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Influence of the number of insertions and removals of telescopic zirconia/alumina crowns on retentive force and settling

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Telescopic crowns made from zirconia/alumina can be manufactured using computer-aided design/computer-aided manufacturing systems. For their successful clinical use, a suitable retentive force must be maintained over an extended period. However, it is unclear how retentive force and secondary crown settling change after repeated crown insertion and removal. The aim of the present study was to investigate the changes in retentive force and secondary crown settling of telescopic crowns made from zirconia/alumina. Primary crowns with tapers of 2° and 4° were used. Repeated insertion and removal tests were performed for 10,000 cycles at a cyclic load of 50 N. The loads applied when measuring retentive force and settling were 50 and 100 N. The number of insertions and removals had a significant effect on retentive force and settling at both loads ($p<0.01$). Taper also had a significant effect on retentive force and settling at both loads ($p<0.01$).

Keywords: Ce-TZP/Al_2O_3, Insertion and removal, Retentive force, Taper, Telescopic crowns

INTRODUCTION

Telescopic crowns have a long history of clinical use as attachments for removable partial dentures. They have many advantages including functionality, comfort, and ease of cleaning, as well as favorable survival rates[1-3]. While gold alloys are currently commonly used for telescopic crowns, their clinical use is limited to patients without metal allergies. With the recent sharp increases in the market price of precious metals, the cost of gold has also affected its use. In contrast to gold, zirconia can be used in patients with metal allergies, has a stable market price; thus, it has attracted attention as an alternative to metals[4]. Moreover, zirconia can be machined using a computer-aided design/computer-aided manufacturing (CAD/CAM) system and does not require the arduous technical processes that are involved in lost-wax casting.

With conventional telescopic crowns that use dental alloys, an experienced dental technician must check that the axis surfaces of the primary and secondary crowns are tightly fitted and adjust the retentive force accordingly. However, a previous study has shown that telescopic crowns using zirconia can be manufactured using a CAD/CAM system, and a stable retentive force can be applied easily[5]. It is thought that using a CAD/CAM system to manufacture telescopic crowns may improve the dental technician's labor efficiency and reduce technical errors.

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is a commonly used zirconia in dentistry, though it has a fatal flaw of low temperature degradation[6,7]. Ceria-stabilized tetragonal zirconia polycrystal (Ce-TZP) has higher fracture toughness compared with Y-TZP, but it has not been used clinically due to its low flexure strength and hardness. Given these limitations, a zirconia/alumina nanocomposite stabilized with cerium oxide (Ce-TZP/Al_2O_3) material was developed. This material is created by reciprocally introducing nanosized Al_2O_3 particles into Ce-TZP crystal grains, or introducing nanosized Ce-TZP particles into Al_2O_3 crystal grains. Compared to Y-TZP, the resulting Ce-TZP/Al_2O_3 has greater biaxial flexure strength and toughness, as well as satisfactory durability in terms of low-temperature aging degradation in various aqueous conditions encountered in dentistry[8,9].

Many studies investigating the retentive forces of telescopic crowns using dental alloys have been conducted. It has been reported that retentive force is reliant on the taper of the primary crown and the load applied to the secondary crown[10-12]. These studies have also indicated that the smaller the taper and the larger the load, the greater the retentive force. This is thought to be due to a "wedge effect" caused by settling of the secondary crown. In a previous study investigating telescopic crowns using Ce-TZP/Al_2O_3, initial retentive force and settling were influenced by both taper and load[5]. However, while suitable retentive force must be maintained over an extended period for successful clinical use, it is unclear how retentive force and secondary crown settling change after repeated crown insertion and removal.

The aim of the current study was to investigate the influence of the number of insertions and removals of telescopic crowns using Ce-TZP/Al_2O_3 on retentive force and secondary crown settling.

MATERIALS AND METHODS

The composition of the material used in the present study is shown in Table 1. The disk of presintered Ce-TZP/Al_2O_3 used in the study was 98.3 mm in diameter, 14.0 mm thick, and had an expansion coefficient of 1.204. Ce-TZP/Al_2O_3 was used as the material for both primary

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Table 1 Materials used

Code	Product name	Manufacturer	Composition	Lot. No.
Ce-TZP/Al_2O_3	KZR-CAD Nano Zirconia	YAMAKIN, Osaka, Japan	10 mol% CeO_2-ZrO_2 30 vol% Al_2O_3	15709E004

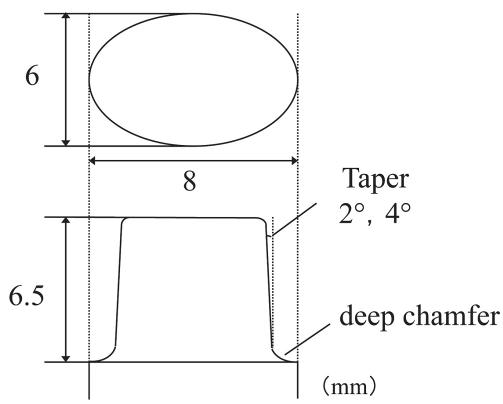

Fig. 1 Dimensions of primary crowns.

