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Original Article

Effect of Connector Design on Fracture Resistance of Zirconia All-ceramic Fixed Partial Dentures

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Abstract

The purpose of the present study was to determine the relationship between cross-sectional design and fracture load using a static load bearing test in yttria-stabilized tetragonal zirconia polycrystal ceramic frameworks on a molar fixed partial denture. The test framework was designed as a 3-unit bridge with two abutment teeth at the second premolar and second molar of the mandible. The cross-sectional area of the connector was 9.0, 7.0, or 5.0 mm^2. In terms of shape, the cross-section was either circular or oval, with a height/width ratio of 1:1, 3:4, or 2:3. For each of the 9 combinations of cross-sectional area and shape, 5 frameworks were prepared (45 in total). Frameworks were cemented to a metallic test model with adhesive resin cement. After fracture load was measured, the percentage of fracture sites was determined and the fracture surfaces observed. In terms of cross-sectional area, there was a statistically significant difference in fracture load between 9.0, 7.0, and 5.0 mm^2. No significant difference in fracture load was observed between any two shapes of connector ($p>0.05$). The fracture load of all frameworks with a cross-sectional area of 9.0 or 7.0 mm^2 was over 880 N, which was recognized as parafunctional occlusal force. Fracture occurred at the distal connector in 82.2% of all frameworks on average. Fracture load decreased as cross-sectional area of the connector became smaller. The cross-sectional shape used in the present study was less influential on fracture load. It appears to be clinical possible to apply a connector with a cross-sectional area of 7.0 mm^2. Fracture often occurred at the distal connector between the pontic and the abutment, corresponding to the second molar.

Key words: Zirconia all-ceramic FPDs—Design—Static load bearing test

Introduction

In recent years, all-ceramic crowns have seen increased clinical use due to their excellent qualities in terms of esthetics and biocompatibility[7,12–14,19]. All-ceramic fixed partial dentures (FPDs) have also begun to be used clinically. Through recent advances in CAD/

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CAM systems, it is now possible to use 3 vol% yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) in dentistry. Yttria-stabilized tetragonal zirconia polycrystals have been attracting close attention as a material offering excellent esthetic features and remarkable strength[21]. Studies have been conducted on the clinical application and evaluation of molar FPDs made of Y-TZP[18] and the cross-sectional area of Y-TZP FPDs[4].

The outstanding feature of Y-TZP ceramics is that they are hard enough to allow their use in the molar region. It is sometimes difficult to secure the proper cross-sectional area and shape in terms of the height of the connector of an FPD in the molar region due to the shape of the abutment tooth. A few studies have been published regarding connectors, including with regard to the morphology of the embrasure with use of lithium disilicate glass ceramics[15,16]. A few studies have also been reported regarding the connectors of zirconia prostheses containing ceramics[1,17] and Y-TZP, especially with regard to the height of the connector and cross-sectional area using a finite element method.

The purpose of the present study was to determine the relationship between cross-sectional design and fracture load in a Y-TZP ceramic framework.

Materials and Methods

1. Materials

The material tested was 3 vol% yttria-stabilized tetragonal zirconia polycrystal (Y-TZP: Kavo Everest® Zirconium Soft, Kavo, Biberach, Germany). This type of zirconia can be used in preparing all-ceramic FPDs for the molar region.

2. Preparation of test frameworks

The metallic master model was designed as a 3-unit FPD with the second premolar and second molar as the abutment teeth in the mandible. The master model was made of stainless steel. The diameter of the abutment was 7.0 mm or 11.0 mm, corresponding to the second premolar and second molar, respectively. The axial surface had a taper of 6°, and the abutment had a height of 5.0 mm. The periphery was designed as a deep chamfer with a curvature radius of 1.0 mm. The distance between abutments was 20.0 mm.

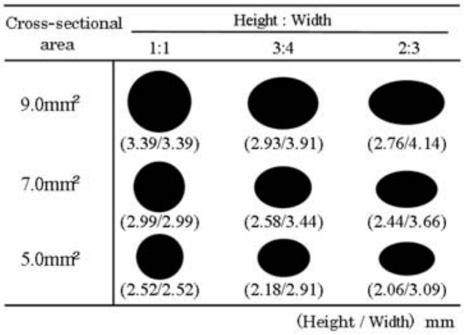

Fig. 1 Designs of cross-section connectors

A coping with 0.55 mm in thickness, 2.0 mm in connector length, and 8.0 mm in pontic width and a flat occlusal surface was designed. The cement space of the coping was set to be 45 μm.

