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Retentive force of telescopic Ce-TZP/A crowns in water

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We compared the retentive force of telescopic Ce-TZP/A crowns in water with the force in the dry state. Ce-TZP/A was used as the material for both the primary and secondary crowns. The half tapered angles of the primary crown were set to 2° and 4°. The retentive force was measured with applied loads of 25, 50, and 100 N on the occlusal surface of the secondary crown. The maximum resistance value during removal of the secondary crown was deemed to be the retentive force. The measurement of retentive force was performed in the dry state and in water for the same sample. The increased retentive force in water with loads of 25, 50 and 100 N was 2.5, 2.5 and 3.3 N, respectively, for crowns at a half tapered angle of 2°. It was 0.8, 1.1 and 2.1 N, respectively, for those at a half tapered angle of 4°. We found that the retentive force of telescopic Ce-TZP/A crowns in water was significantly greater than in the dry state. When manufacturing telescopic Ce-TZP/A crowns, it is necessary to consider the influence of saliva to evaluate the retentive force. (J Osaka Dent Univ 2019 ; 53 : 171-177)

Key words : Telescope ; Zirconia ; Retentive force ; Saliva

INTRODUCTION

Telescopic crowns have a long history, and have been applied clinically for several years as attachments for removable partial dentures. They offer many advantages, including excellent functionality and comfort, as well as ease of cleaning. In addition, they reportedly have a good survival rate.[1-3] Currently, telescopic crowns are usually fabricated using metal alloys. However, several associated issues such as metal allergies and soaring metal prices have resulted in their limited clinical application. In particular, metal allergies from dental materials have become an urgent issue in recent years.[4] Zirconia, a ceramic material, is now garnering attention as a potential alternative to metal and can be used for patients with metal allergies.[5] In addition, it has a stable market price. Zirconia crowns are fabricated using computer aided design/computer aided manufacturing (CAD/CAM) technology. As a result, cumbersome laboratory procedures, such as the lost wax method, are not required. When telescopic crowns are fabricated from conventional metals, a skilled dental technician performs strict fitting checks and examines retentive force adjustment. In contrast, the CAD/CAM system easily produces a stable retentive force of the zirconia telescopic crowns.[6] Fabrication of telescopic crowns using the CAD/CAM system can possibly improve working efficiency, shorten work time, and reduce technical errors.

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), which is a typical zirconia often used in dentistry, has the fatal disadvantage of low temperature degradation.[7,8] Ceria-stabilized tetragonal zirconia polycrystal (Ce-TZP), despite displaying higher toughness values than Y-TZP, has not yet been adopted for practical use due to its poor rigidity and resistance to bending. Therefore, Ce-TZP/ Al_2O_3 nanocomposite (Ce-TZP/A) was developed to compensate for this disadvantage. This material is made by introducing nano-sized Al_2O_3 particles into Ce-TZP crystal grains as well as introducing nano-sized Ce-TZP granules into Al_2O_3 crystals to provide greater resistance to fracture than Y-TZP[9, 10], and superior resistance to degradation at low temperatures.

The retentive force of telescopic crowns made from dental alloys has been widely reported. Factors that affect retentive force include taper angle and the magnitude of the load. Smaller taper angles and larger loads are associated with greater retentive force.[11-13] In a previous study,[6] we also demonstrated that the taper angle and magnitude of the load affect the initial retentive force in telescopic crowns made from Ce-TZP/A. Furthermore, because clinical application of telescopic crowns made from Ce-TZP/A would require appropriate retentive force to be maintained over the long term, we investigated changes in retentive force after secondary crowns were repeatedly fitted and removed 10,000 times ; the results indicated that the decreases in retentive force were minimal.[14, 15] However, as these studies measured retentive force in the dry state, actual moist conditions within the oral cavity were not taken into account during measurements. Against this background, the objective of the present study was to demonstrate the retentive force of telescopic crowns made from Ce-TZP/A in water by performing comparisons with measurements taken in the dry state.

MATERIALS AND METHODS

Both the primary and secondary crowns were made from Ce-TZP/A. The primary crowns were integrated with the abutment tooth, which is 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,[17-19] 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 of curvature. The margin was given a deep chamfer with a 0.8 mm radius of curvature. The half taper angles were set to 2° and 4° (Fig. 1). We used 3D CAD software (CATIA V5 ; Dassault Systems,Vélizy-Villacoublay, France) to design the crowns, and a milling machine (CAM 250 i ; Panasonic Health Care, Tokyo, Japan) to process Ce-TZP/A discs based on the 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.

