RESEARCH AND EDUCATION

Evaluation of fracture resistance of inlay-retained fixed partial dentures fabricated with different monolithic zirconia materials

Hilal Siriner Gumus, DDS, PhD,a Nilufer Tulin Polat, DDS, PhD,b and Guler Yildirim, DDS c

Various materials have been used to restore a single missing tooth, including metal-ceramic, ceramic, direct or indirect fiber-reinforced composite resin, and dental implants. Traditionally, metal-ceramic fixed partial dentures have been used to treat a single missing tooth. Single implant-supported crowns have also shown good long-term results. However, patients may reject implant therapy, which takes time, is costly, and can require bone and soft-tissue surgery. Traditional gold-inlay-retained fixed partial dentures are a conservative option, but the metal abutments may be esthetically unacceptable. Recently, a range of esthetic materials has been introduced, including microfilled or fiber-reinforced composite resins and high-strength ceramics used as veneered frameworks or for monolithic restorations.

With the development of computer-aided design and computer-aided manufacturing (CAD-CAM) technology and zirconia materials, monolithic zirconia restorations have become popular. In vitro investigations have shown that monolithic zirconia single crowns can withstand fracture loads higher than those of layered zirconia restorations. The increased translucency of monolithic zirconia is accomplished by modifying the production and sintering stages. Replicating natural tooth color is achieved by using precolored zirconia blocks and coloring liquids. As a result of their high fracture resistance, monolithic zirconia crowns are resistant to the forces of mastication in the molar region, even

ABSTRACT

Statement of problem. Data are lacking on the fracture resistance of monolithic zirconia inlay-retained fixed partial dentures as a conservative treatment for a single missing tooth.

Purpose. The purpose of this in vitro study was to evaluate the fracture resistance of inlay-retained fixed partial dentures produced from 3 different monolithic zirconia materials and based on 2 preparation types and applications with and without thermocycling.

Material and methods. A model with missing right and left mandibular first molars was used for different cavity preparations. A tube-shaped cavity and a box-shaped cavity were prepared. Seventy-two epoxy resin casts were prepared from an additional silicone impression. Twenty-four inlay-retained fixed partial dentures from each monolithic zirconia material (Prettau, Zirkonzahn; Katana, Noritake; and Copran, Whitepeaks) were fabricated for each preparation type and cemented to their epoxy model with dual-polymerizing adhesive resin cement; 50% of all specimens were thermocycled for 10,000 cycles. The specimens were subjected to a fracture resistance test using a universal testing machine with a crosshead speed of 0.5 mm/min. Fracture surfaces were examined with scanning electron microscopy (SEM), and a specimen from each group was examined for structural changes with differential thermal analysis (DTA).

Results. No statistically significant differences in terms of fracture resistance were found among brands with both cavity designs and with and without thermal cycles (P > .05). However, SEM and DTA results showed some changes in monolithic zirconia structure after 1 year of aging.

Conclusions. The brands and cavity preparation types for single posterior tooth loss generated similar fracture resistance. (J Prosthet Dent 2018;119:959-64)
with a 0.5-mm occlusal thickness. These high-strength materials require less tooth reduction, leading to less risk of pulpal damage, and may be suitable for inlay-retained fixed partial dentures. A complication of ceramic inlay fixed partial dentures has been chipping or debonding of the veneer at the retainer-pontic junction. Although ceramic materials are now widely used in dentistry, they often cannot resist mastication forces and are limited in their use.

The fracture resistance of a dental prosthesis depends on the elastic modulus of the supporting structure, the properties of the bonding agent, the thickness of the restoration, and the design of the preparation. The shape of fixed dental prostheses is not constant but varies in terms of its complex structure, consisting as it does of many concave and convex contours depending on the geometry. In particular, because the connectors need to be small for biological and esthetic reasons, they experience greater levels of stress than elsewhere in a 3-unit fixed partial denture.

