in a furnace (Katana F-1; Kuraray Noritake Dental Inc.) at 1375°C for 90 min. After using the caliper to confirm the framework dimensions, the framework surface was abraded with airborne 50-μm aluminum oxide particles at a pressure 0.2 MPa for 20 s.

All copings were then layered with feldspathic porcelain (Cerabien ZR; Kuraray Noritake Dental Inc.) (CZR) with the same index that was used to standardize the thickness of the layering porcelain for PFM specimens (Fig. 1). Two layers of opaque porcelain (SBA2), two layers of dentin porcelain (A2B), and enamel porcelain (E2) were sequentially applied to all specimens (Table 2). All specimens were then finalized with a glazing procedure. Adaptation of all frameworks and finished crowns was checked with the same procedure for PFM group.

**ZIC-E Group**

Eleven KZR frameworks were fabricated with the same procedure used for the ZAC specimens. EOP (Kuraray Noritake Dental Inc.) was immediately applied to the surface of the frameworks, which were then layered with an indirect composite material, according to the manufacturer’s recommendations. A thin layer of opaque material (Estenia C&B Body Opaque OA2; Kuraray Noritake Dental Inc.) was applied as an additional bonding agent, and the specimen was light-cured for 90 s in a laboratory light polymerization unit (α-light II; J. Morita Corp., Suita, Japan). An additional layer was applied to the primary opaque material in the same manner. Afterward, the dentin (Estenia C&B Dentin DA2; Kuraray Noritake Dental Inc.) and enamel composite material (Estenia C&B Enamel E1; Kuraray Noritake Dental Inc.) were applied to all specimens with the same index used for the PFM specimens. Additional composite material was added to areas with insufficient coverage. The specimen was then light-cured in the polymerization unit for 5 min and polymerized in an oven (KL-310; J. Morita Corp.) at 110°C for 15 min. The caliper and silicone index were used to confirm the thickness of the layering
composite material (Fig. 1), after which the specimen was polished with the companion polishing accessory (Polishing Instrument Kit; Kuraray Noritake Dental Inc.). Adaptation of all frameworks and finished crowns was checked with the same procedure for PFM group.

**ZIC Group**

All specimens were prepared in a manner similar to that described for the ZIC-E group, except that EOP was not applied to the surface of KZR specimens.

**Cementation**

Before cementation, the intaglio surface of the frameworks was airborne-particle-abraded with 50-μm aluminum oxide particles (Hi-Aluminas; Shofu Inc.) at a pressure of 0.2-MPa for 10 s. All crowns were placed onto the implant abutments with a glass-ionomer cement (Ketac Cem Easymix; 3M ESPE, St. Paul, MN, USA), according to the manufacturer’s recommendations. To simulate finger pressure applied during crown placement, a standardized load of 30 N was applied to the occlusal surface of the crown for 7 min. After crown placement, excess cement was removed with a dental explorer. The specimens were then stored in distilled water at 37°C for 24 h before fracture resistance testing.

**Thermal cycling and cyclic loading**

The specimens of ZAC and ZIC groups were underwent 10,000 thermal cycles between 5°C and 55°C water with a dwell time of 1 min per bath with a thermocycler (Thermal Shock Tester TTS–1 LM, Thomas Kagaku Co. Ltd., Tokyo, Japan). Subsequently, the specimens were subjected to 1.2 million cycles of mechanical fatigue in a computer-controlled chewing simulator (K517, Tokyo Giken Inc.). A force of 49 N was applied occlusally in the central fossa of the crowns at a frequency of 1.7 Hz using a stainless steel ball with a diameter of 6.0 mm. After the cyclic loadings, the specimens were examined using a stereomicroscope (Stemi DV4, Carl Zeiss Co., Ltd., Jena, Germany) at an originally magnification of ×32 to classify as fractured or not. All specimens that did not fracture during thermal cycling and cyclic loading were provided to fracture resistance testing.
Fracture resistance testing