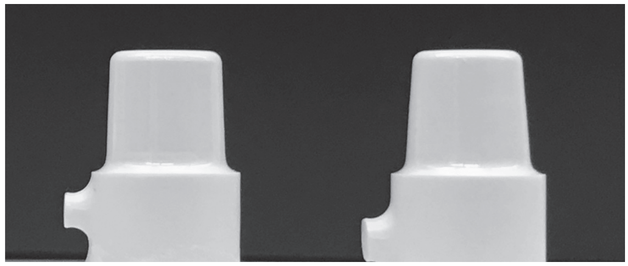

Fig. 2 Completed primary crowns (left 2º, right 4º).

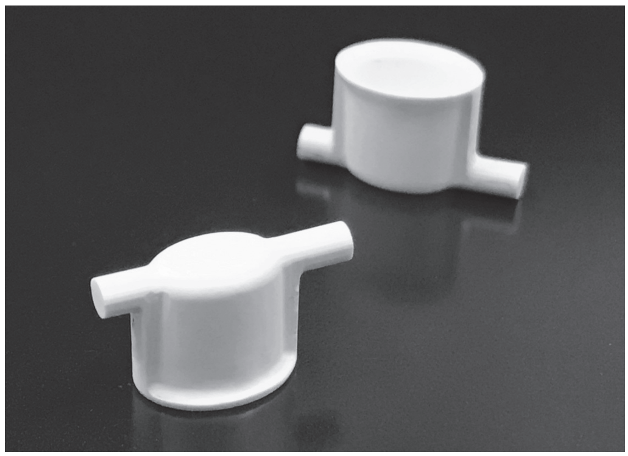

Fig. 3 Completed secondary crowns.

and secondary crowns. Primary crowns were integrated with the abutment tooth, which is thought to be the standard Japanese premolar tooth[13]. Based on previously published methods[11,12,14], the primary crown morphology used was a truncated cone with a major diameter of 8 mm and a minor diameter of 6 mm at the cervix and a height of 6.5 mm (Fig. 1). The line angle intersecting the axial surface and the occlusal surface was rounded with a 0.65-mm radius of curvature. The cervical margin was a deep chamfer with a 0.8-mm radius of curvature. Taper was set to 2º or 4º. The design of the primary crown was created using three-dimensional (3D) CAD software (CATIA V5, Dassault Systems, Vélizy-Villacoublay, France). Ce-TZP/Al_2O_3 disks were machined based on the primary crown stereolithography data using a milling machine (CAM250i, Panasonic Health Care, Tokyo, Japan). A knob was placed on the side of the inferior portion of the primary crown to regulate the insertion direction of the secondary crown. In accordance with the manufacturer's instructions, all primary crowns were sintered for approximately 5 h and were maintained at 1,450°C for 2 h in a sintering furnace (inFire HTC, Sirona Dental Systems, St Leonards, Australia). They were then removed and cooled at room temperature. All primary crowns were initially polished using silicone polishers (LOT 1114217, CERAMASTER Coarse, Shofu, Kyoto, Japan) and a high-speed electric handpiece mounted in a surveyor device (Bego Paraskop, BEGO Bremer Goldschlägerei Wilh. Herbst, Brernen, Germany), then high polished with dental polishing brushes (LOT 0614021, POLIRAPID GERMANY, Polirapid Dr. Montemerlo, Singen, Germany) and polishing paste (LOT 7670, Zircon-Brite, Dental Ventures of America, Corona, CA, USA) using a handpiece. Figure 2 shows the completed primary crowns (n=5).