This study evaluated the fracture resistance of posterior inlay-retained fixed partial dentures made from a recently developed translucent monolithic zirconia. The effects of different cavity preparations and thermocycling were also investigated. The null hypotheses tested were that no difference would be found in the fracture resistance of 3 different brands of monolithic zirconia and that no difference would be found between the fracture resistances of tube- and box-shaped cavity designs.

**MATERIAL AND METHODS**

A total of 12 groups were formed according to 2 different types of cavities and the application of thermocycling. Three different monolithic zirconia brands (Prettau; Zirkonzahn, Katana; Noritake, and Copran; Whitepeaks) were used (Table 1). A power analysis showed that for α=.05 and 1−β=.8, at least 12 specimens from each group (144 specimens in total) had to be prepared for an average change of 150 N in fracture resistance.

The right and left first molar teeth were removed from a mandibular typodont model (ANA-4; Frasaco). The area was filled with wax, and an edentulous contour was made. On the right side, the second premolar and the second molar were prepared in a tubular design, while the left side was prepared in a box shape. The depth of the proximal tube from the occlusal surface to the cavity base was 2 mm. The mesiodistal width of the cavity base was 6 mm in the molar teeth and 4 mm in the premolar teeth (Fig. 1A). The buccolingual width of the occlusal isthmus was 3 mm in molar teeth and 2 mm in premolar teeth (Fig. 1B).

The depth of the proximal box was 2 mm from the occlusal surface to the base of the cavity. The mesiodistal width of the cavity base was 6 mm in molar teeth and 4 mm in premolar teeth. The occlusocervical height of the cavity wall was 2 mm in both molar and premolar teeth (Fig. 2). The mesiodistal width was 1 mm in both molar and premolar teeth, and the buccal-lingual width of the occlusal tooth was prepared as 3 mm for the molar tooth and 2 mm for the premolar tooth (Fig. 1B).

Impressions of the mandibular models were made with addition silicone materials (Elite HD + Maxi Putty Soft Fast Setting and Italian Elite HD + Light Body Fast Setting; Zhermack) to create epoxy resin casts, which were then embedded in acrylic resin blocks.

The epoxy casts were scanned, and restoration designs were made (Dental Wings Inc). Three different monolithic zirconia materials for inlay-retained fixed partial dentures were produced for each type of preparation (Yenamak 5 axis; Yena Machinery Industry Co Ltd) using the Pica Soft program (Picasoft; Dental Cam). Each restoration was cemented on its own epoxy cast using the adhesive cement (Panavia F 2.0; Kuraray Noritake Dental Inc) in accordance with the manufacturer’s instructions. All specimens were stored in deionized water at 37°C for 24 hours. Then, 72 specimens were subjected to thermocycling (10 000 cycles, 5°C-55°C, 30-second intervals) and loaded until fracture in a universal testing machine (Instron Tensometer). The load was vertically applied with a 5-mm-diameter stainless steel ball placed at the center of the occlusal surfaces of the pontic and a crosshead speed of 0.5 mm/min.

A fractography analysis was performed using a standard scanning electron microscope (SEM) on selected specimens, which were sputter-coated (Bal-Tec SCD 050; Bal-tec AG) with a 15-nm layer of Au–Pd. The images were examined at 20 kV with a magnification range of between ×500 and ×10 000.

Fractured specimens of only 1 brand (Copran), both undergoing and not undergoing thermal cycles, were analyzed on the differential thermal analysis (DTA) device (DTA-50; Shimadzu), because the groups did not differ in terms of SEM images or fracture resistance.

