Comparison of retentive forces between telescopic crowns made of poly(ether ether ketone) and type 4 gold alloy

Mikayo NAKAMURA1, Akihiro TANAKA1, Akinori TASAKA1, Masao YOSHINARI2, Shinji TAKEMOTO3 and Shuichiro YAMASHITA1

1Department of Removable Partial Prosthodontics, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061 Japan
2Oral Health Science Center, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061 Japan
3Department of Biomedical Engineering, Iwate Medical University, 1-1-1 Idaidori, Yahaba-cho, Shiwa-gun, Iwate 028-3694 Japan
Corresponding author, Shinji TAKEMOTO; E-mail: takemoto@iwate-med.ac.jp

In this study, retentive forces were compared between telescopic crowns (TSC) made with poly(ether ether ketone) (PEEK) using computer-aided design and manufacturing and type 4 gold alloy using the conventional method. The retentive forces of TSCs were evaluated by performing a pull-out test with primary and secondary crowns. Initial retentive force was approximately 12 N for both PEEK and gold alloy TSCs. The retentive force of PEEK TSC was approximately 6.5 N after 10,000 cycles of insertion and removal. The reduction rate in retentive force was smaller for gold alloy TSC. PEEK TSC displayed greater surface roughness on the primary crown compared to the gold alloy TSC. Surface roughness slightly increased at the cervical margin after repetitive insertion and removal. The retentive force of PEEK TSC was smaller than gold alloy TSC, however the retentive force of PEEK TSC was adequate for stabilizing dental prostheses even after 10,000 cycles.

Keywords: PEEK, Retentive force, Conical crown, Gold alloy

INTRODUCTION

A removable partial denture (RPD) is a prosthesis used to restore occlusal function by placing retainers on abutment teeth. Among various attachments used for RPDs, the telescopic crown (TSC) stabilizes the prosthesis through the wedge effect and the frictional force generated between the primary and secondary crowns10. The TSC also considers a significant aspect of preventive dentistry because this prosthesis enables the abutment tooth to be readily cleaned2-4. The conical crown is a type of TSC which consists of a primary crown that is bonded to an abutment tooth, and a secondary crown that is incorporated into the denture base. The primary and secondary crowns are generally casted with type 4 gold alloy. The conical crown demonstrates exceptional strength and marginal accuracy, however, the range of its application is limited because of the complicated fabrication process which demands high precision and technique5,6.

In order to manage complications involved with casting, computer aided design and computer aided manufacturing (CAD/CAM) technology has received attention as an alternative method for fabricating TSCs7,8. Nakagawa et al. created primary and secondary crowns with zirconia and studied factors among manufacturing conditions which influenced retentive force. They reported that adequate retentive force of the secondary crown could not be obtained even with a load of 100 N when the taper of the primary crown was 6°7. When the crown taper was less than 4°, they reported that the retentive force of the secondary crown with a load of 50 N was greater than 8 N7. On the contrary, Merk et al. indicated that when the primary and secondary crowns were made of zirconia or cobalt chromium (Co-Cr) alloy with various tapers, the retentive force was independent of material type when the taper of the primary crown was 1°8.

Poly(ether ether ketone) (PEEK) is a thermoplastic polymer characterized by its high strength, low water absorption, excellent heat resistance, and biocompatibility. In industry, high strength PEEK is machined by milling and used as an alternative material to metals9. Since PEEK can be machined into various shapes by milling or injecting into molds, there have been studies looking into PEEK for fixed partial dentures10. Merk et al. fabricated a secondary crown with PEEK against the primary crown made of zirconia and measured its retentive force. As a result, retentive force was independent of fabrication method and no significant differences were observed10. On the other hand, Stock et al. made primary and secondary crowns with PEEK and studied retentive force according to various tapers and fabrication method. As a result, retentive force was influenced by the number of insertion/removal, fabrication method, and taper12.