Completed primary crowns were scanned using a 3D scanner (D700, 3shape, Copenhagen, Denmark). Secondary crowns were designed based on data collected from the primary crowns using CAD software (Dental System 2015, 3shape). The space between the primary and secondary crown was set to 10 µm, and the thickness of the secondary crown was set to 0.4 mm. To facilitate the insertion and removal of secondary crowns, two knobs of differing lengths were incorporated onto their external surfaces. The longer of these two secondary crown knobs had the same orientation as the primary crown's knob, to ensure the appropriate insertion direction. The secondary crowns were manufactured using a CAD/CAM system and the same method used for the primary crowns, but were not polished. Figure 3 shows the completed secondary crowns (n=5).

Repeated insertion and removal tests were performed for 10,000 cycles for each crown at a cyclic load of 50 N using a dynamic fatigue testing machine

(EHF-F1, Shimadzu, Kyoto, Japan). The frequency was set to approximately 0.5 Hz, and the amplitude was set to approximately 4 mm. Retentive forces were measured using a tensile testing machine (EZ-SX, Shimadzu) after every 2,500 insertion and removal cycles. The secondary crown was set on the primary crown, and a 50 or 100 N load was applied to the secondary crown for 5 s. The secondary crown was then removed vertically using a polyethylene line at a crosshead speed of 40 mm/min. The maximum resistance value during removal of the secondary crown was deemed to be the retentive force. Retentive force was measured five times, and the mean of these five values was calculated. Figure 4 depicts the measurement of retentive forces.

Previously described methods utilizing microfocus X-ray computed tomography (SMX-130CT, Shimadzu) and 3D volume rendering software (VG Studio Max 1.2, Volume Graphics, Heidelberg, Germany)[5] were used to assess settling. Measurements were performed after every 2,500 insertion and removal cycles. The secondary crown was set on the primary crown and either no load force or a load force of 50 or 100 N was applied to the secondary crowns for 5 s with the tensile testing machine. During this load application, the space between the primary and secondary crowns (inter-crown space) at the occlusal surface was measured. Imaging conditions were set to an X-ray tube voltage of 130 kV and a tube current of 50 µA. The amount of settling was defined as the difference between the inter-crown space with a load of 50 or 100 N and that with no load.

Fig. 4 Measurement of retentive force.

Differences in retentive force and settling at 50 and 100 N were assessed *via* two-way factorial analysis of variance with the factors and levels shown in Table 2. The level of significance was set to 1%. When the number of insertions and removals was found to be a significant factor, multiple comparisons were then conducted with the Bonferroni correction method. All statistical analyses were performed using SPSS statistical analysis software (IBM SPSS Statistics ver. 19, IBM Japan, Tokyo, Japan). A power analysis was performed to assess the sample size. Power (1-β) was calculated based on the sample size, level of statistical significance, and effect size. pη2 was calculated for the effect size[15]. G*Power software (Ver. 3.1, Heinrich Heine University, Düsseldorf, Germany) was used for the power analysis[16].

RESULTS

Changes in retentive force at a load of 50 N are shown in Fig. 5. The initial retentive force with a 2° taper was 20.8 N, and with a 4° taper it was 8.5 N. After 10,000 insertion and removal cycles, the retentive force with a 2° taper was 18.5 N (−11%), and with a 4° taper it was 6.0 N (−30%). Taper and the number of insertions and removals both had significant effects on retentive force (p<0.01). Greater retentive forces were observed with a 2° taper than with a 4° taper. There were significant differences between the retentive forces observed after 2,500, 5,000, 7,500, and 10,000 insertion/removal cycles. Interaction was not significant (p=0.865). A 1-β of 0.998 was calculated from the sample size, level of statistical significance, and effect size.

Changes in retentive force at a load of 100 N are shown in Fig. 6. Initial retentive force with a 2° taper was 40.7 N, and with a 4° taper it was 17.1 N. After 10,000 insertion and removal cycles, the retentive force with a 2° taper was 36.5 N (−10%), and with a 4° taper it was 12.7 N (−26%). Taper and the number of insertions and removals both had significant effects on retentive force (p<0.01). Greater retentive forces were observed with a 2° taper than with a 4° taper. There were significant differences between the retentive forces observed after 2,500, 5,000, 7,500, and 10,000 insertion/removal cycles. Interaction was not significant (p=0.982). A 1-β of 1.000 was calculated from the sample size, level of statistical significance, and effect size.

