J Osaka Dent Univ 2021 (April) ; **55 (1)** : 123−128.

Fracture strength of telescopic zirconia secondary crowns of different taper and thickness

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The objective of this study was to clarify the influence of the half taper angle and thickness of the zirconia secondary crown on its fracture strength. Y-TZP was used for both primary and secondary crown. Samples were prepared at the half taper angles of 2° and 4° and a secondary crown thickness of 0.5 and 1.0 mm (n＝7). The secondary crown was restored on the primary crown and the fracture strength was determined by loading all specimens until fracture using a universal testing machine. The load applied at the time of secondary crown fracture was regarded as fracture strength. Based on the analysis of variance, although the fracture strength at 1.0-mm thickness was significantly greater than that at 0.5-mm thickness, the taper angle had no influence on the fracture strength. (J Osaka Dent Univ 2021 ; 55 : 123-128)

Key words : Telescopic crowns ; Y-TZP ; Zirconia ; Fracture strength

INTRODUCTION

Telescopic crowns have a long history. They were introduced by Körber[1] more than 30 years ago, and are widely used throughout Europe and East Asia.[2, 3] Telescopic crowns are used as abutments for removable partial dentures, are easily cleaned, functional, and have a favorable survival rate.[4-6] Although they have usually been made of metal, an increase in patients with metal allergies has become a problem in Japan.[7] It has been reported that metals have a risk of inducing allergies because they are ionized in the oral cavity.[7] The use of non-metal materials has recently been covered by the Japanese national health insurance program, resulting in an increased need for low-ionized materials, such as zirconia and ceramics, for use in dental treatment.[7] At present, zirconia used as a dental material includes yttria-stabilized tetragonal zirconia polycrystals (Y-TZP), and ceria stabilized tetragonal zirconia polycrystalline and alumina nanocomposite (Ce-TZP/A). Although Y-TZP has a high fracture strength comparable to precious metal alloys generally used in dental treatment[8] it has the disadvantage of deteriorating in a low-temperature environment.[9, 10] On the other hand, Ce-TZP/A has been reported to have the greatest fracture toughness among ceramics and to have resistance to low temperature deterioration over time.[11, 12]

We investigated the influence of taper and space settlings on the retentive force of telescopic crowns made using Ce-TZP/A based our previous study.[13] In addition, we investigated the influence of the insertion/removal frequency of Ce-TZP/A telescopic crowns on the retentive force and amount of settling.[14] No major change was noted after 10,000 times of insertion and removal. Based on the above, we recommend the clinical application of telescopic crowns using zirconia. Zirconia does not require complicated technical processes, such as waxing-up and casting, because its cutting process employs CAD/CAM. In addition, telescopic crown preparation using the CAD/CAM system may improve work efficiency and reduce technical errors, making them very accurate. However, for zirconia telescopic crowns to be used clinically, the fracture strength of the zirconia secondary crown must be able to resist occlusal forces. No study performing a fracture strength test on telescopic crowns prepared with a brittle material, such as zirconia, has been reported, and information is lacking on the degree of influence of the design of monolithic zirconia telescopic crowns on the fracture strength.

The fracture strength of Ce-TZP/A secondary crown was investigated in a previous study.[15] We found that a minimum thickness of 0.6 mm was required for Ce-TZP/A secondary crowns to resist the maximum occlusal force. This suggests that the clinical application of Ce-TZP/A telescopic crown can be recommended. However, because there are few reports on the actual clinical application of Ce-TZP/A, and because its cream-like monochromatic color is not esthetic, it is not appropriate for some cases. Crowns made with Y-TZP have been used for both anterior and posterior restorations.[8] It has more possible restorative applications than Ce-TZP/A.

The aim of this study was to evaluate the effect of taper angle and secondary crown thickness on the fracture strength of secondary crowns for telescopic crowns made using Y-TZP, which is often used for esthetic dental treatment.

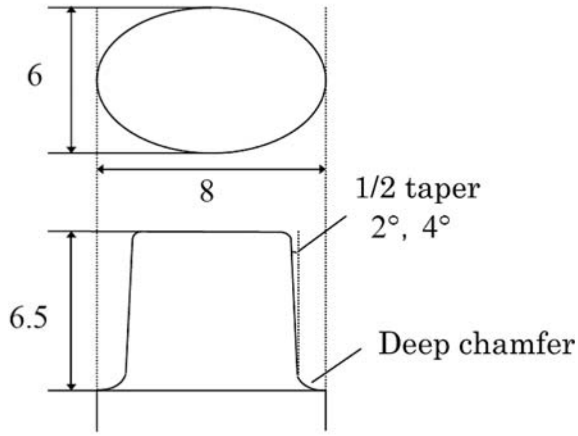

Fig. 1 Dimensions of the primary crowns (mm).

