In recent years, metal-free restoration has been increasingly focused to promote the clinical application of all-ceramic prosthesis that is considered to be beneficial in terms of esthetics and biocompatibility. Particularly, the recent progress in CAD/CAM technologies has facilitated the use of zirconia as a framework material. Clinical results have shown that all-ceramic crowns fabricated by using zirconia framework showed high success rate after long-term function, except for complication of chipping. A study reported that framework design affected the fracture load of zirconia all-ceramic crown. Other study showed that the design of the yttria stabilized zirconia (Y-TZP) framework with a support-type is important to avoid the chipping for all-ceramic restorations from in vitro study. Moreover, many researchers have examined the effect of supportive form. Bonfante et al. reported that framework with linguosupportive form attached to the cervical region indicated particularly high reliability. Other researchers reported that framework with occlusally-supportive form was effective to avoid the complication. Although, chipping of veneering porcelain on proximal region is frequently occurred, there is no study to determine the fracture load applied to supportive proximal region. Moreover, the effect of supportive shape was unclear according to the previous studies.

The purpose of the present study is to examine the relationship between the supportive design of proximal region of zirconia framework on the fracture load. The zirconia frameworks with four different supportive designs on the proximal region were fabricated and classified with their radiuses of curvature (R): R=0.5 mm, R=1.0 mm, R=1.5 mm, and R=2.0 mm. The zirconia frameworks were conditioned with sandblast and veneering porcelain was fired. Subsequently, fracture tests were performed at 3 different load points: right above the lowest point of the boundary between veneering porcelain and zirconia framework; 0.5 mm inside from right above point; and 0.5 mm outside from right above point. The fracture load increased with an increase in the radius of curvature of supporter design when loading was applied from above and inside. This suggested that supportive design influenced the fracture load.

Keywords: Prosthodontics, Ceramics, Dental materials, Computer aided design, Prostheses
was fired according to the instruction of manufacture. In a second firing, the veneering porcelain was added to compensate for the shrinkage of the sintering process.

**Fracture load**

Fracture tests were performed at 3 different load points, using 5 samples each: right above the lowest point of the boundary between veneering porcelain and zirconia framework (above: A); 0.5 mm inside from right above the lowest point of the boundary between veneering porcelain and zirconia framework (inside/above: I); and 0.5 mm outside from right above the lowest point of the boundary between veneering porcelain and zirconia framework (outside/above: O; Fig. 3).

Among these tests, it was not feasible for samples with the I-group test using the R-0.5 (R-0.5-I group) during the pilot study. The fracture load of samples was measured using a universal testing machine (Autograph, AG-I, 20kN, Shimadzu) equipped with a 1.0 mm diameter tungsten carbide ball and 20kN load cell with set at 0.5 mm/min cross-head speed. The fracture test was performed until the sample was completely destructed, and the maximal value was adopted as the fracture load.

**Observation of fracture pattern**

The fracture patterns were morphologically observed using a microscope (VH-5000, KEYENCE, Osaka, Japan); in some cases, the pattern of surface texture of the sample was observed with the scanning electron microscope (SEM; SU-6600, HITACHI, Tokyo, Japan).

The mean values of each group were statistically analyzed using one-way analysis of variance (ANOVA).

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**Table 1** Materials used in this study

<table>
<thead>
<tr>
<th>Material</th>
<th>Brand name</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia</td>
<td>Cercon Base</td>
<td>Degudent, Hanau-Wolfgang, Germany</td>
</tr>
<tr>
<td>Veneering Porcelain</td>
<td>Cercon Ceram Kiss DA3</td>
<td>Degudent, Hanau-Wolfgang, Germany</td>
</tr>
</tbody>
</table>

**Table 2** Firing schedule

<table>
<thead>
<tr>
<th>Pre-drying Temperature (°C)</th>
<th>Time (min)</th>
<th>Heating rate (°C/min)</th>
<th>Firing temperature (°C)</th>
<th>Holding time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>5</td>
<td>55</td>
<td>820</td>
<td>5</td>
</tr>
</tbody>
</table>

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**Fig. 1** Schematic drawing of master model.