Changes in settling at a load of 50 N are shown in Fig. 7. Initial settling with a 2° taper was 122 µm, and

Table 2 Factors and levels

Factors	Levels				
Taper				2	4 (°)
Setting and removal time	0	2,500	5,000	7,500	10,000 (times)

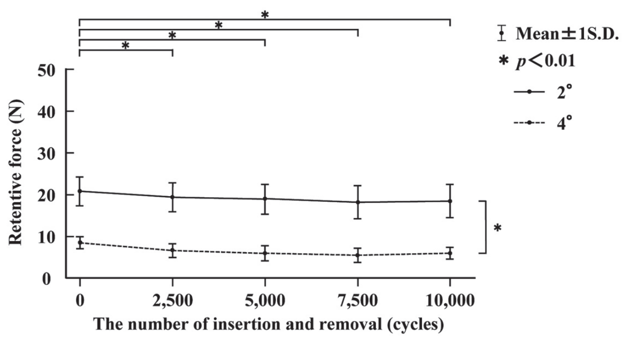

Fig. 5 Changes in retentive force with a load of 50 N.

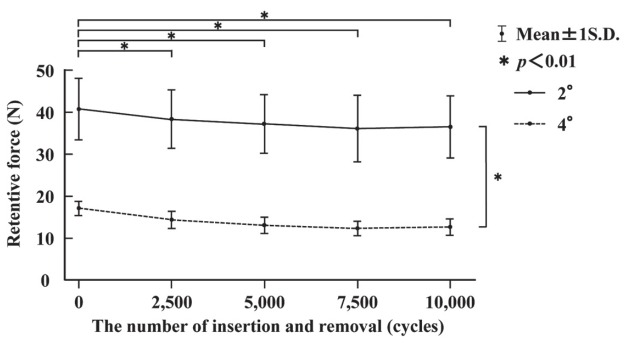

Fig. 6 Changes in retentive force with a load of 100 N.

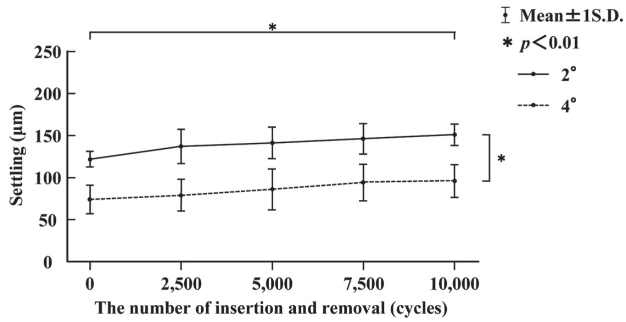

Fig. 7 Changes in settling with a load of 50 N.

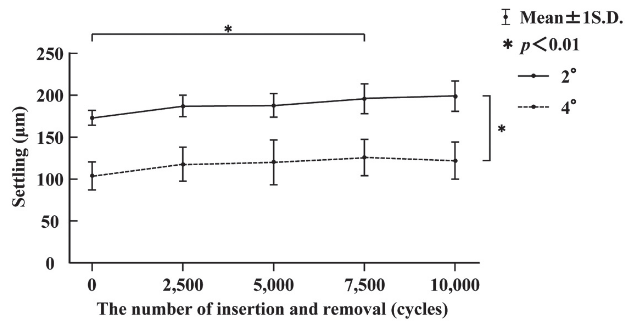

Fig. 8 Changes in settling with a load of 100 N.

with a 4º taper it was 74 µm. After 10,000 insertion and removal cycles, settling with a 2º taper was 151 µm (+24%), and with a 4º taper it was 96 µm (+30%). Taper and the number of insertions and removals both had significant effects on settling ($p<0.01$). Greater settling was observed with a 2º taper than with a 4º taper. There was significant difference between settling observed after 10,000 insertion/removal cycles. Interaction was not significant ($p=0.672$). A 1-β of 0.936 was calculated from the sample size, level of statistical significance, and effect size.

Changes in settling at a load of 100 N are shown in Fig. 8. Initial settling with a 2º taper was 173 µm, and with a 4º taper it was 104 µm. After 10,000 insertion and removal cycles, settling with a 2º taper was 199 µm (+15%), and with a 4º taper it was 122 µm (+17%). Taper and the number of insertions and removals both had significant effects on settling ($p<0.01$). Greater settling was observed with a 2º taper than with a 4º taper. There was significant difference between settling observed after 7,500 insertion/removal cycles. Interaction was not significant ($p=0.537$). A 1-β of 0.939 was calculated from the sample size, level of statistical significance, and effect size.