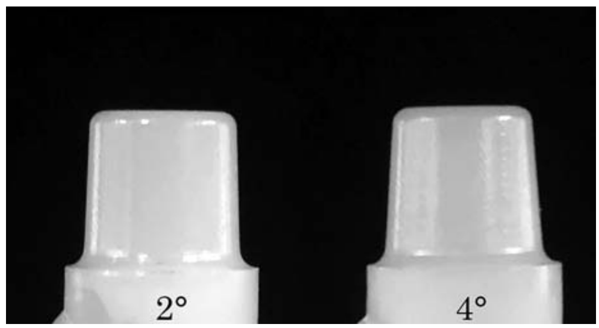

Fig. 2 Completed primary crowns.

MATERIALS AND METHODS

In this study both the primary and secondary crowns were made from Y-TZP. The primary crowns were integrated with the abutment tooth, which was assumed to be a premolar. The primary crown shape was designed to allow for the abutment shape of a standard Japanese premolar.[16] Referencing past literature,[13, 14] we used a truncated cone shape with an 8 mm long diameter, a 6 mm short diameter, and a 6.5 mm height. The line angle where the axial and occlusal surfaces intersected was given a curve with a 0.65 mm radius. The margin was given a deep chamfer with a 0.8 mm radius of curvature. The half taper angle was set to 2° and 4° (Fig. 1). We used CATIA V5 3D CAD software (Dassault Systems, Vélizy-Villacoublay, France) to design the crowns, and a CAM 250 i milling machine (Panasonic Health Care, Tokyo, Japan) to process Y-TZP discs based on the standard tessellation language (STL) data of the primary crowns that we designed. The knob used to determine the fitting direction of the secondary crowns was set on the lower lateral surface of the primary crown.

Sintering was done with a Super Burn MGV-1414 sintering furnace (MOTOYAMA, Osaka, Japan) on all primary crowns in accordance with the manufacturer's instructions. After cooling, all primary crowns were polished with Ceramaster Coarse silicone polishers (Shofu, Kyoto, Japan) using an electric, high-speed handpiece, mounted in a Bego Paraskop surveyor (Bego Bremer Goldschlägerei Wilh. Herbst, Brernen, Germany). They were then given a high polish with Polirapid Germany dental polishing brushes (Polirapid Dr. Montermerlo GmbH, Singen, Germany) and a Zircon-Brite polishing paste (Dental Ventures of America, Corona, CA, USA) using a handpiece. Figure 2 shows completed primary crowns (n=7).

Next, we used a D 2000 scanner (3 shape, Copenhagen, Denmark) to scan the completed primary crowns. The secondary crowns were de-

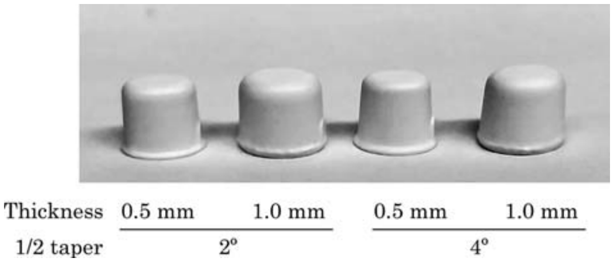

Fig. 3 Completed secondary crowns.

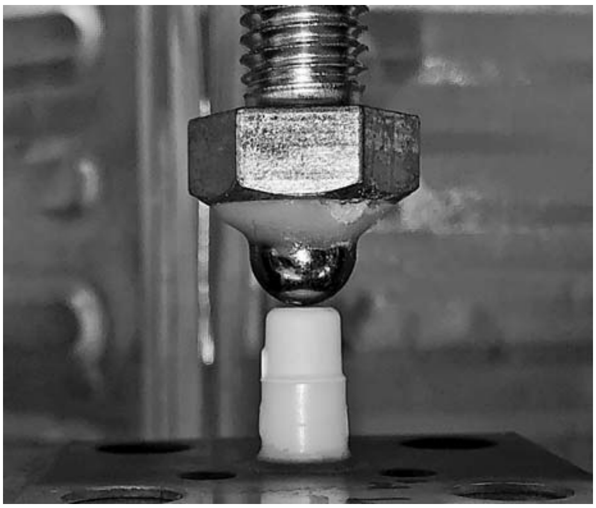

Fig. 4 Measurement of fracture strength.

signed based on data on the primary crown using Dental System 2018 CAD software (3 shape). The space between the primary and secondary crowns was set to 10 μm, and the secondary crown thicknesses was set to 0.5 mm and 1.0 mm. To determine the fitting direction, the knob of the secondary crown was engaged to the side of the primary crown knob. The secondary crowns were fabricated in the same manner as the primary crowns using the CAD/CAM system based on secondary crown STL data. The secondary crowns were not polished. Figure 3 shows completed secondary crowns (n=7).

