Fitting accuracy and fracture resistance of crowns using a hybrid zirconia frame made of both porous and dense zirconia

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The purpose of this study is to evaluate the fitting accuracy and fracture resistance of crowns using a hybrid zirconia frame made of both porous and dense zirconia. Commercial semi-sintered zirconia, sintered dense zirconia and sintered hybrid zirconia were used. Sintered zirconia was milled using the CAD/CAM system, and semi-sintered zirconia was milled and sintered to fabricate molar crown frames. Completed frames were veneered with tooth-colored porcelain. The marginal and internal gaps between frames/crowns and abutments were measured. Each crown specimen was subjected to a fracture test. There were no significant differences in marginal and internal gap among all the frames and crowns. The crown with the hybrid zirconia frame had a 31–35% greater fracture load than that with the commercial or dense zirconia frame (p<0.01). This suggests that the all-ceramic crowns with a hybrid zirconia frame have a high fracture resistance.

Keywords: Porous zirconia, Crown, CAD/CAM, Fitting accuracy, Fracture resistance

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Fig. 1 Hybrid zirconia block consisting of both porous and dense zirconia (a) and its SEM image (b).

A commercial semi-sintered Y-TZP block (C-Pro HT zirconia, Panasonic Healthcare Co., Ltd, Tokyo, Japan) was used as a control.

Using a jacket crown epoxy abutment of the maxillary first molar with a heavy chamfer of 0.8 mm wide on the entire periphery as a model (X688B, Nissin Dental Products Inc, Kyoto, Japan), a titanium abutment of the same shape was made by using a dental CAD/CAM system (C-Pro System, Panasonic Healthcare). For the hybrid zirconia block, their completely sintered blocks were milled using the dental CAD/CAM system (C-Pro System) to fabricated crown frame specimens which are suitably adapted to the abutment. All the frame specimens were given a support collar at their lingual side. The hybrid zirconia frame specimens were designed so that the porous structure is on the occlusal surface side (Fig. 2). As a control, a commercial semi-sintered zirconia block was milled to the specified shape using a dental CAD/CAM system and fully sintered at 1,450°C for 2 h to fabricate the control frames. There were seven frame specimens made for each type of sample.

Each of the completed zirconia frames was checked for chipping, both visually and under a microscope (VH-Z100UR, Keyence Corporation, Osaka, Japan). After that, the marginal gap was measured as follows: Each of the marginal areas (buccal, lingual, mesial and distal) of the abutment was struck with 10 marks to use as points for measuring the marginal gap. With each frame specimen trial fitted to the abutment, the measurement points were observed under a microscope (Fig. 3). The marginal gaps at a total of 40 points were measured and the results were averaged.

In the same manner as in a previous report, we also obtained the average gap between the inner surface of the frame and the outer surface of the abutment using a fitting test material. The fitting test material (Fit Checker, GC Corporation, Tokyo, Japan) was mixed and loaded inside the frame. The frame was then placed on the abutment and positioned in place using a force of 9.6 N imposed by a clothespin (Daiya Corporation, Tokyo, Japan). Excess material was wiped away and the fitting test material inside the frame was cured. After curing, the fitting test material was removed and its mass was measured on an electronic scale. From the mass and density of the fitting test material removed and the surface area of the abutment, the average film thickness was calculated, to use to define the internal gap. The surface area of the abutment was obtained by scanning the abutment's shape with a dental CAD/CAM system (DentaCAD, Hint-Els, Griesheim, Germany) and analyzing data thus collected using a software program (MiniMagics 2, Materialise Corporation, Leuven, Belgium).

Fracture load of all-ceramic crowns

After measuring the marginal and internal gaps, each frame specimen was sandblasted in the usual manner, and veneered with tooth colored porcelain (Cerabien ZR, Kuraray Noritake Dental Inc., Tokyo, Japan) and fired at the schedule recommended by the manufacturer.

To standardize the shape of the crowns, a full contour zirconia crown had been previously fabricated using a dental CAD/CAM system, and then porcelain was veneered using a plaster core cast from a mold of
this crown. All the veneering was performed by the same dental technician. The marginal and internal gaps of each crown were obtained in the same manner as for the zirconia frame specimens.