The framework was designed with 3 sizes of cross-sectional area: 9.0, 7.0, or 5.0 mm². Among these 3 sizes, the cross-sectional shape of the connector was designed to assume a circular or oval shape with the height/width ratio of 1:1, 3:4, or 2:3 (Fig. 1).

At first, an impression of the metallic master model for the FPD abutment was taken to make a working cast. Scanning of the working cast with ultra-hard plaster (Kavo Everest® Rock, Kavo) specifically used for this purpose was carried out with the CAD/CAM System (Kavo Everest® System, Kavo), followed by computerized design of the framework. Milling and sintering of semi-sintered zirconia was then carried out to complete the framework. Millering and sintering of semi-sintered zirconia was then carried out to complete the framework. Five frameworks were prepared for each design (45 frameworks in total).

Test modes made to the same specifications as the master model and inserted into the abutment holder. Silicone material 1.0 mm in

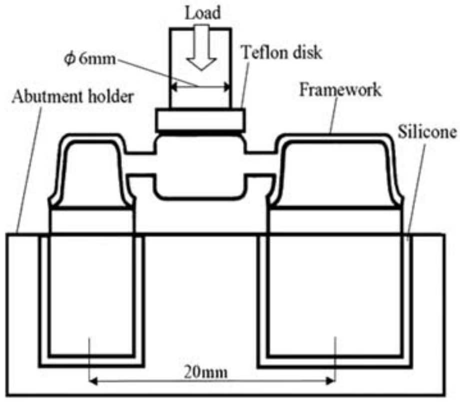

Fig. 2 Test device for determination of static load bearing of 3-unit framework

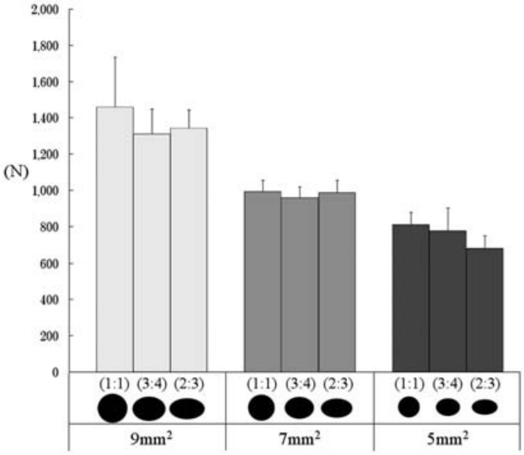

Fig. 3 Load required for fracture by type of connector

thickness was placed between the abutment holder and the test model.

After the frameworks were fabricated, each coping was checked to see that it fitted well at the margin using silicone impression material (Fit Checker, GC, Tokyo, Japan). Each framework was cemented to the test model with adhesive resin cement (ResiCem: LOT12060701, SHOFU, Kyoto, Japan) according to the manufacturer's instructions. The cemented framework was immersed in distilled water (37°C) for 24 hr.

3. Testing method

The static load bearing test was carried out at a constant cross-head speed of 1.0 mm/min with a universal testing machine (Autograph AG-I 20kN, SHIMADZU, Kyoto, Japan), and the load was applied at the pontic with a stainless steel stamp-type cylinder in the axial direction of the tooth until fracture occurred in each framework (Fig. 2). A teflon disk was used as a shock absorber material between the loading cylinder and the pontic. The 2 mm thick teflon disk was replaced with a new one at each examination.

After the static load bearing test, the site of the fracture of the connector was determined. The fractured surface conditioned with Au-Pd coating material was observed through a scanning electron microscope (JSM-6340F, JEOL, Tokyo, Japan).

4. Statistical analysis

Data on fracture load were subjected to a two-way analysis of variance (ANOVA) involving two factors (area and shape of connector). In addition, a multiple comparison Tukey test was carried out. Statistical analyses were performed using the computer program SPSS ver.11 (SPSS v.11, SPSS Corp., IL, USA). A p-value of $p<0.05$ was regarded as statistically significant.