**Table 1. Compositions and manufacturers of materials**

<table>
<thead>
<tr>
<th>Brand Name</th>
<th>Manufacturer</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prettau</td>
<td>Zirkonzahn</td>
<td>ZrO2, Y2O3 (4-6), Al2O3 (&lt;1), SiO2 (max. 0.02), Fe2O3 (max. 0.01), Na2O (max. 0.04)</td>
</tr>
<tr>
<td>Copran</td>
<td>White Peaks</td>
<td>ZrO2, Y2O3 (5.15-5.55), Al2O3 (0.03-0.07), Fe (0-0.01), others (0-0.02)</td>
</tr>
<tr>
<td>Katana</td>
<td>Noritake</td>
<td>ZrO2, Y2O3, others</td>
</tr>
</tbody>
</table>

**Clinical Implications**

The fracture resistance of inlay-retained fixed partial dentures made of monolithic zirconia to replace a posterior single missing tooth suggest that it is suitable for clinical use.
The experimental results were statistically analyzed using software (SPSS Statistics v17.0; SPSS Inc). The 3-way analysis of variance test was used to compare groups ($\alpha=.05$).

RESULTS

The minimum, maximum, mean, and standard deviation of the data obtained from the fracture resistance test of the specimens are given in Table 2. The difference in the fracture resistance of the tube-shaped and box-shaped cavities between specimens that did and did not undergo thermocycling was not statistically significantly different ($P>.05$).

![Figure 1. Tube-shaped cavity design. A, Buccal view. B, Occlusal view.](image1)

![Figure 2. Box-shaped cavity.](image2)

Table 2. Fracture resistance values and standard deviations of specimens (N)

<table>
<thead>
<tr>
<th>Brand Name/ Cavity Design</th>
<th>Thermocycle</th>
<th>Fracture load ±SD</th>
<th>95% Confidence Interval</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prettau</td>
<td>Tube-shaped</td>
<td>-</td>
<td>520 ±31.4</td>
<td>458.1</td>
<td>581.8</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>501 ±22.1</td>
<td>457.2</td>
<td>544.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box-shaped</td>
<td>-</td>
<td>583.1 ±31.3</td>
<td>521.2</td>
<td>645</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>524.3 ±22.2</td>
<td>480.6</td>
<td>568.1</td>
<td></td>
</tr>
<tr>
<td>Copran</td>
<td>Tube-shaped</td>
<td>-</td>
<td>571.5 ±31.3</td>
<td>509.7</td>
<td>633.4</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>568.2 ±22.1</td>
<td>524.4</td>
<td>611.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box-shaped</td>
<td>-</td>
<td>567.7 ±31.3</td>
<td>505.8</td>
<td>629.6</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>567.2 ±22.1</td>
<td>523.5</td>
<td>611</td>
<td></td>
</tr>
<tr>
<td>Katana</td>
<td>Tube-shaped</td>
<td>-</td>
<td>537.4 ±31.3</td>
<td>475.6</td>
<td>599.3</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>541.8 ±22.1</td>
<td>498.1</td>
<td>585.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box-shaped</td>
<td>-</td>
<td>516.5 ±31.3</td>
<td>454.6</td>
<td>578.4</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>531.2 ±22.1</td>
<td>487.4</td>
<td>574.9</td>
<td></td>
</tr>
</tbody>
</table>

$F(2, 204)=.247, P=.781, P>.05.$

After the fracture test, the thin connector area was examined. The fractured area at the tube-shaped inlay-retained fixed partial dentures was located at the junction of the occlusal cavity and pontic connector, and the fractured area at the box-shaped inlay-retained fixed partial dentures was located at the junction of the occlusal and proximal parts of the cavity. However, no significant conclusion could be drawn regarding the location of the connector (mesial or distal). The SEM images (Fig. 3) showed that the boundaries of the fracture surface of the 3 brands were more pronounced and sharper with specimens that did not undergo thermocycling and smoother with those that did.

The application of 1 year of aging with 10 000 cycles did not cause a significant change in the durability of the specimens. However, a significant change in the structure, which appeared to start from the surface, was noted. This is evident from the DTA thermograms in Figure 4.