All specimens received compressive loading in a universal testing machine (Type 5567; Instron Corp., Canton, MA, USA), with force application perpendicular to the occlusal surface of the crowns and a cross-head speed of 0.5 mm/min. The load was applied with a stainless-steel ball (diameter, 6.0 mm) placed on the occlusal surface of the crowns to simulate the bite force at the molar area (Fig. 2). To ensure equal force distribution, a piece of tin foil with a 1 mm thickness (Dentaurum, Ispringen, Germany) was placed between the crown and stainless-steel ball. The specimens were loaded to failure (defined as any fracture regardless of location), and load values at the moment of failure were recorded. The applied force was also graphically recorded on a load-deflection curve. The break detector level was set at a 10% loss of maximum force, as in previous studies (Lehmann et al. 2004).

The results of fracture strength were analyzed with software for statistical analysis (SPSS version 15.0; SPSS, Inc., Chicago, IL, USA). Equality of variance in fracture strength values was primarily analyzed with the Kolmogorov-Smirnov test. When the Kolmogorov-Smirnov test showed equality of variances, mean fracture strength of without the artificial aging was calculated for all groups and compared with one-way analysis of variance (ANOVA) and Tukey’s HSD test. An independent t-test was used to determine differences in fracture resistance values of two groups after the artificial aging, and between each group of before and after the artificial aging. A power analysis demonstrated that a sample size of 11 specimens per group was adequate to provide sufficient power (more than 99%). Statistical significance was set at $P = 0.05$.

After fracture resistance testing, fractured interfaces of specimens were examined with a stereomicroscope (Stemi DV4; Carl Zeiss Co., Ltd.) at an original magnification of $\times32$ to determine the mode of fracture, which was classified as veneer fracture or framework fracture. After inspection, representative specimens were sputtered with osmium and observed with a scanning electron microscope (SEM; S-4300; Hitachi High Technologies Co. Ltd., Tokyo, Japan) operated at 15 kV.

RESULTS

Table 3 shows fracture resistance values and post-test fracture patterns without the artificial aging. Mean fracture resistances (SD) were as follows: PFM, 3.09 (0.22) kN; ZAC, 3.11 (0.34) kN; ZIC-E,
2.84 (0.21) kN; and ZIC, 2.50 (0.36) kN. One-way ANOVA revealed a significant difference among groups ($P < 0.05$). However Tukey’s HSD test only showed a significant difference between the ZIC group and the other groups. ZIC specimens had significantly lower fracture strength ($P < 0.05$) as compared with the other groups. The fracture resistances resulted for each group are presented by a scatter plot in Fig. 3. All groups showed relatively small variations of fracture resistances. For ZIC group, most of the data were displayed lower than 2.50 kN.

The number of restorations without framework fracture after fracture resistance testing was 11 of 11 in PFM, 5 of 11 in ZAC, 3 of 11 in ZIC-E, and 6 of 11 in ZIC. Examination of the fractured restorations revealed that the crowns of PFM, ZAC, and ZIC-E specimens had a similar fracture mode, that is, mixed cohesive fracture of the framework and layering materials (Fig. 4a-c). In contrast, only adhesive failure was seen in ZIC specimens (Fig. 4d).

Figs. 5 and 6 show SEM images of the metallic framework surface of a PFM and zirconia-ceramic surface, respectively, after airborne-particle abrasion. Sharp edges and undercuts can be seen in both images. Figs. 7-10 show representative SEM images after fracture resistance testing. A small amount of remaining material, such as composite or porcelain, was observed in PFM, ZAC, and ZIC-E specimens (Figs. 7-9). In contrast, little material remains on the zirconia surface of a ZIC specimen after fracture resistance testing (Fig. 10).