DISCUSSION

The retentive force of telescopic crowns is influenced by many factors, including taper and the load applied to the secondary crown[10-12]. In a previous study, it was reported that the initial retentive force of telescopic crowns using Ce-TZP/Al_2O_3 was also influenced by both taper and load[5]. In clinical practice, telescopic crowns that have become likely to get dislodged are often encountered. This is due to reduced retentive forces resulting from long-term use. If telescopic Ce-TZP/Al_2O_3 crowns are to be applied clinically, it is necessary to maintain the retentive force for a significant period of time. Therefore, the present study investigated the effects of repeated insertion and removal cycles on retentive force, based on an assumption of long-term use of telescopic crowns. Moreover, because changes in the amount of secondary crown settling over time may affect occlusion, the effects of repeated insertion and removal cycles on settling were also investigated.

Although various factors can affect retentive force such as the taper or the height of the primary crown[11], with regard to conditions pertaining to the manufacturing of specimens, the focus of the current study was taper. Therefore, all specimens were manufactured under the same conditions with the exception of taper. Primary crowns were integrated with the abutment tooth, which is thought to be the standard Japanese premolar tooth[13]. Accounting for the thickness of the Ce-TZP/Al_2O_3 secondary crown, primary crowns were generated with a truncated cone morphology with a major diameter of 8 mm and a minor diameter of 6 mm at the cervix and a height of 6.5 mm. The taper of telescopic crowns using conventional dental alloys is generally set to 6º. In a preliminary experiment it was found that the static frictional coefficient of Ce-TZP/Al_2O_3 was approximately 0.1. According to Körber's equation[14], that result suggests that the taper of telescopic crowns using Ce-TZP/Al_2O_3 should be smaller than that adopted when using dental alloys. In a previous study[5], retentive force did not develop with a 6º taper but was stable at tapers of 2º and 4º. Therefore, 2º and 4º were adopted in the present study. Further, to ensure sufficient thickness of the secondary crown, the margin of the primary crown was generated with a deep chamfer form. Because polishing zirconia reduces the effects of wear on paired materials[17], mechanical polishing and mirror surface polishing were performed on the primary crown to reduce abrasion with the secondary crown.

All secondary crowns were manufactured under the same conditions after scanning the primary crowns. It has been suggested that Ce-TZP/Al_2O_3 crowns should be at least 0.3 mm thick[18], and the secondary crown thickness utilized in the present study was 0.4 mm, to reduce the risk of fracture. However, due to the manufacturing process, the thickness of the inferior surface of the secondary crown's knob was not 0.4 mm. In the aforementioned previous study[5], a gap between the primary and secondary crowns was observed along the entire occlusal surface, and stable retentive force was confirmed for all specimens at a space setting of 10 µm. Therefore, the space setting utilized in the present study was 10 µm. The interior surface of the secondary crown was not polished due to the associated risk of retentive force variation.

In repeated insertion and removal tests, the cyclic load was assumed to be the functional force —that is, the bite force during mastication. Of course, the bite force measured during mastication differs between individuals and is influenced by a variety of factors, including the number of missing teeth, the tooth position measured, the presence of prostheses, and characteristics of the test food. Based on prior studies[19-22], the cyclic load applied in the present study was 50 N. For each specimen, 10,000 insertion and removal cycles were performed. It has been reported that the average number of insertions and removals of dentures was four times per day[23]. Based on this report, 10,000 insertion and removal cycles would be equivalent to approximately 7 years of use. Given this, 10,000 cycles were thought to be sufficient.

Retentive force and settling were measured after every 2,500 insertion and removal cycles. The load during measurement was set to 50 or 100 N. While the cyclic load of 50 N was assumed to be the bite force during mastication, 100 N was also applied to account for exceptional instances of added bite force, based on previous studies[19-22]. Retentive force and settling were thus examined at these two loads.

Many previous studies suggest that with regard to telescopic crowns, a smaller taper is associated with a higher retentive force[10,11]. Concordantly, in the present study, taper was a significant factor at all loads. More specifically, the retentive force after repeated insertions and removals —and not merely the initial retentive force— was greater with a 2º taper than with a 4º taper. This result suggests that telescopic crowns with a smaller taper can exhibit higher retentive force than those with a larger taper, even after long-term use.

There were significant differences between the retentive forces measured after 2,500, 5,000, 7,500, and 10,000 insertions and removals, for both loads. While repeated insertion and removal reduced retentive force, after 2,500 cycles of insertion and removal retentive force was not significantly decreased. It is thought that wear between the primary and secondary crowns in areas of strongest contact may have reduced retentive forces until 2,500 cycles, but that as the area of contact gradually stabilized, the reduction in retentive force slowed. Further, the rate of retentive force reduction was smaller with a 2º taper than with a 4º taper for both loads. This result suggests that telescopic crowns with a 2º taper can maintain retentive force in the long-term.