To test the fracture strength of a secondary crown, it was placed on the primary crown, and a vertical load was applied at a crosshead speed of 0.5 mm/min using an Autograph AGS-J 5 kN precision universal testing machine (Shimadzu, Kyoto, Japan), with a stainless steel ball of 10 mm diameter placed at the center of the occlusal surface of the secondary crown (Fig. 4). The fracture strength was the load value recorded when the secondary crown broke. Table 1 shows the factors and levels. We performed a two-way analysis of variance in which the half taper angle of the telescopic crown (2° or 4°) and the thickness of the secondary crown (0.5 or 1.0 mm) were the factors (α=0.01). The statistical software used was IBM SPSS Statistics ver. 26 (IBM Japan, Tokyo, Japan). To support the sample size in the fracture strength test, the effect size was calculated[17, 18]. For the analysis, we used G*Power software version 3.1 (Heinrich Heine University, Dusseeldolf, Germany).[19]

Table 1 Factors and levels

Factors	Levels	
1/2 taper (degree)	2	4
Thickness (mm)	0.5	1.0

RESULTS

Figure 5 shows the results of the fracture strength of the secondary crowns. When the half taper angle was 2°, the strength of crowns with a thickness of 0.5 mm was 331± 67 N, whereas that of crowns with a thickness of 1.0 mm was 1,345±75 N. When the half taper angle was 4°, the strength of the secondary crowns with thicknesses of 0.5 and 1.0 mm were 384±63 N and 1,426±94 N, respectively. The fracture strength of secondary crowns with a thickness of 1.0 mm was nearly 4 times that

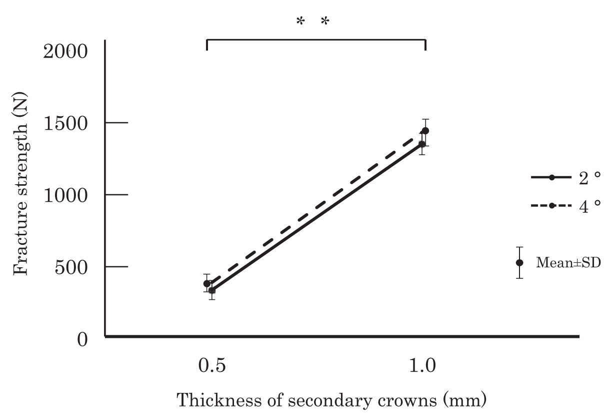

Fig. 5 Fracture strength of the secondary crowns (n=7, $^{**}p<0.01$).

Fig. 6 Representative fracture mode of secondary crowns.

Table 2 Analysis of variance table

Source	SS	df	MS	F	p
Taper	30757	1	30757	5.4	0.29
Thickness	7395432	1	7395432	1296	0.000**
Taper × thickness	1400	1	1400	0.3	0.625
Error	136934	24	5706		
Total	28834352	28			

$^{**}p<0.01$

of those with a thickness of 0.5 mm. Figure 6 shows a representative fracture mode of the secondary crowns. Regardless of the taper angle and secondary crown thickness, almost all samples broke in two from the occlusal surface to the axial surface.

Two-way analysis of variance (Table 2) showed that only the secondary crown thickness was a significant factor in resisting the load ($p<0.01$). The one-half taper angle was not significant ($p=0.29$). No interactions were significant, i.e., the thickness of the secondary crown influenced the secondary crown fracture strength. The fracture strength significantly increased at a thickness of 1.0 mm compared with that at 0.5 mm. On the other hand, the one-half taper angle did not influence the secondary crown fracture strength.

DISCUSSION

Clinical application of zirconia telescopic crowns requires them to have sufficient strength to resist occlusal forces. Thus, we adopted the following two hypotheses for this study: First, the secondary crown fracture strength is greater when the one-half taper angle of the secondary crown is 4° rather than when it is 2°. Second, the fracture strength is greater when the secondary crown thickness is 1.0 mm than when it is 0.5 mm. To predict the minimum necessary secondary crown thickness of telescopic crowns prepared with zirconia and to clarify the degree of the influence of the design of zirconia telescopic crowns on the fracture strength, Y-TZP, which is generally used in dental treatment, was used for the samples. In previous study,[15] Ce-TZP/A was used for a similar fracture strength test.