The results of fracture load for each group after the artificial aging are presented in Table 4. None of the restorations or implants was fractured with thermal cycling and cyclic loading in the artificial environment. All specimens received the following fracture resistance testing. The mean fracture resistance values (SD) of the tested zirconia-based restorations were 3.05 (0.39) kN for ZAC group, and 2.37 (0.29) kN for ZIC group. An independent t-test indicated the fracture resistance value of ZAC group was significantly higher than that of ZIC groups ($P < 0.05$). No significant difference in fracture resistance value was found between before and after the artificial aging for both ZAC ($P = 0.69$) and ZIC ($P = 0.38$) groups. The number of restorations for veneer fracture after fracture resistance testing was 3 of 11 in both ZAC and ZIC specimens.

Total fractures of the restorations were frequently observed in the two groups. When examining the fracture patterns of these specimens, the ZAC group demonstrated similar fracture pattern of mixed
cohesive fractures of feldspathic porcelain and zirconia frameworks (Fig. 4e). On the other hand, the ZIC group showed a different fracture pattern, which failure of both layering material and zirconia frameworks was seen (Fig. 4f).

The surface of specimens of the ZAC group was dominantly covered with the layering materials of feldspathic porcelain (Fig. 11). Conversely, little amount of indirect composite retained on the fractured surface of ZIC group (Fig. 12).

**DISCUSSION**

This study investigated fracture resistance of single-tooth implant-supported PFM, zirconia-based AC, and IC molar restorations. The results show no significant differences among PFM, ZAC, and ZIC-E specimens. Thus, the stated first null hypothesis — that the fracture strength of single-tooth implant-supported zirconia-based IC molar restorations would be equal to that of zirconia-based AC molar restorations — was partially accepted. However, ZIC specimens had a significantly lower fracture strength than ZIC-E specimens, which indicates that application of EOP increased the fracture resistance of these restorations. Therefore, the second null hypothesis — that the fracture strength of single-tooth implant-supported zirconia-based IC molar restorations would not be affected by priming the zirconia framework surface with a specific functional monomer — was rejected. The fracture resistance values of ZAC and ZIC specimens after the artificial aging were not significant different from those of ZIC and ZIC specimens without the artificial aging. These findings support the third null hypothesis; artificial aging would not influence the fracture strength.

Posterior restorations must tolerate high masticatory stresses. Physiologic maximal posterior masticatory forces vary from 0.81 or 0.88 kN, depending on facial morphology and age (Bates et al. 1976; Kiliaridis et al. 1993; Sondang et al. 2003). Although the results of the present in vitro study cannot be directly compared with in vivo conditions, the present mean fracture strengths before and after the artificial aging were higher than maximal physiologic masticatory forces in all groups. It can, therefore, be assumed that all evaluated restorations could potentially withstand physiologic masticatory forces.

In this study, no significant difference existed in the fracture strength of PFM, ZAC, and ZIC-E
restorations without the artificial aging. The absence of a significant difference in the fracture resistance of PFM and ZAC restorations is consistent with the findings of previous studies (Rosentritt et al. 2009; Augstin-Panadero et al. 2012). No other studies have evaluated fracture resistance of zirconia-based indirect composite-layered restorations. Comparisons with the existing literature are, therefore, not possible. PFM, ZAC, and ZIC-E specimens showed a similar fracture pattern, that is, mixed cohesive fracture of the framework and layering materials (Fig. 4a-c). This particular fracture mode, along with high fracture load values, is evidence of the strong adhesive effects at the composite and zirconia framework interfaces, as is the presence of residual ceramics and composite material after fracture (Figs. 7-9). Our results agree with those of other in vitro studies, which reported mixed cohesive fracture of layering materials in PFM and zirconia-based AC restorations (Zahran et al. 2008; Hosseini et al. 2012). Therefore, application of indirect composite may be a promising alternative to ceramic layering for single-tooth implant-supported zirconia-based molar restorations.