In daily practice, clinicians must consider the reduction of retentive force for RPD clasps due to repetitive insertion and removal. Shimo reported that the clasp's retentive force decreases by 34–50% after repetitive insertion/removal of 10,000 cycles using type 4 gold, Co-Cr, and titanium clasps13. Nakata et al. reported that the retentive force of a Co-Cr alloy clasp fabricated with additive manufacturing was reduced by 2,000 cycles of repetitive insertion/removal14. Tanaka et al. also reported that the retentive force of silver-palladium-copper alloy clasps against zirconia crown decreased with repetitive insertion/removal15. These
studies demonstrated that it is necessary to evaluate denture retention by examining the influence of repetitive insertion/removal on retentive force. There are currently no studies which compare the retentive forces between TSCs made with PEEK using CAD/CAM and type 4 gold alloy using the conventional method.

The objective of this study was to determine the influence of the repetitive insertion/removal test on the retention of TSCs fabricated with PEEK. A comparison was made with the retentive force of TSC fabricated conventionally with type 4 gold alloy. The null hypotheses were as follows: 1. The retentive force of PEEK TSC is not influenced by repetitive insertion/removal test and 2. There is no difference in the retentive force between PEEK and gold alloy TSC.

MATERIALS AND METHODS

Preparation of conical crown TSC

The abutment tooth model was prepared with a margin diameter of 5.6 mm and crown length of 6.0 mm on a stainless-steel die assuming the mandibular first premolar. An impression of the die was made with vinyl silicone impression material (Examixfine regular type, GC, Tokyo, Japan) and the working model was made with high strength dental stone (New Fuji Rock, GC).

For gold alloy TSC specimens, the primary crown was waxed-up (plastic sheet, Wada Precision Dental Laboratories, Osaka, Japan and Carving wax, Yamahachi Dental MFG, Aichi, Japan) on the working model. The wax pattern was invested (Crist Heat Shock, Yamahachi Dental MFG) then casted (Pressure casting machine, HAMIEL Z, ODIC, Osaka, Japan) with type 4 gold alloy (Cast master gold i, IDS, Tokyo, Japan). The primary crown wax-up was designed to have a height of 7 mm, diameter at cervical margin of 7 mm, and a taper of 6° (milling machine, Heraus S3 master, Hanau, Germany). The final cast primary crown was polished using a finishing carbide bar (milling bur 408RH 6°, Busch, Engelskirchen, Germany) and silicone point (Corncr cone polisher 9314F, Japan Dental Supply, Tokyo Japan and Stone Point #20, Selec Osaka, Japan) (Fig. 1a). The secondary crown was waxed-up on the primary crown, incorporating a knob on the occlusal surface for the pull-out test, and casted with type 4 gold alloy. Adjustments were made (Shofu white point, Shofu silicon point, Shofu, Kyoto, Japan and WADA carborundum point, Selec) on the inner surface of the secondary crown to adapt to the primary crown. The secondary crown was adjusted so that maximum thickness was 0.7 mm (Fig. 1b). Seven pairs of primary and secondary crown specimens were fabricated.

For PEEK TSC specimens, the abutment tooth model was used to make the working model with high strength dental stone. The working model was scanned using a dental laboratory scanner (3shape D2000, 3shape, Copenhagen, Denmark). The primary crown was designed using a CAD software (3shape Dental Designer, 3shape) and a PEEK disc (JUVORA Dental Disc, JUVOR, Lancashire, UK) was milled using a milling machine (DWX-51D, Roland DG, CA, USA). The primary crown was designed to have a height of 7.5 mm, diameter at cervical margin of 8.4 mm, and a taper of 6°. The milled crown was polished in the same manner as type 4 gold alloy as described above (Fig. 1c). After polishing, the primary crown was scanned and a secondary crown was designed with a knob on the occlusal surface for the pull-out test and with 30 µm space between primary and secondary crowns. The secondary crown was adjusted so that maximum thickness was 1.5 mm (Fig. 1d). Seven pairs primary and secondary crown specimens were fabricated.

Measurement of retentive force

Each of the primary crowns made of gold alloy and PEEK were cemented with self-adhesive resin cement (Clearfil SA luting, Kuraray Noritake Dental, Tokyo, Japan) to an abutment made of cold-cured resin (Unifast III, GC). For the pull-out test, the corresponding secondary crown was mounted on the primary crown with a jig and a load of 49 N was applied for 20 s. The specimen was then transferred onto a universal testing machine (Autograph EZ-S, Shimadzu, Kyoto, Japan). The secondary crown was pulled from the primary crown at a cross head speed of 50 mm/min, and the maximum value during the crown detachment was taken as the retentive force. This procedure was repeated 10 times for each pair of crown, and the average of the obtained values was taken as the initial retentive force. Retentive force was expressed as the mean value and standard deviation.
**Repetitive insertion/removal test**

Repetitive insertion/removal test was carried out using a insertion/removal tester (JM100-T, Japan Mecc, Tokyo, Japan). Specimens were immersed in 37°C distilled water and repetitively inserted/removed at a cross head speed of 950 mm/min for a total of 10,000 cycles. The retentive force was measured every 1,000 cycles using the same method as when deriving the initial retentive force. Retentive force was expressed as the mean value and standard deviation of 10 measurements.