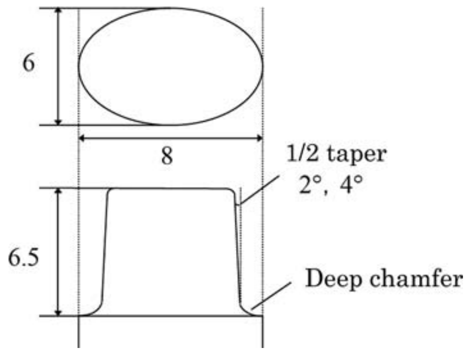

Fig. 1 Dimensions of primary crowns (mm).

Sintering was performed using a sintering furnace (inFire HTC ; Sirona Dental Systems, St Leonards, NSW, Australia) on all primary crowns in accordance with the manufacturer's instructions. All primary crowns were sintered for about five hours to 1,450°C, were held at that temperature for two more hours, and then were cooled naturally. All primary crowns were polished with silicone polishers (Ceramaster Coarse ; Shofu, Kyoto, Japan) using an electric, high-speed handpiece, mounted in a surveyor device (Bego Paraskop ; Bego Bremer Goldschlägerei Wilh. Herbst, Brernen, Germany). They were then given a high polish with dental polishing brushes (Polirapid Germany, Singen, Germany) and a polishing paste (Zircon-Brite ; Dental Ventures of America, Corona, CA, USA) using a handpiece. Figure 2 shows the completed primary crowns (n = 5).

Next, we used a scanner (D700 ; 3 shape, Copenhagen, Denmark) to scan the completed primary crowns. The secondary crowns were designed based on data on the primary crown using CAD software (Dental System 2015 ; 3 shape). The space between the primary and secondary crowns was set to 10 μm, and the secondary crown thickness was set to 0.4 mm. Knobs with different lengths for lifting up the secondary crowns were affixed at two sites on the external surface of each of the secondary crowns. The attachment direction was set so that the longer secondary crown knob would face in the same direction as 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 the completed secondary crowns (n = 5).

The retentive force was measured using a tensile testing machine (EZ-SX; Shimadzu, Kyoto, Japan). The secondary crowns were placed on the primary crowns, and loads of 25, 50 and 100 N were applied to the center of the occlusal surface of each of the secondary crowns for 5 seconds. Then, a polyethylene line was hooked onto the secondary crown knob, and the secondary crown was pulled vertically at a crosshead speed of 40 mm/min. The maximum value of the resistance during withdrawal of the secondary crown was assumed to be the retentive force. We measured the retentive force five times and used the mean value of these measurements as a representative value. We measured the retentive force in water in an acrylic tank fixed to the measurement stage using distilled water at 37°C. Figure 4 shows the measurements of retentive force. We performed a paired *t*-test to investigate the retentive force in dry conditions and in water with applied loads of 25, 50 and 100 N ($\alpha = 0.05$). The software used for statistical analysis was IBM SPSS Statistics ver. 19 (IBM Japan, Tokyo, Japan).

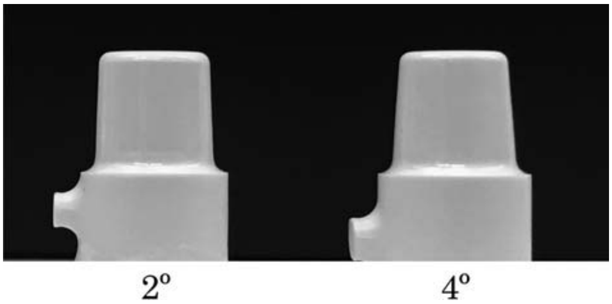

Fig. 2 Completed primary crowns.

Fig. 3 Completed secondary crowns.