**Fig. 2** Schematic drawing of completed specimen.

**Fig. 3** Schematic drawing of mechanical strength test of loading point. (I) Loading point of inside load. (A) Loading point of above load. (O) Loading point of outside load.
to identify the significant differences among supportive design.

If differences were found, Fisher’s LSD analysis was used to evaluate significant differences. All analyses were conducted at a 95% confidence level.

RESULTS

Fracture load
On the A group, the mean fracture load is shown (Fig. 4). The one-way ANOVA revealed statistically significant differences in fracture load between supportive designs. The R-2.0-A was a highest value among A groups.

On the I group, the mean fracture load is shown (Fig. 5). The one-way ANOVA revealed statistically significant differences in fracture load between supportive designs. The R-2.0-I showed highest value, there is no statistical difference between R-1.5-I and R-2.0-I.

On the O group, the mean fracture load is shown (Fig. 6). On statistical analysis, there was no significant difference among the groups.

Observation of fracture pattern
Typical fracture patterns under microscope observation with different conditions were shown in Fig. 7. On the microscope-based observation of fracture patterns, veneering porcelain or their boundaries were broken in all samples.

The adhesive fractures that the interfaces of veneering porcelain and zirconia were partially exposed were frequently observed on R-0.5 and R-1.0 samples in the I and A groups.

In most of samples, the boundary between veneering porcelain and zirconia framework tended to be exposed close to the support on R-2.0 samples.

In contrast, the cohesive fractures of veneering porcelain were frequently observed on the O group. However, zirconia tended to be exposed at the support in most of samples. While there were no zirconia framework fractures.

On the SEM-based observation, the hackle lines indicating the direction of fractures were radially spread from the load points toward the support’s edges in all groups (Fig. 8).

When the loading point was O group, the veneering porcelain surrounding the support were remained with the arc-shaped ribmark (Fig. 9).

DISCUSSION

The incidence of chipped veneering porcelain has been reported to be 8 to 15% in single all-ceramic crowns with zirconia framework. It has been reported that there are various causes of veneering porcelain chipping such as inappropriate conditioning for framework; excessive attachment of veneering porcelain to framework; inappropriate adhesive materials; aging degradation; residual stress; inappropriate thermal expansion coefficients (CTEs); and inappropriate framework designs. A large number of studies have...
Fig. 7  Typical fracture patterns under microscope observation with all conditions. Dot: Interfaces of veneering porcelain and zirconia was partially exposed.

Bonfante et al. reported that framework with lingually supportive form to the cervical region showed higher reliability than without supportive form by the finite element analysis.

Although fracture of veneering porcelain is likely to occur more frequently in the lingual cervical region due to greater occlusal loads, the fact that the esthetic demand is not necessarily emphasized in this region leads to freely modify the framework design. In some of the preceding studies examining shapes of supports for the cervical region on the lingual side, 1.0-mm supports were created for 1.0 or 1.5 mm abutment teeth with a chamfer-type marginal shape. Although they are examined the effect of support, supportive design was unclear. In particular, no studies were reported about supportive design.

In contrast, veneering porcelain chipping on proximal region is frequently occurred. The present study aimed to examine the proper supportive design of framework with the simple experimental design.

Fig. 8  SEM image of specimen after loading. Arrow: Loading point, Dot arrow: Hackle line When the loading point was all groups, the hackle lines were observed.

Fig. 9  SEM image of specimen after loading. Arrow: Loading point, Dot arrow: Ribmark When the loading point was O group, the Ribmark were observed.
focusing on the proximal region. The shape of samples were closely resembled the maxillary first premolar in the study. The adopted radiiuses of curvatures (R) were 0.5, 1.0, 1.5, and 2.0 mm. It was helpful to clarify the relationship between fracture load and framework design in order to appropriately consider these factors into clinical situation. The locations of loading point were divided into three different areas based on the lowest point of boundary between veneering porcelain and zirconia framework as the base point, and set A at 0.5 mm above, I at 0.5 mm inside and O at 0.5 mm outside from the base point respectively. Among these samples, R-0.5 sample was not involved in the present study since it was not possible to measure fracture load of veneering porcelain from the shape of sample and loading position during the preliminary experiment.