Results

Figure 3 shows the data on fracture load. Mean fracture load in all sizes of cross-sectional area (9.0 and 7.0 mm^2) exceeded 900 N. Ever though no remarkable differences were observed between shape of connector, these results indicated a tendency toward a higher fracture load with a shape and height/width ratio of 1:1. Table 1 shows a comparison of fracture load among the different cross-sectional shapes of framework. The two-way ANOVA revealed statistically significant differences in fracture load between cross-sectional areas ($p<0.05$). In terms of cross-sectional

Table 1 Mean fracture load of FPD frameworks

Cross-sectional area (mm^2)	n	Mean ± SD (N)	Tukey analysis*
9.0	15	1,370 ± 186	A
7.0	15	980 ± 61	B
5.0	15	755 ± 102	C
Connector shape			
1:1	15	1,087 ± 323	A
3:4	15	1,015 ± 252	A
2:3	15	1,003 ± 290	A

* Mean with same letter were not significantly different at $p<0.05$.

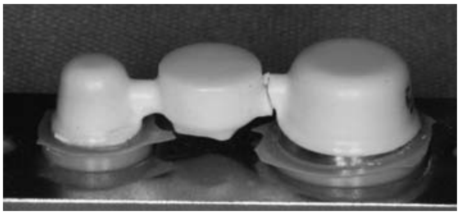

Fig. 4 The observation shows the typical fractured framework under static load bearing test.

Table 2 Site of fracture

Cross-sectional area (mm^2)	Connector shape	Mesial connector (%)	Distal connector (%)
9.0	1:1	40.0	60.0
	3:4	20.0	80.0
	2:3	0	100.0
	Total	20.0	80.0
7.0	1:1	20.0	80.0
	3:4	0	100.0
	2:3	0	100.0
	Total	6.7	93.3
5.0	1:1	40.0	60.0
	3:4	40.0	60.0
	2:3	0	100.0
	Total	26.6	73.3

area, the multiple comparison revealed statistically significant differences in fracture load between 9.0, 7.0, and 5.0 mm^2. No statistically significant difference in fracture load was observed between any cross-sectional shape of connector ($p<0.05$). Analysis of interaction between cross-sectional area and shape of connector also revealed no statistically significant difference in terms of fracture load.

Figure 4 shows a typical fractured framework under the static load bearing test observed at the distal connector. Table 2 shows the fracture site of the connector under the static load bearing test. When the cross-sectional

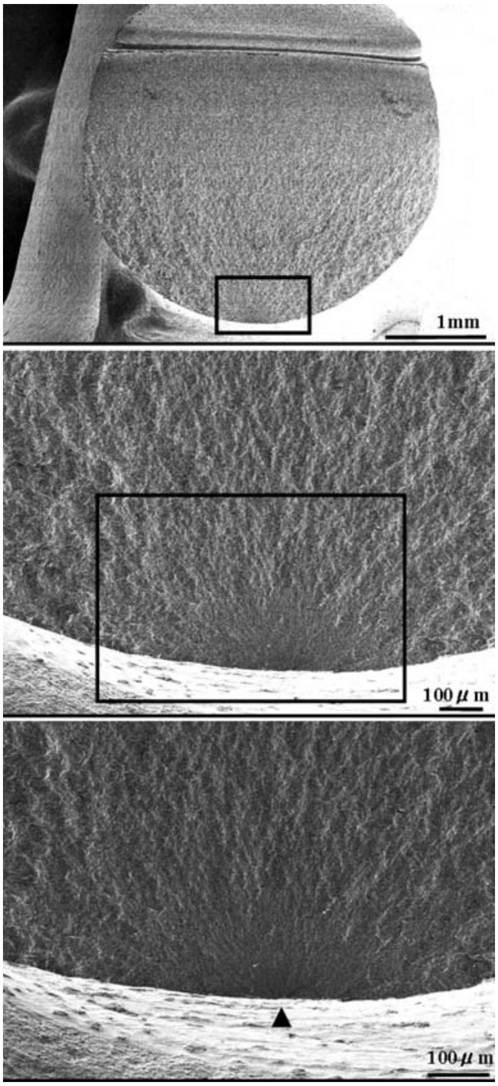

Fig. 5 SEM observation showed cross-section of fracture.
Figure represents a zoom-in from the upside to the downside.

area was 9.0, 7.0, and 5.0 mm^2, fracture occurred at the distal connector in 80.0, 93.3, and 73.3% of all framework, respectively.

The bottom of Fig. 5 represents a typical fractured surface on the gingival side. The fracture initiated at a point close to the gingival side of the connector. There were no differences between the mesial and distal connectors of the framework.