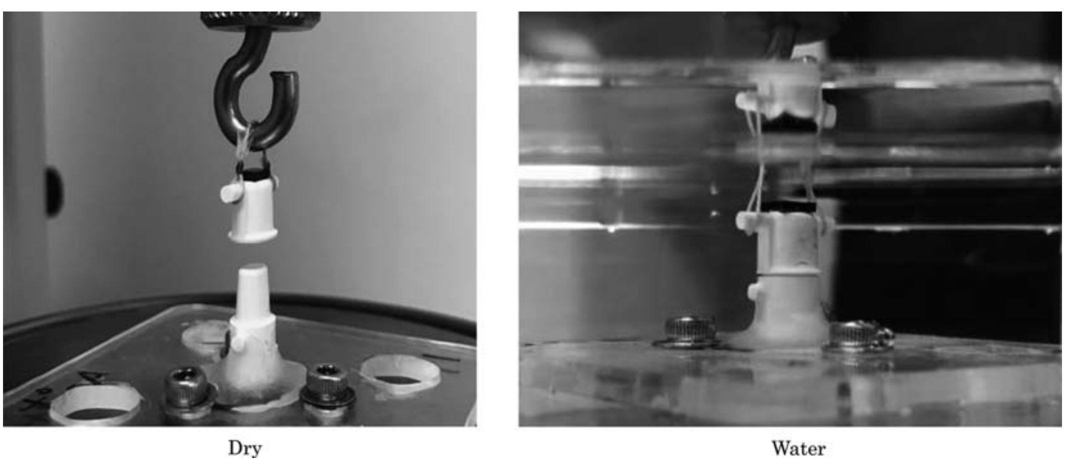

Fig. 4 Measurement of retentive force.

RESULTS

Figures 5 to 7 show the retentive forces with loads of 25, 50 and 100 N and a half taper angle of 2°. With a load of 25 N (Fig. 5), the retentive forces in dry conditions and in water were 9.7 and 12.2 N, respectively, indicating that the force was 2.5 N greater in water than in dry conditions ($p < 0.05$). Similarly, the retentive forces with a load of 50 N (Fig. 6) were 20.1 and 22.6 N, respectively, indicat-

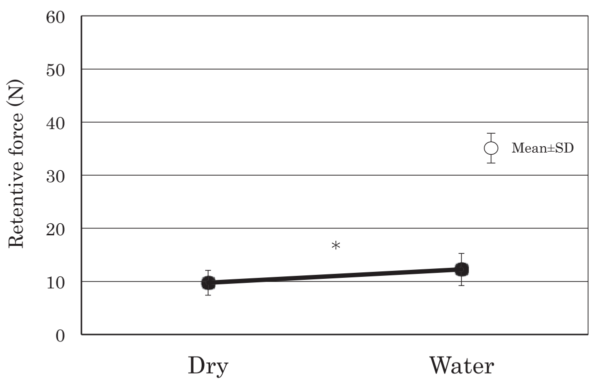

Fig. 5 Retentive force of telescopic crowns of half taper 2° with a load of 25 N (n=5, *$p < 0.05$).

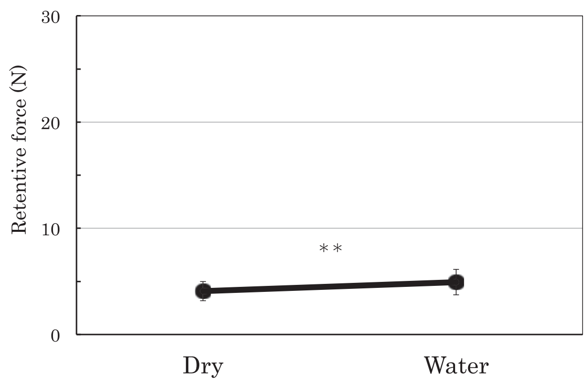

Fig. 8 Retentive force of telescopic crowns of half taper 4° with a load of 25 N (**$p < 0.01$).

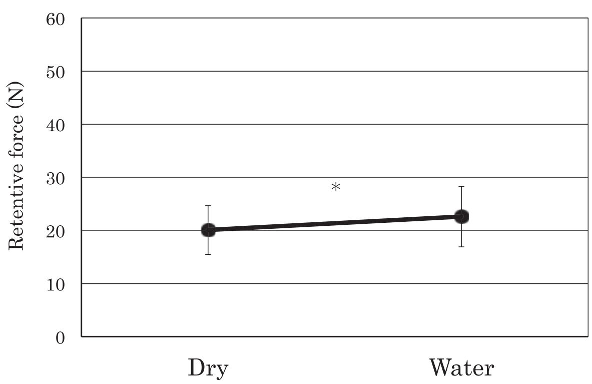

Fig. 6 Retentive force of telescopic crowns of half taper 2° with a load of 50 N.

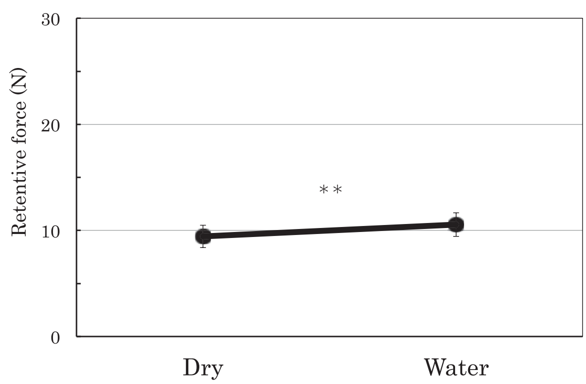

Fig. 9 Retentive force of telescopic crowns of half taper 4° with a load of 50 N.