Zirconia-based indirect composite-layered crown restorations, which no EOP was applied to the framework surface before layering indirect composite material, had lower fracture resistance than ZIC-E restorations. This indicates that application of a specific functional monomer, such as a hydrophobic phosphate (MDP), could enhance the fracture strength of zirconia-based indirect composite-layered molar restorations. Our data on fracture mode support this hypothesis. Although ZIC-E specimens showed mixed cohesive failure of the framework and layering composite materials, ZIC specimens showed adhesive failure. The SEM image of the ZIC specimen was comparable to that of the zirconia ceramic surface after airborne-particle abrasion (Figs. 6 and 10). In addition, framework fracture modes were more common in the ZIC-E restorations. This complete fracture mode together with the high fracture strengths suggests that strong bond of indirect composite to zirconia treated with EOP might positively affect at the layering materials and framework interfaces. Previous studies demonstrated that MDP application is valid and durable in bonding an indirect composite material to zirconia ceramic (Kobayashi et al. 2009; Komine et al. 2013). Thus, greater bond strength between an indirect composite and zirconia ceramic may result in higher fracture strength in zirconia-based IC molar restorations.

To simulate clinical condition, thermal cycling with 10,000 cycles and dynamic cyclic loading of
1.2 million cycles was performed inducing stress to the crown specimens in the current study. These artificial agings have been verified to be relevant to clinical situations evaluating the performance of restorations nearly 5 years (Sakaguchi et al. 1986; Delong et al. 1992). In the current study, the artificial aging did not significantly affect the fracture strength of either zirconia-based restoration layered with feldspathic porcelain or indirect composite material supported by dental implants. Thus, the zirconia-based restorations layered with the indirect composite material could have the long-term durability of the restorations, and possess the potential to undergo the harsh clinical condition in the oral environment. However, further in vitro studies should be conducted to evaluate the effect of priming agents to zirconia frameworks on the fracture resistance of this type of restorations after the artificial aging.

Reports suggest that layering the metallic framework with materials such as acrylic resin, which is more flexible and softer than metal or ceramics, has a shock-absorbing effect on occlusion in implant-supported restorations (Brånemark 1983; Jemt 1986). Some investigators recommend layering indirect composite materials onto the metallic framework, which may reduce the impact force or stress distribution around implant tissues (Çiftçi & Canay 2000; Stegaroiu et al. 2004; Conserva et al. 2009). Layering implant-supported posterior restorations with indirect composite materials may provide functional advantages, especially in area of high occlusal stress. However, composite-layered restorations have several shortcomings, such as insufficient wear resistance, and facilitate plaque accumulation due to surface degradation of composite materials (Ohlmann et al. 2006, 2007). Several clinical studies demonstrated that composite materials have negative impacts for esthetics, wear resistance (Ababneh et al. 2011), and plaque accumulation (Vanoorbeek et al. 2010) compared to ceramics. Some authors do not recommend composite materials for permanent restorations (Behr et al. 2003; Bohlsen & Kern 2003). However, the new generation of indirect composite materials has been currently developed, and given promising in vitro results with regard to color stability (Douglas 2000), wear (Suzuki et al. 2002) and fracture resistance (Ku et al. 2002). Additional clinical trials are necessary to assess these issues.

The design of this study has some limitations that complicate any comparison with clinical conditions. To measure fracture strength, the present study adopted a compressive test, which has been
substantiated by numerous researchers (Bindl et al. 2006; Wolf et al. 2008; Zahran et al. 2008). However, in vitro studies have many disadvantages, for example, the need to evaluate isolated mechanical properties under standardized conditions and the limited number of variables in such environments. As compared with in vitro cyclic loading studies, compressive testing is less suited for reproducing conditions in the oral environment. Nevertheless, the results of compressive testing provide valid information that can be extrapolated to clinical situations.