Discussion

Several studies on the morphology of bridge connectors were primarily based on the finite element method[5,11,16)]. Earlier reports on the load bearing testing of ceramics often investigated glass or alumina ceramics, and very few such reports on Y-TZP have been published[15,16)]. In the present study, load bearing tests were conducted employing a 3-unit bridge designed to compensate for the loss of the lower first molar (a type of FPD frequently used clinically).

In order to improve the duration of FPD restoration, it is desirable to make the cross-sectional area of the framework connector as large as possible, regardless of the material used. Clinically, however, an excessively large cross-sectional area in an FPD connector is undesirable from the viewpoints of morphology and esthetics. When all-ceramic FPDs are prepared with emphasis on esthetic features, an adequate space is required at the connector to allow formation of a porcelain-based veneer. Therefore, it is important to determine the minimum acceptable cross-sectional area of the connector in ceramic frameworks.

When an all-ceramic FPD framework for the molar region is designed with lithium disilicate glass or glass-infiltrated alumina ceramics, the connector is required to have a height of 5 mm and a buccolingual dimension of 4 mm if glass ceramic is used[3,17)], or a height of 4–5 mm and a buccolingual dimension of 3–4 mm if glass-infiltrated zirconia ceramics is used[1,17)].

When an FPD for the molar region is prepared with Y-TZP, many manufacturers recommend that the cross-sectional area of the framework connector should be over 9.0 mm^2. To achieve a cross-sectional area of 9.0 mm^2 in a circular shape (a shape which can reduce stress concentration), the diameter needs to be over 3.4 mm. However, when an appropriate embrasure is reproduced with this magnitude of diameter, adequate veneer porcelain formation may be hampered.

In the present study, an oval shape with longer bucco-lingual width was adopted to secure the cross-sectional area of connector. The static load bearing tests on various Y-TZP frameworks were conducted, including ones with a connector cross-sectional area of less than 9.0 mm^2 and ones with an oval shape of connector, in order to identify the cross-sectional area and shape of the connector showing adequate resistance to occlusal force.

Analysis of fracture load for each design generated the following findings. Fontijn *et al.*[6] reported that maximum occlusal force was 250–400 N in the posterior dentition, and other authors suggested that parafunctional occlusal force was assumed 500–880 N[2,9,10]. The fracture load was higher than the maximum occlusal force for all frameworks. Also, fracture load was over 880N in all frameworks with a cross-sectional area of 9.0 or 7.0 mm^2. Although it is difficult to compare the obtained results with data from clinical studies[2,9,10], it is possible to that a 7.0 mm^2 cross-sectional area connector is feasible.

According to the result of the bending test, the fracture load was proportional to the sum of the squares of the height of connector. In the present study, the cross-sectional shape of the connector was designed to assume a circular or oval shape with a height/width ratio of 1:1, 3:4, or 2:3. There was no statistically significant difference among shapes of connector. With an oval shape connector, the radius of the gingival side increases in size. In addition, given that the fracture initiated from the gingival side of the connector, the results suggest that the radius of the gingival side of the connector reduces fracture load. Furthermore, in the present study, few differences were observed between shapes of connector, as Y-TZP is much stronger than conventional ceramics.

The area in the SEM micrograph indicated by the arrow in Fig. 4 is surrounded by wrinkles radiating outward, suggesting the point of origin of the fracture. The fact that it was located close to the surface at the gingival embrasure of the connector corresponds with earlier reports[4,11].

Analysis of fracture site revealed that the distal connector was the site of fracture in 82.2% of the frameworks. Thus, there was a marked tendency for fracture to occur at the connector between the pontic and abutment corresponding to the second molar. This result was the same as that reported by Sorensen *et al.*[20] and Tsumita *et al.*[22]. Tsumita *et al.* attributed this tendency to the structural characteristic that the distance between the center of the distal abutment and the middle of the pontic is larger than the distance between the center of the other abutment and the middle of the pontic[22].

The present study was a static framework study using a universal testing machine. Bending strength determined in an earlier dynamic study was lower than the strength recorded in the present study[8]. Failure of FPDs with a Y-TZP framework is clinically considered as fracture of veneering ceramic material. The causes of this phenomenon are mainly derived from the strength and thickness of the veneering ceramics. Further study extending the present study, using frameworks with veneered porcelain and dynamic conditions, for example, will be necessary to verify the present findings.

Conclusions

Fracture load decreased as cross-sectional area of the connector became smaller. The cross-sectional shape used in the present study was less influential on fracture load. Fracture often occurred at the distal connector, between the pontic and the abutment, corresponding to the second molar.

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