To make fracture test specimens, each crown was then cemented with resin cement (SA Luting, Kuraray Noritake Dental Inc., Tokyo, Japan) to a titanium abutment. After the excess cement was wiped away, the crown was held in place for 30 min by a force of 9.6 N, imposed by a clothespin. Each crown specimen was subjected to a fracture test by applying a vertical load with a steel ball, 7 mm in diameter, placed at the center of the occlusal surface of each crown specimen, using a universal testing machine (Autograph AG-20kNG, Shimadzu Corporation, Kyoto, Japan) to impose a crosshead speed of 0.5 mm/min. In this way, the fracture load of the three types of crown specimens was obtained, one with a frame made from hybrid zirconia block, one with a frame made from dense zirconia block and one with a frame made with semi-sintered zirconia block.

Statistical analysis
A statistical analysis of the results was performed using one-way ANOVA and Tukey’s multiple comparisons test. SPSS Statistics 17.0 (IBM Japan Corporation, Tokyo, Japan) was the statistical software program used. The level of significance was set at 5%.

RESULTS
Marginal and internal gap
Under visual and microscopic observations, there was no sign of chipping found in any of the three types of zirconia frames: the hybrid zirconia frame, the dense zirconia frame and the commercial zirconia frame. The average marginal gaps of the frame specimens were 48.9–58.2 μm. The average marginal gaps of the crowns with three different types of zirconia frames were 48.6–59.4 μm. There were no significant differences in marginal gap among all the frames and crowns (Fig. 4).

The average internal gaps of the frame specimens were 125.6–139.5 μm. The crowns with three different types of zirconia frames had average internal gaps of 128.2–138.2 μm. There were no significant differences in internal gap among all the frames and crowns (Fig. 5).

Fracture resistance
The fracture loads of the crown with the commercial zirconia frame was 1,863±115N, that of the crown with the dense zirconia frame was 1,930±146N, and that of the hybrid zirconia frame was 2,530±313N. The crown with the hybrid zirconia frame had a fracture load 31% greater than that with the dense zirconia frame and 35% greater than that with the commercial zirconia frame (p<0.01) (Fig. 6).

After fracture testing, all seven crown specimens with the commercial zirconia frame and all seven specimens with the dense zirconia frame had porcelain veneer dislodged from the frame. On the other hand, five...
of the seven crown specimens with the hybrid zirconia frame had fractured frames but no porcelain veneer dislodged from the frames (Fig. 7).

**DISCUSSION**

When porous zirconia is applied for use in the human body, it is often as a bone development scaffold, in combination with hydroxyapatite\(^6\)\(^-\)\(^8\)\(^,\)**. Porous zirconia used as scaffolding usually has a porosity of more than 70% and therefore it has little mechanical strength. It is known that an increase in the content of pore-forming agent increases the porosity of the zirconia, which leads to reducing its mechanical strength and modulus of elasticity\(^6\)\(^,\)**. In a previous experiment, we fabricated experimental porous zirconia on a trial basis by adding two types of pore-forming agents, plastic beads and cornstarch\(^6\)\(^,\)**. In this experiment, we used porous zirconia with a porosity of 18%, which had been fabricated by adding plastic beads as a pore-forming agent. It had a higher bending strength than porous zirconia made by adding cornstarch\(^6\)\(^\). The porous zirconia used in this experiment had a low 3-point flexural strength, about 25% (306 MPa) of that (1,220 MPa) of dense zirconia made by sintering the same Y-TZP powder. This is also lower than the 419 MPa of glass-infiltrated alumina\(^6\)\(^,\)**. It is said that fixed partial denture frames using glass-infiltrated alumina are vulnerable to fracture\(^6\)\(^,\)**. In experiments performed similarly to our experiment, researchers reported marginal gaps in zirconia frames loaded onto the maxillary second molar of 57 to 71 μm\(^6\)\(^,\)**, and they also found that zirconia frames for the mandibular first molar, which were made by milling a completely sintered zirconia block using a CAD/CAM system, had marginal gaps of 18 to 58 μm and internal gaps of 105 to 120 μm\(^6\)\(^,\)**. The marginal gap values (48.9 to 59.4 μm) and the internal gap values (125.6 to 139.5 μm) obtained in our experiment were close to the results reported in those studies. Although there was no significant difference in marginal and internal gap, the crowns using a zirconia frame made with a commercial semi-sintered zirconia block tended to have larger marginal and internal gaps than the crowns made with a dense zirconia frame or the hybrid zirconia frame made from a completely sintered zirconia block. It has been reported that if a semi-sintered zirconia block is completely sintered after being milled with a CAD/CAM system, it will affect the adaptation of the ultimately completed zirconia frame\(^2\)**. Possibly, this tendency toward shrinkage of the commercial semi-sintered zirconia block might be attributed to the shrinkage of zirconia caused by the final sintering of the semi-sintered zirconia block. It is also reported that in clinical use all-ceramic crowns using zirconia frames have marginal gaps of 41 to 57 μm and inner surface gaps of 79 to 215 μm\(^9\)\(^,\)**. Therefore, all the crowns fabricated in this experiment seemed to have a clinically acceptable level of adaptability. None of the three types of zirconia frames had any significant differences in marginal or inner surface gaps from before and after bonding the porcelain to the frame. This suggests that bonding on the porcelain did not affect the adaptability of the frame.