CONCLUSIONS

Within the limitations of the present in vitro study, the following conclusions were drawn, the fracture resistance of single-tooth implant-supported zirconia-based molar restorations in which an indirect composite material is layered onto a zirconia framework primed with Estenia Opaque Primer (ZIC-E) is comparable to that of porcelain-fused-to-metal (PFM) and zirconia-based all-ceramic (ZAC) restorations. Application of EOP to a Katana zirconia ceramic framework increases the fracture resistance of implant-supported zirconia-based molar restorations in which an indirect composite material is layered onto the zirconia framework. Thermal cycling and cyclic loading do not affect the fracture resistance of zirconia-based restorations layered with the indirect composite material supported by the dental implants.
REFERENCES


Prosthetic Dentistry 92: 258-264.


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<tr>
<td>Katana Zirconia</td>
<td>KZR</td>
<td></td>
<td>ZrO$_2$ 94.4%, Y$_2$O$_3$ 5.4%</td>
<td>Kuraray Noritake Dental Inc.</td>
</tr>
<tr>
<td><strong>Feldspathic porcelain for zirconia</strong></td>
<td></td>
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<tr>
<td>Cerabien ZR</td>
<td>CZR</td>
<td>019413, 022946, 029193</td>
<td>SBA2, A2B, E2</td>
<td>Kuraray Noritake Dental Inc.</td>
</tr>
<tr>
<td><strong>Indirect composite material</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estenia C&amp;B</td>
<td></td>
<td>00043B, 00038C, 00086A</td>
<td>OA2, DA2, E1</td>
<td>Kuraray Noritake Dental Inc.</td>
</tr>
<tr>
<td><strong>Priming agents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estenia Opaque Primer</td>
<td>EOP</td>
<td>00172A</td>
<td>MDP, monomer solvent</td>
<td>Kuraray Noritake Dental Inc.</td>
</tr>
<tr>
<td><strong>Glass-ionomer cement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ketac Cem Easymix</td>
<td></td>
<td>448093</td>
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<td>3M ESPE</td>
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Table 2. Firing schedules for feldspathic porcelain (based on manufacturer recommendations)

<table>
<thead>
<tr>
<th>Feldspathic Porcelain</th>
<th>Predrying Temperature (°C)</th>
<th>Predrying Time (min)</th>
<th>Heating Rate (°C/min)</th>
<th>Firing Temperature (°C)</th>
<th>Holding Time (min)</th>
<th>Cooling Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAA</td>
<td></td>
<td></td>
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<tr>
<td>Paste Opaque (POA2)</td>
<td>500</td>
<td>8</td>
<td>65</td>
<td>980</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Body (A2B), Enamel (E2)</td>
<td>600</td>
<td>7</td>
<td>45</td>
<td>930</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Glaze</td>
<td>600</td>
<td>5</td>
<td>50</td>
<td>930</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CZR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shade Base (SBA2)</td>
<td>600</td>
<td>5</td>
<td>45</td>
<td>930</td>
<td>1</td>
<td>4</td>
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<tr>
<td>Body (A2B), Enamel (E2)</td>
<td>600</td>
<td>8</td>
<td>45</td>
<td>935</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Glaze</td>
<td>600</td>
<td>5</td>
<td>50</td>
<td>930</td>
<td>0.5</td>
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</table>

Table 3. Results of fracture resistance (kN) and post-test fracture pattern before fatigue test

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>SD</th>
<th>Category*</th>
<th>Post-test fracture pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V</td>
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<tr>
<td>PFM</td>
<td>3.09</td>
<td>3.14</td>
<td>3.36</td>
<td>2.72</td>
<td>0.22</td>
<td>a</td>
<td>11</td>
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<tr>
<td>ZAC</td>
<td>3.11</td>
<td>3.09</td>
<td>3.63</td>
<td>2.64</td>
<td>0.34</td>
<td>a</td>
<td>5</td>
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<tr>
<td>ZIC-E</td>
<td>2.84</td>
<td>2.83</td>
<td>3.14</td>
<td>2.39</td>
<td>0.21</td>
<td>a</td>
<td>3</td>
</tr>
<tr>
<td>ZIC</td>
<td>2.50</td>
<td>2.48</td>
<td>3.05</td>
<td>1.99</td>
<td>0.36</td>
<td>b</td>
<td>6</td>
</tr>
</tbody>
</table>

PFM: porcelain-fused-to-metal crowns, ZAC: zirconia-based all-ceramic crowns, ZIC-E: zirconia-based composite crowns in which an indirect composite material is layered onto a zirconia framework primed with EOP.