Sakai *et al.*[14] examined how the retentive force of telescopic crowns using a Ti-6Al-7Nb alloy changed over the course of 1,000 insertion and removal cycles with a cyclic load of 100 N. They reported that the retentive force decreased to 33% below the initial retentive force with a 4º taper after 1,000 cycles. Güngör *et al.*[11] examined how the retentive force of telescopic crowns using a gold-silver-palladium alloy changed over the course of 10,000 cycles of insertion and removal with a cyclic load of 5 kg. They reported that retentive forces decreased by 60% with a 2º taper, by 65% with a 4º taper, and by 65% with a 6º taper after 1,000 cycles. They also reported that retentive forces decreased by 90% with a 2º taper, by 95% with a 4º taper, and by 98% with a 6º taper after 10,000 cycles compared to the initial retentive force. Reductions in the retentive force of telescopic crowns, which can be a problem in clinical practice, are thought to occur due to wear between the primary and secondary crowns and loss of the wedge effect. Given this, it is important to consider the material used. It has been reported that Y-TZP exhibited better wear resistance than type III gold alloys, lithium disilicate glass ceramics, heat-pressed feldspathic porcelains, and heat-cured composite resins[24]. It has also been reported that Ce-TZP/Al_2O_3 had much greater phase stability than Y-TZP, and that its wear properties were not influenced by aging[25], suggesting that Ce-TZP/Al_2O_3 has excellent wear properties. In the present study, retentive force decreased by 11% with a 2º taper and by 30% with a 4º taper after 10,000 cycles compared to the initial retentive force at a load of 50 N. It is thought that due to the prominent wear properties of Ce-TZP/Al_2O_3, there was less wear between the primary and secondary crowns, less change in contact areas, and less reduction in retentive forces. Moreover, Ce-TZP/Al_2O_3 is classified as a ceramic that exhibits no work hardening, a phenomenon specifically found in metals, which would conceivably further promote maintenance of the wedge effect.

In a previous study[5], settling of telescopic crowns increased as taper decreased. Similarly, in the present study, taper significantly affected settling at all loads. More specifically, settling after repeated insertions and removals, and not merely initial settling, was greater with a 2º taper than with a 4º taper. This result suggests that telescopic crowns with a smaller taper may exhibit greater settling than those with a larger taper, even after long-term use.

Settling differed from baseline (0 insertion and removal cycles) significantly after 10,000 cycles at a load of 50 N and after 7,500 cycles at a load of 100 N. These results indicate that though repeated insertion and removal increased settling, after 2,500 cycles settling had not increased significantly. This resembles what was observed with regard to retentive force. It is thought that wear between the primary and secondary crowns in areas of strongest contact may have increased settling until 2,500 cycles, but that as the area of contact gradually stabilized, the increase in settling slowed.

In a previous study[5], the initial retentive force and settling of telescopic crowns increased as the load applied on the secondary crown increased. A similar tendency was observed in the present study at both tapers. Therefore, it is thought that the taper should be larger in patients with a strong bite force and smaller in those with a weak bite force. Clinically, the appropriate retentive force of a telescopic crown is thought to be between 5 and 9 N for one abutment device[26]. The present study employed a cyclic load of 50 N, which is thought to be comparable to the bite force during mastication. At 50 N, an appropriate retentive force was maintained with a 4º taper (8.5–6.0 N). However, the retentive force with a 2º taper was thought to be too large for clinical use (20.8–18.5 N). Consistent with the results of the present study, a previous study also found that a suitable retentive force was generated with a 4º taper at 50 N[5]. At 100 N however, the retentive force was considered too great for clinical use at both tapers.

The present study had some limitations. Firstly, because this was an *in vitro* study, the results still need to be confirmed by clinical studies. Further, the present study only evaluated the retention of a single telescopic crown; the use of multiple telescopic crowns may have different effects on the retentive force.

The results of the present study indicate that retentive forces can be adjusted *via* changes in taper. To ensure telescopic crowns maintain appropriate retentive force in the long-term, it is important to evaluate a patient's bite force during mastication and then select the appropriate taper. It is suggested that if a suitable retentive force of the telescopic Ce-TZP/Al_2O_3 crown is obtained initially, it can be maintained in the long-term. Additionally, compared to metal primary crowns, zirconia primary crowns may lead to better esthetic outcomes when the denture is removed, as their white color resembles the color of natural teeth more closely.

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