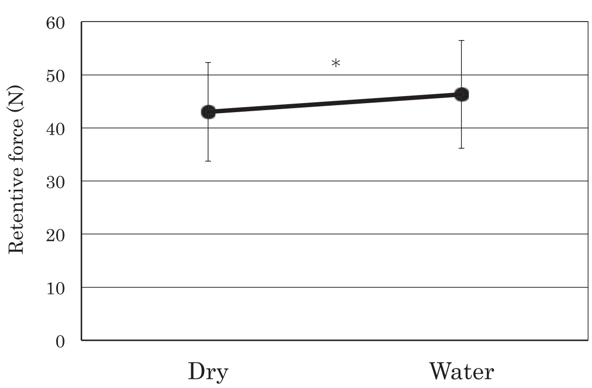

Fig. 7 Retentive force of telescopic crowns of half taper 2° with a load of 100 N.

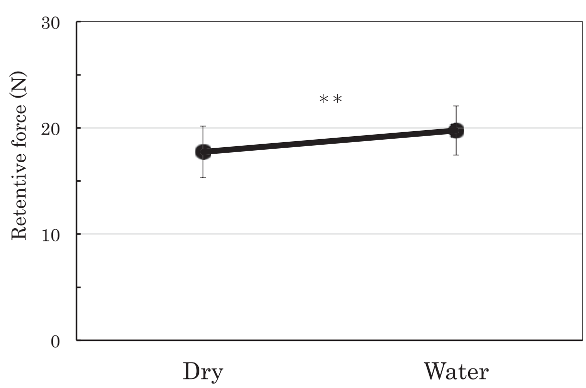

Fig. 10 Retentive force of telescopic crowns of half taper 4° with a load of 100 N.

ing that the force was 2.5 N higher in water than in dry conditions ($p < 0.05$). The retentive forces with a load of 100 N (Fig. 7) were 43.0 and 46.3 N, respectively, indicating that the force was 3.3 N higher in water than in dry conditions ($p < 0.05$). Figures 8 to 10 show the retentive forces with loads of 25, 50 and 100 N for a half taper angle of 4°. With a load of 25 N (Fig. 8), the retentive forces in dry conditions and in water were 4.1 and 4.9 N, respectively, indicating that the force was 0.8 N greater in water than in dry conditions ($p < 0.01$). Similarly, the retentive forces with a load of 50 N (Fig. 9) were 9.4 and 10.5 N, respectively, indicating that the force was 1.1 N greater in water than in dry conditions ($p < 0.01$). The retentive forces with a load of 100 N (Fig. 10) were 17.7 and 19.8 N, respectively, indicating that the force was 2.1 N greater in water than in dry conditions ($p < 0.01$).

DISCUSSION

When setting the conditions for fabrication of materials, of all the various factors that could affect the retentive force, we focused on taper alone. Except for taper, we kept all other conditions of fabrication constant. The primary crowns were integrated with the abutment tooth, and taking into consideration secondary crown thickness, we set a short diameter of 6 mm, a long diameter of 8 mm, and a height of 6.5 mm. Telescopic crowns made from conventional gold alloys generally have a half taper angle of 6°. However, as a preliminary experiment showed that the coefficient of static friction of Ce-TZP/A was smaller than that of gold alloy, we decided that the taper had to be set to a smaller value than that for gold. A prior study[6] showed that no retentive force was displayed with a half taper angle of 6°, whereas a stable retentive force was achieved with angles of 2° and 4°. Accordingly, in the present study, we set the half taper angles to 2° and 4°. Moreover, to ensure thickness around the edge portion of the secondary crowns, we gave the edge of the primary crowns a deep chamfer shape. It has been reported that appropriately polishing zirconia can reduce the impact of paired material abrasion.[17] Therefore, to reduce abrasion between the primary and secondary crowns, we performed mechanical polishing and mirror polishing on the primary crowns.

After the primary crowns were scanned, the secondary crowns were fabricated under the same conditions. Although crowns made from Ce-TZP/A must have a minimum thickness of 0.3 mm,[18] we set the thickness to 0.4 mm in this study, taking into account the risk of fracture. However, due to processing requirements, this limitation does not apply to the thickness of the undercut region on the lower surface of each of the two knobs. We set the space between the primary and secondary crowns to 10 μm because stable retentive force was demonstrated with this space in prior studies.[6, 14, 15] To avoid variation in the retentive force, we did not polish the inner surfaces of the secondary crowns. The load applied to the secondary crowns was set to imitate the occlusal force during mastication. Prior studies reported various values of occlusal force, which may be affected by many factors other than an individual difference during mastication, such as defect type, fitted prosthesis, test site, and test food.[19-22] Taking these past studies into account, we set the applied load values to 25, 50 and 100 N.