The monolithic zirconia specimens were placed in the DTA device with the occlusal surfaces in contact with the surface of the thermocouples. For the specimen surface, the peak at 279°C without thermocycling (No-TC) was not observed in the thermocycled (TC) specimens. The energy change in the phase transitions at around 900°C was about one-half for specimens that underwent the thermocycling compared with those that did not undergo thermocycling. Furthermore, the peak in the exothermic phase transition at 404°C without thermocycling was not observed in specimens that underwent thermal cycles (Fig. 4). Based on these findings, the surface characteristics of the specimens were changed.
DISCUSSION

Inlay-retained fixed partial dentures, which require minimal preparation, are a conservative alternative to conventional metal-ceramic or ceramic prostheses. Recently, anatomic contour monolithic zirconia crowns have been developed with fracture toughness, esthetic appearance, minimal abrasive properties of opposing teeth, conventional preparation, and the potential for long-term clinical success. Studies evaluating the fracture resistance of inlay-retained fixed partial dentures have shown that these restorations require a minimum load of 500 N to resist the mastication forces in the molar region. Kilicarslan et al found that the fracture resistance of zirconia fixed partial dentures (1247 N) was similar to that of conventional metal-ceramic fixed partial dentures (1318 N) and that the inlay-retained metal-ceramic fixed

partial dentures were able to withstand the mastication forces in the posterior region (958 N). Lithium disilicate specimens had significantly lower fracture resistance (303 N). A few studies on inlay-retained fixed partial dentures have been reported. The monolithic zirconia crowns were therefore compared in this study in terms of their fracture resistance. Lameira et al12 showed that the fracture resistance of polished zirconia (3476.2 ±791.7 N) and glazed zirconia crowns (3561.5 ±991.6 N) was similar, and these 2 groups were more durable than layered (0.8-mm zirconia coping + 0.7-mm porcelain veneer) zirconia crowns (2060.4 ±810.6 N). Johansson et al13 reported that monolithic zirconia crowns (2795 N and 3038 N) demonstrated greater fracture resistance than other crown types, and zirconia–ceramic crowns (2229 N) were more resistant than monolithic lithium disilicate crowns (1856 N) and veneered monolithic zirconia crowns (1480 N and 1808 N).

Because this study aimed to retain the cavity size, the connector size was kept smaller than usual to test the applicability of the monolithic zirconia inlay-retained fixed partial dentures without the need for extra preparation for the veneer material. Although the connector diameter was not reduced extensively enough to be conservative, all the brands of restorations used in this study could tolerate average mastication forces.

When the failure modes were examined, all the specimens fractured in the connector area. In clinical practice, as in this study, the use of connectors of traditional rather than minimal size is considered more appropriate. The formation of the thinnest region of the fracture in both types of preparation suggested that the occlusal cavities had no effect on fracture resistance.

Further studies should evaluate slotted restorations made from monolithic zirconia materials. Also, the number of restorations in which structural changes occur and resistance begins to be affected should be investigated.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Inlay-retained fixed partial dentures produced from Prettau, Copran, and Katana CAD-CAM monolithic zirconia blocks had similar fracture resistance with and without thermocycling.
2. The fracture resistance was higher than that required for a posterior restoration.
3. Thermocycling equivalent to 1 year of aging had no effect on the resistance of zirconia restorations.
4. The fracture resistance of restorations with tube- and box-shaped cavity designs did not differ.

REFERENCES


Access to The Journal of Prosthetic Dentistry Online is reserved for print subscribers!

Full-text access to The Journal of Prosthetic Dentistry Online is available for all print subscribers. To activate your individual online subscription, please visit The Journal of Prosthetic Dentistry Online. Point your browser to http://www.journals.elsevierhealth.com/periodicals/ympr/home, follow the prompts to activate online access here, and follow the instructions. To activate your account, you will need your subscriber account number, which you can find on your mailing label (note: the number of digits in your subscriber account number varies from 6 to 10). See the example below in which the subscriber account number has been circled.

Sample mailing label

This is your subscription account number

****** AUTO** SCH 3-DIGIT 001

1 V97-3 J010 12345678-9
J. H. DOE
531 MAIN ST
CENTER CITY, NY 10001-001

Personal subscriptions to The Journal of Prosthetic Dentistry Online are for individual use only and may not be transferred. Use of The Journal of Prosthetic Dentistry Online is subject to agreement to the terms and conditions as indicated online.