**Surface observation and roughness measurement**

The primary crown surface was observed using 3D measurement laser microscope (OLS 4000, OLYMPUS, Tokyo, Japan) before and after insertion/removal test. Four surfaces rotated at 90° were considered the regions of interest (ROI), and three points (top, middle, and bottom surfaces) that were within the ROI were established as measurement points. The range of measurement point was 1,280×1,280 µm². The average roughness (Ra) of the central region of the laser image was measured at a cutoff value of 250 µm.

**Cross-sectional observation**

After repetitive insertion/removal of 10,000 cycles, a load of 49 N was applied on the specimen which was embedded in epoxy resin (Scandiplex, Fritsch Japan, Kanagawa, Japan) and sectioned with a cutting machine (Fine cut, Heiwa Technica, Kanagawa, Japan). The sectioned sample was observed with a metallurgical microscope (BX 51, OLYMPUS).

**Statistical analysis**

One-way analysis of variance (ANOVA) was performed on the retentive force of each type of TSC (PEEK and gold alloy) using the number of insertion/removal cycle as a factor. The retentive force for every 1,000 cycles of insertion/removal was compared against the initial retentive force using the Dunnett’s test. In addition, comparison of retentive force according to type of TSC before and after every 1,000 cycles of insertion/removal cycles was conducted using the Student’s t-test. Two-way ANOVA was performed on the surface roughness on the top, middle, and bottom surfaces based on the type of TSC and the number of insertion/removal cycles.

**RESULTS**

**Change in retentive force**

Changes in retentive force of TSCs made with PEEK (a) and gold alloy (b) are shown in Fig. 2. The initial retentive forces of PEEK and gold alloy TSCs were 12.9±4.0 N and 12.3±2.2 N, respectively; no statistical significance was indicated. The retentive force of PEEK TSC reached 7.3±2.0 N at 3,000 cycles, and 6.5±2.7 N at 10,000 cycles. Statistical analysis revealed a significant difference between initial retentive force and retentive force after 3,000 cycles of insertion/removal (ANOVA and Dunnet’s test, p<0.05). The reduction in retentive force of gold alloy TSC was less compared to PEEK TSC. The retentive force of gold alloy TSC was 9.6±1.8 N after 10,000 cycles of insertion/removal. There was a significant difference between the initial retentive force and retentive force after 10,000 cycles of insertion/removal (ANOVA and Dunnet’s test, p<0.05). When the retentive force depending on number of insertion/removal cycles was compared between PEEK and gold alloy TSCs in Fig. 2(c), significant differences were indicated after insertion/removal of 3,000, 9,000, and 10,000 cycles (t-test, p<0.05).

**Surface observation and roughness**

Representative microscopic images of the primary crown surfaces (top, middle, and bottom surfaces) of PEEK and gold alloy TCSs are shown in Figs. 3 and 4, respectively. Images display initial surfaces (a–c) and after 10,000 cycles of repetitive insertion/removal (d–f). Abrasive marks consistent with the direction of insertion and removal were observed on both primary crowns (arrow). These marks were independent of surface region (top, middle, and bottom) on the 4 locations.

Surface roughness of the top, middle, and bottom surfaces of the primary crown made with PEEK and gold alloy are represented in Fig. 5. The Ra value at
Fig. 3 Representative microscopic images of PEEK primary crown before and after 10,000 cycles of insertion/removal. 
(a)–(c): before cyclic insertion/removal test, (d)–(f) are after cyclic test, (a) and (d); top of crown, (b) and (e); middle, and (c) and (f); bottom. White arrows in (d)–(e) indicate the scratches.