In prior studies that we conducted on telescopic crowns made from Ce-TZP/A,[6, 14, 15] the retentive force was measured in dry conditions. To obtain more clinically relevant data on the retentive force, we thought it would be best to conduct retentive force testing in water to imitate the conditions in the mouth. Therefore, in the present study, we conducted our retentive force experiment on telescopic crowns in distilled water at 37°C, which is similar to body temperature. The half taper and secondary crown load application conditions were set based on those described in prior studies.[6, 14, 15] The results of our experiment indicated that regardless of taper angle or the magnitude of load applied, the telescopic crown retentive force in water was increased compared with that in dry conditions. Experiments investigating the retentive force in Y-TZP double crowns and electroformed telescopic crowns have also indicated that the retentive force is greater in water or saliva than under dry conditions.[23-26] Schwindling *et al*.[26] reported that adhesive force was generated by the sealing of water in small gaps between the primary and secondary crowns.

Weigl *et al*.[23] investigated the adhesive force generated between ceramic primary crowns and electroformed secondary crowns and found that the van der Waals and adhesive forces in saliva were activated between the primary and secondary crowns. Accordingly, we believe that in the present experiment, water filled the microscopic gaps between the Ce-TZP/A primary and secondary crowns, activating intermolecular force and absorptive power and resulting in improved retentive force in water. Retentive force is improved even further in saliva.[12, 25, 27] While the viscosity of the distilled water used in our experiment was 0.719 mPa·s[28] at 35°C, the viscosity of saliva has been reported to be greater than this, at 1.2–7.7 mPa·s.[29] Nishizaki *et al*.[25] conducted an experiment investigating the retentive force of electroformed telescopic crowns in dry conditions, water, and artificial saliva with different viscosity settings. Their results indicated that the retentive force was greater in water than in dry conditions and that it tended to increase slightly with increased viscosity of artificial saliva. Accordingly, we predicted that the retentive force of the Ce-TZP/A telescopic crowns used in this study would be slightly increased in saliva compared with that in water.

The increases in retentive forces resulting from placement in water for crowns with half taper angles of 2° were 2.5, 2.5 and 3.3 N, respectively, when loads of 25, 50 and 100 N were applied. For crowns with half taper angles of 4°, the values were 0.8, 1.1 and 2.1 N, respectively. Greater increases may have been observed for the 2° taper crowns than the 4° taper crowns because the 2° taper primary crowns had a larger surface area than the 4° crowns, resulting in greater generation of the aforementioned intermolecular force and water absorptive force. We found that as the magnitude of load increased, the retentive force resulting from placement in water tended to be further increased. The increase in the magnitude of load applied causes the secondary crown to intercuspate further onto the primary crown, reducing the gap between the primary and secondary crowns. This may have resulted in increased hydraulic adhesion.[23]

Clinically, an appropriate telescopic crown retentive force is reported to be approximately 5 to 9 N.[30] If the load is considered to be 25 N for a patient with relatively weak occlusal force, an appropriate retentive force can basically be achieved in saliva for a Ce-TZP/A telescopic crown with a half taper angle of 2°. However, as the retentive force is low, even in saliva, for a telescopic crown with a taper angle of 4°, use of a support tooth could be considered. For a patient with moderate occlusal force (a load of 50 N), an approximately twofold appropriate retentive force could be achieved even in saliva for a Ce-TZP/A telescopic crown with a half taper angle of 2°, and some adjustment of the retentive force would be necessary; however, appropriate retentive force could generally be achieved even in saliva for a telescopic crown with a taper angle of 4°. For a patient with strong occlusal force (a load of 100 N), a relatively strong retentive force would be achieved with a telescopic crown with a half taper angle of 2°, resulting in this being contraindicated. Clinically, some retentive force adjustment would be required for a 4° telescopic crown.

The retentive force of Ce-TZP/A telescopic crowns in water was found to be clearly greater than that in dry conditions. To achieve a clinically appropriate retentive force for telescopic crowns made from Ce-TZP/A, an appropriate taper angle needs to be selected after patient saliva volume and viscosity are investigated in detail, in addition to occlusal force during mastication.

The authors declare no conflict of interests. This study was presented at the 563th meeting of the Osaka Odontological Society, June 8, 2019, Hirakata, Japan. We appreciated the cooperation of the members of the Department of Fixed Prosthodontics and Occlusion, Osaka Dental University.

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