The fracture load on the crowns with a dense zirconia...
frame was 1,930 N and on those with a commercial zirconia frame was 1,863 N. Larsson et al., reported that the fracture load of a crown with a dense zirconia frame made by milling a completely sintered zirconia block in the same manner as was done in our experiment was 1,800 N; and Ereifej et al., and Zahran et al., also stated in their reports that the fracture load of a crown with a dense zirconia frame designed for a lower molar was 2,081 N (Ereifej) and 1,459 N (Zahran). However, one cannot compare these results one-for-one, because the experimental conditions including the abutment design, the shape and location of the crowns, the point of loading and the loading method varied from one experiment to another. Anyway, these fracture load values were close to those obtained from our experiment.

The crowns with a dense zirconia frame or a commercial zirconia frame underwent the dislodgement of the veneering porcelain from the zirconia frame after fracture testing. In previous reports, there were fractures or dislodgements of the porcelain veneer from frames after fracture testing. By contrast, for five of the seven crowns with a hybrid zirconia frame, the zirconia frame fractured with the veneering porcelain still stuck to it, exposing the abutment tooth. This was the same mode of fracture as the all-ceramic crowns fabricated without a high-strength frame, which seemed due to the fact that the zirconia frame is completely united with the veneering porcelain.

It seems that this result is at least partly if not entirely due to the fact that when porous zirconia is used, the porcelain penetrates into the pores in the zirconia surface and becomes mechanically joined with it, thus increasing the bond strength of the porcelain about 28% beyond that of the bond to dense zirconia.

It is reported that 78% of the failures of crowns using zirconia frames on an implant abutment are because of a fracture of the veneering porcelain. Titanium, which is used to make implant abutments, was used to make the abutment in this experiment. We used titanium because we believe that hybrid zirconia frames will be particularly effective for crowns that involve an implant abutment.

It has been reported in an experiment using finite element analysis that when the bond of veneering porcelain to a zirconia frame is very strong, the dislodgement or fracture of the porcelain veneer is reduced. Therefore, it was thought that in the crowns with a hybrid zirconia frame, the porcelain veneer would be strongly bonded to the porous zirconia portion of the frame. In a preliminary experiment, we conducted using the same resin cement and zirconia as was used in this experiment, it was clarified that the cement bonds better to porous zirconia (11.5±1.2 MPa) than to dense zirconia (9.2±0.9 MPa). This fact also appears to contribute to the improved resistance to fracture of the crowns with a hybrid zirconia frame.

CONCLUSION

A hybrid zirconia block can be machined as well as a conventional zirconia block. All-ceramic crowns with a hybrid zirconia frame experience great resistance of the veneering porcelain to dislodgement, and they stand up to a high fracture load imposed on the crown.

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