Fig. 4 Representative microscopic images of gold primary crown before and after 10,000 cycles of insertion/removal. 
(a)–(c): before cyclic insertion/removal test, (d)–(f) are after cyclic test, (a) and (d); top of crown, (b) and (e); middle, and (c) and (f); bottom. White arrows in (d)–(e) indicate the scratches.

Fig. 5 Surface roughness of outer side on primary crowns measured using 3D laser microscope. 
(a) Top surface, (b) Middle surface, (c) Bottom surface
specimen before insertion/removal test was greatest on the top surface. Statistical analysis revealed significant differences between PEEK and gold alloy TSCs on all surfaces (two-way ANOVA, \(p<0.05\)). Analysis of the cycles of insertion/removal indicated a significant difference for the bottom surface (two-way ANOVA, \(p<0.05\)).

**Cross-sectional observation**

The cross-sectional images of PEEK and gold alloy TSC subjected to 10,000 cycles of insertion/removal are displayed in Fig. 6. Between the occlusal surfaces of the primary and secondary crown, gaps of approximately 500 to 700 µm and 190 to 210 µm were observed for PEEK and gold alloy TSCs, respectively. When the gap between the axial surfaces of the primary and secondary crowns were considered, gold alloy TSC showed a uniform thickness of approximately 20 µm, whereas PEEK TSC ranged in thickness from 50 to 100 µm.

**DISCUSSION**

TSCs are used clinically as a retainer which puts into practice the concept of rigid support, however, its production involves complicated laboratory work requiring high precision. In this study, in order to consider the possible clinical application of TSC with PEEK fabricated using CAD/CAM, the influence of repetitive insertion/removal on the retentive force of TSC was investigated. In addition, primary crown surface morphology of TSCs using PEEK and gold alloy were studied and compared.

**Fabrication methods**

The appropriate retentive force of TSCs was reported to be between 6 to 10 N; some suggested this value to be more around 9.8 N\(^1\).\(^{10}\). The suitable taper of the conventional primary crown made of gold alloy was said to be approximately 5 to 8°\(^1\).\(^3\). When zirconia was used for the primary crown, reports indicated that the necessary taper was 0 to 2° in order to exert the same retentive force as conventional TSC\(^17\). Since this study compared dentures fabricated with the conventional method using gold alloy, the taper of PEEK primary crowns was established as 6°.

The representative molding methods of PEEK include milling using CAD/CAM and injection molding. PEEK blocks made for milling possess larger mechanical strength compared to PEEK made for injection molding\(^10\). In this study, mechanical properties of PEEK were taken into consideration and primary and secondary crowns were fabricated using CAD/CAM blocks. The tensile strengths of PEEK and type 4 gold alloy are 115 MPa and 520 MPa, respectively. The elastic modulus of PEEK is 4 GPa, which is smaller than that of type 4 gold alloy. In this study, the differences in strength was taken into consideration and the thickness of the secondary crown made with PEEK was designed to be more than twice the thickness of type 4 gold alloy. Preliminary experiments confirmed that PEEK TSC with thickness of 1.5 mm with adequate initial retentive force could be fabricated using the CAD/CAM system.

**Retentive force of TSC**

The retentive force of TSC is exerted by a wedge effect caused by a small elastic deformation of the secondary crown generated during fitting. Retentive force was measured by placing the secondary crown on the primary crown and applying a constant load assuming occlusal force. The specimen was loaded on a universal testing machine and the secondary crown was pulled for the pull-out test. The maximum force at the time of crown detachment was recorded as the retentive force. The initial retentive force of PEEK TSC was 12.9±4.0 N, which was almost the same as gold alloy TSC. The initial retentive forces of PEEK and gold alloy TSCs in this study indicated values larger than 6 to 10 N\(^1\).\(^{10}\), therefore, values were considered to be within the clinically appropriate range.

The retentive force of PEEK TSC gradually decreased due to repetitive insertion/removal, and the
force significantly decreased compared to initial retentive force after more than 3,000 cycles of insertion/removal. Therefore, the first null hypothesis that the retentive force of PEEK TSC is not influenced by repetitive insertion/removal test was rejected. Gold alloy TSC showed a significant decrease in retentive force compared to initial retentive force after 10,000 cycles of insertion/removal. Although there was no significant difference in retentive force between both TSCs at the initial stage of repetitive insertion/removal, the retentive force of PEEK TSC was smaller than that of gold alloy after 3000, 9000, and 10,000 cycles. Therefore, the second null hypothesis that there is no difference in the retentive force between PEEK and gold alloy TSCs was accepted for initial retentive force, however, the hypothesis was rejected after 10,000 cycles of insertion/removal.