The customized fixture for the sample on measurement was fabricated to facilitate the reproducibility of the loading point. On the A and I group, the mean fracture load increased as the radius of curvature of the supportive design increased followed by the R-0.5-A, R-1.0-A, R-1.5-A, and R-2.0-A groups in order. Shirakura et al. reported that the thickness of veneering porcelain for all-ceramic crowns did not influence the fracture load\textsuperscript{20}. On the other hand, Benetti et al. pointed out that reduced thickness of veneering porcelain would show high fracture load\textsuperscript{21}. These researches concluded that it was effective to reduce the thickness of veneering porcelains without considering the supportive design. The result of the present study suggested the fracture load was related to the radius of supportive design on A and I groups.

In contrast, on the O group the mean fracture load of the R-0.5-O, R-1.0-O, R-1.5-O, and R-2.0-O groups were 551.6±141.5 to 637.0±220.2 N, irrespective of radius of curvature of the supportive design; these values were similar to the mean fracture load of 584.1±105.7 N in the FP-O group without zirconia framework. Waltimo et al. reported that occlusal load was 600 to 800 N\textsuperscript{22}. According to the result, samples with occlusal load of more than 800 N were shown observed with 1.0 to 2.0 mm I and A groups. Based on this result, it may be appropriate to set the load point inside/above the support with more than 1.0 mm in radius of curvature of supportive design.

The fracture load of I and A group is higher than the fracture load of O group in this experiment. In the O group, it is thought that shearing force was applied to veneering porcelain and compressive load is conversely applied to veneering porcelain by the support in the I and A group. Therefore, the effect of support and the relation of an occlusal contact point are important in the clinical situation.

Among the I and A groups, observation of fracture pattern showed mixed fracture that the interface partially was exposed on R-0.5 and R-1.0 samples. While, the zirconia exposure was observed typically close to the support on R-2.0 samples. These facts suggested that the support was resisted vertically the loading force.

The radius of the supportive design was not affected to the O group, and the exposed zirconia was observed on only the support.

 Clinically acceptable bond strength values between zirconia framework and veneering porcelain are not yet clear. Saito et al. reported that shear bond strength of feldspathic porcelain to the zirconia framework material was comparable to that of feldspathic porcelain to gold alloy\textsuperscript{17}. There was little adhesive failure which zirconia exposed to the whole surface and there was much cohesive failure in this experiment. Therefore, it is thought that this experiment was also enough as bond strength values between zirconia framework and veneering porcelain.

A large number of studies regarding fracture tests\textsuperscript{23-25} reported that the maximal stress is concentrated to loading point of sample. The radiated hackle lines from the impulsive loading point to the support among all samples shown on the SEM observation indicated the direction of rapid destruction (Fig. 8). The hackle line initiate just outside the indenter contact area, where tensile stress occurs.

In addition to the hackle line, ribmarks were occurred on the O group (Fig. 9). This was considered that the crack had stopped temporarily in the portion of the rib mark. In the case of O group, compared with A and I groups, it is thought that the difference of fracture pattern have affected fracture load.

Although zirconia framework is cemented (adhered) to the abutment surface in clinical situation, cement is not used in this experiment. Van Meerbeek et al. reported that cements may work as a kind of shock absorber\textsuperscript{20}. The thicker cement layer, the higher the absorbing affect of the cement and the lower the impact of the loading on the contact point. Therefore, the findings of this in vitro study might not be transferred to the clinical situation.

For clinical application, when the location of occlusal contact area was set at the marginal ridges of all-ceramic crown, the occlusal contact on inside or above the support should be designed.

The design of the present study had several limitations, making it difficult to compare the results to the clinical situation. However, since the aim of this study was to examine the framework with supportive design the actual shape may not have a significant role as long as it is consistent and standardized for all specimens. Furthermore, the influence of the framework with different design on chipping has to be investigated in further studies.

The influence of supportive design was focused on the present study through the static fracture test. Further studies will be needed to investigate the fracture load after cyclic loading, because this static fracture test might not be always simulate clinical condition.

**CONCLUSION**

The fracture load increased with an increase in the radius of curvature of supportive design when loading was applied from above and inside the support. This
suggested that supportive design influenced the fracture load.

In contrast, when loading was applied from outside the support, the radius of curvature of supportive design did not influence the fracture load.

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REFERENCES