When preparing the samples, we focused only on the half taper angle and secondary crown thickness out of the numerous factors that may influence the fracture strength without adding anatomical morphology to the secondary crowns. The primary crown was integrated with the abutment tooth and its morphology was set on the assumption of the average premolar in Japanese.[16] The half taper angle was set at 2° or 4° because no retentive force was generated at 6°, whereas a stable retentive force was observed at 2° and 4° in a preceding study.[13] In addition, to secure marginal thickness in the secondary crowns, a deep chamfer was selected for its marginal morphology. It was previously reported that the influence on wear of the opposing material was reduced by appropriate polishing of zirconia.[20] To reduce wear of the primary and secondary crowns, the primary crown was mechanically polished by mirror polishing.

Although the reported minimum thickness of crowns using Y-TZP is 0.5 mm,[21] we set the thickness for this study at 0.5 and 1.0 mm. The knob specifying the restoration direction was made as small as possible. The space between the primary and secondary crowns was set at 10 μm because a stable space of this amount is capable of providing an adequate occlusal surface of the secondary crown without polishing the inner surface of the secondary crown. A stable retentive force was confirmed in a preceding study.[13] The fracture load was measured following the method reported by Omori et al.[21] which was used to investigate the fracture strength of zirconia-ceramic crown frameworks. A load was applied to the center of the occlusal surface of the crown along the longitudinal axis of the jig using a rod equipped with a ball end until it fractured using the universal testing machine. The maximum load applied at the time of crown fracture was defined as the fracture strength.

The secondary crown was fractured into two parts from the occlusal surface to the axial surface regardless of the taper angle or the secondary crown thickness in almost all of the samples (Fig. 6). When a secondary crown is placed on a primary crown, a space is generated on the occlusal surface between the two crowns.[13] When the secondary crown occlusal surface receives a vertical load to the central region in this state, the secondary crown sinks,[13, 14] and the primary crown spreads out along the axial surface of the secondary crown, generating compressive stress on the outer surface of the central occlusal surface region of the secondary crown. On the other hand, tensile stress is generated on the primary surface, which may have broken the occlusal surface over the axial surface bearing the most concentrated stress.

Statistical analysis clarified that the secondary crown fracture strength was strongly influenced by the thickness. Many researchers have reported that the retentive force of telescopic crowns increases as the taper decreases.[22, 23] It has also been clarified that when the taper angle is small, a large surface drag is generated, which produces a wedge effect-induced high-level retentive force.[23-26] We predicted that the secondary crowns with a 2° half taper angle would be fractured by a relatively small load if the secondary crowns had a 4° half taper angle because the surface drag loaded on the axial surface of the secondary crown is larger at 2° than at 4° due to larger stress generated in the secondary crown with the 2° half taper angle. In this experiment, the mean values of the secondary crowns with 2° and 4° half taper angles were 838 and 905 N, respectively, demonstrating that the fracture strength was slightly greater at 4°. However, the difference due to the one-half taper angle was not significant by statistical analysis, rejecting the second hypothesis that the fracture strength is greater at 4° than that at 2°. However, this does not apply when the vertical dimension of the abutment tooth is large or a large difference is present in the taper angle between two samples.

The fracture strength was greater when the secondary crown thickness was 1.0 mm than at 0.5 mm, as hypothesized in the second hypothesis. Niklas et al. reported that the fracture strength of Y-TZP crowns increased almost linearly in proportion to the thickness.[8] Thus, we determined linear equations of the mean fracture strength at 0.5- and 1.0-mm thickness by using the physiological maximum occlusal force in the molar region in adults of 841-857 N.[27] Based on this, it was estimated that a thickness of approximately 0.7 mm of Y-TZP is required for the secondary crowns to resist the maximum occlusal force. In addition, it has been reported that the fracture strength for a 0.5-mm thickness Y-TZP crown placed on an abutment tooth with adhesive resin cement was 5,558 N,[28] suggesting that a primary crown of 0.5 mm thickness has sufficient resistance for both materials. Therefore, a primary Y-TZP crown thickness of 0.5 mm is sufficient for clinical application when there is at least 1.2 mm of clearance with the opposing teeth.

We are deeply grateful to Professor Emeritus Masahiro Tanaka. Without his encouragement, this paper would not have been possible.

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