As discussed earlier, tensile and elastic strength of PEEK is smaller than type 4 gold alloy. Considering this difference in mechanical strength, the thickness of the secondary crown made of PEEK in this study was designed to be thicker than that of gold alloy. The secondary crown exhibits retentive force by being slightly deformed when placed on the primary crown, but the crown returns to its original shape by elastic deformation when removed. Before the repetitive insertion/removal test, there was no difference in the retentive force of the secondary crown even with the difference in thickness. However, material fatigue accumulated due to repetitive elastic deformation after 10,000 cycles of insertion/removal. As a result, the reduction in strength of PEEK material caused by repetitive insertion/removal of the secondary crown was significantly greater than that of gold alloy. Further investigation is required to determine the fatigue strength of PEEK.

**Surface observation**

The surface roughness of primary crowns made with PEEK was slightly larger than crowns made with gold alloy even before the repetitive insertion/removal test. This was most likely a result of differences in final polishing of primary crown during specimen preparation. In addition, since the PEEK secondary crowns were fabricated using CAD/CAM, scratches on the inner surface caused by burs during milling caused an increase in surface roughness of the primary crown after repetitive insertion/removal test. PEEK TSC showed inferior adaptation compared to gold alloy after 10,000 cycles of insertion/removal as shown in Fig. 6. Initial roughness was greater, however, final roughness did not significantly increase at the top and middle surfaces of the primary crown, since repetitive insertion/removal did not induce wear between primary and secondary crowns. Analysis according to crown surface indicated that for the number of insertion/removal cycles, a significant difference was only observed in the bottom surface. For the conical crown TSC, the secondary crown does not come in contact with the primary crown initially during fitting, however pushing the primary crown into the secondary crown at a certain position causes the secondary crown to deform and exhibit retentive force. In this study, since roughness increased only on the bottom surface of the primary crown upon repetitive insertion/removal, it was suggested that the wedge effect influenced the retentive force of TSC mainly in the cervical region. Abrasive materials for primary crown made of PEEK should be investigated to improve the initial roughness.

**Clinical implication**

Denture retainers include TSCs, clasps, and bar attachments. Shimpo reported that the retentive force of clasps decreased by 34–50% after repetitive insertion/removal of 10,000 cycles when type 4 gold alloy, Co-Cr alloy, or titanium were used. Tanaka et al. also reported that the retentive force of clasp on crown was 5.6±1.1 N after 10,000 cycles of insertion/removal (15). The number of 10,000 cycles of insertion/removal was considered clinically suitable, assuming this number was equivalent to about 9 years of denture use when insertion/removal of denture was done 3 times a day. Therefore, conventional TSC made with type 4 gold alloy possessed greater retentive force compared to cast clasp. Adequate retention of denture using PEEK was considered possible because PEEK TSCs demonstrated similar retentive force as cast clasps.

The PEEK used to make TSCs in this study was gray in color and weaker than type 4 gold alloy, therefore, the color and mechanical strength of PEEK materials need to be improved before consideration for clinical use. In addition, the abrasive materials for PEEK need to be developed with further studies.

**CONCLUSIONS**

In this study, TSC, a retainer used for partial dentures, was fabricated with PEEK using CAD/CAM, and the retentive force was compared to TSC made with type 4 gold alloy using the conventional method. As a result, the following conclusions were obtained.

1. The initial retentive force of PEEK TSC was equivalent to that of gold alloy TSC.
2. The retentive force of PEEK TSC decreased due to repetitive insertion/removal, and abrasion marks were observed on the bottom of the primary crown.
3. The retentive force of PEEK TSC after repetitive insertion/removal was smaller than that of the gold alloy TSC, however retentive force was adequate for denture retention.

**ACKNOWLEDGMENTS**

We greatly appreciate the members of Department of Removable prosthodontics, Tsurumi University School of Dental Medicine for assistance and cooperation throughout the study.

**CONFLICT OF INTEREST**

The authors declare no conflict of interest.
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