ZIC: zirconia-based composite crowns in which a composite material is layered onto a zirconia framework without any other treatment, V: veneer fracture, F: framework fracture.

*The presence of identical letters indicates that values are not significantly different (Tukey’s HSD test; P > 0.05).

Table 4. Results of fracture resistance (kN) and post-test fracture pattern after fatigue test

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>SD</th>
<th>Category*</th>
<th>Post-test fracture pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>ZAC</td>
<td>3.05</td>
<td>3.06</td>
<td>3.65</td>
<td>2.38</td>
<td>0.39</td>
<td>c</td>
<td>3</td>
</tr>
<tr>
<td>ZIC</td>
<td>2.37</td>
<td>2.36</td>
<td>2.89</td>
<td>1.96</td>
<td>0.29</td>
<td>d</td>
<td>3</td>
</tr>
</tbody>
</table>

ZAC: zirconia-based all-ceramic crowns, ZIC: zirconia-based composite crowns in which a composite material is layered onto a zirconia framework without any other treatment, V: veneer fracture, F: framework fracture.

*The presence of identical letters indicates that values are not significantly different (t-test; P > 0.05).
Fig. 1. Cross-section of a finished single-tooth implant-supported restoration.

Fig. 2. Set-up for fracture resistance testing: position of stainless-steel ball and tin foil at onset of loading.

Fig. 3. Scatterplot of fracture resistance before fatigue test for porcelain-fused-to-metal crowns, zirconia-based all-ceramic crowns, zirconia-based composite crown with an indirect composite material layered onto a zirconia framework primed with Estenia Opaque Primer, and zirconia-based indirect composite-layered crowns groups.
Fig. 4. Representative post-test fractured restorations: (a) porcelain-fused-to-metal crown, (b) zirconia-based all-ceramic crown, (c) zirconia-based composite crown with an indirect composite material layered onto a zirconia framework primed with Estenia Opaque Primer (ZIC-E), (d) zirconia-based composite crown with indirect composite material layered onto a zirconia framework, without other treatment (zirconia-based indirect composite-layered crowns), (e) zirconia-based all-ceramic crown after fatigue test, (f) zirconia-based composite crown with indirect composite material layered onto a zirconia framework, without other treatment after fatigue test.

Fig. 5. SEM image of the metallic framework surface of a porcelain-fused-to-metal crowns restoration after abrasion with airborne Al₂O₃ particles (original magnification ×1000).
Fig. 6. SEM image of KZR surface after abrasion with airborne Al$_2$O$_3$ particles (original magnification ×1000).

Fig. 7. SEM image of fractured surface of porcelain-fused-to-metal crowns restoration (original magnification ×1000).

Fig. 8. SEM image of fractured surface of zirconia-based all-ceramic crowns restoration (original magnification ×1000).
Fig. 9. SEM image of fractured surface of zirconia-based composite crown with an indirect composite material layered onto a zirconia framework primed with Estenia Opaque Primer (ZIC-E) restoration (original magnification ×1000).

Fig. 10. SEM image of fractured surface of zirconia-based indirect composite-layered crowns restoration (original magnification ×1000).

Fig. 11. SEM image of fractured surface of zirconia-based all-ceramic crowns restoration after fatigue test (original magnification ×1000).
Fig. 12. SEM image of fractured surface of zirconia-based indirect composite-layered crowns restoration after fatigue test (original magnification ×1000).