Effects of repetitive insertion/removal cycles and simulated occlusal loads on retention of denture retainers

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The purpose of this study was to investigate the effects of repetitive insertion/removal cycle tests on denture retainers with simulated occlusal loads on the retentive force and deformation of clasp. Abutment teeth in the form of mandibular secondary premolars and clasp in the form of Akers clasps were prepared. The retentive force of the clasp on the abutment teeth were evaluated before and after undergoing repetitive insertion/removal cycle tests with or without cyclic loading. Changes in the clasp shape were monitored using a 3D scanner and scanning electron microscope. The initial retentive force was approximately 10 N and this value later decreased due to deformation of the clasp tips. In contrast to the non-load group, the load group exhibited a reduction in retentive force during earlier stages. Therefore, cyclic loading was related to a decrease in retentive forces, specifically in the early stages of repetitive insertion/removal cycles.

Keywords: Clasp, Retentive force, Repetitive insertion/removal test, Removable partial denture

INTRODUCTION

The use of a removable partial denture (RPD) is a viable treatment option for individuals with partially edentulous cases; ranging from the loss of a single tooth to the loss of all but one tooth in the dentition. Retainers are a component of the RPD and include clasps with several different types of attachments. Retainers exhibit adequate retentive force when placed on the appropriate path of insertion where the clasp tip is positioned in a suitable undercut region relative to the survey line. The Akers clasp is one of the most frequently used retainers for RPDs. The Akers clasp is classified as a type of suprabulge clasp where the retentive arm is designed to start from the occlusal rest and reach beyond the maximum height of contour into the undercut region of the abutment tooth. The retentive force of the retainer is exhibited through its close adaptation to the abutment, and its removal requires the retentive arm to undergo elastic deformation. The Akers clasp prototype does not include a structure corresponding to the proximal plate, however, in a clinical setting, a proximal plate is added to the clasp body. As a result, overall retention is improved due to the friction generated between the proximal plate and the guiding plane with the aid of an encircling clasp arm. Mothopi-Peri and Owen studied the effects of guiding planes and proximal plates on clasp retention and reported that retentive force was kept when the guiding plane and the proximal plate were well adapted.

Retentive force of the Akers clasp has been reported to decline after repetitive insertion and removal (insertion/removal) from the abutment tooth. Tanaka et al. reported a decrease in retentive force of clasps made of cobalt-chromium (Co-Cr) alloy on zirconia crowns after the retainer was subjected to a repetitive insertion/removal test, and wear marks were observed on the zirconia crowns. Previous papers reported that the retentive force of Co-Cr clasps on stainless steel abutments were reduced to more than 40% and that the retentive force of the clasp made of type 4 gold alloy, Co-Cr alloy, and titanium alloy decreased by 50–65% after repetitive insertion/removal tests. The retentive force of the clasp on an abutment tooth during repetitive insertion/removal tests was influenced by the shape and material of the clasp and abutment tooth in previous experiments. A number of repetitive insertion/removal tests using Akers clasps have been examined, however, in these studies, the retainers were loaded only at the time of clasp insertion. These studies have not considered the effects of occlusal loads, which are significant load factors that may affect the retention force of RPD retainers in clinical settings.

In cases of elderly individuals using RPDs, the maximum occlusal force recorded was 249.5 N. This data suggests that large forces are loaded on retainers through the denture base and the artificial teeth. No previous study has considered the effects of occlusal force, in addition to repetitive insertion/removal cycles, on changes in retentive force and deformation of retainers. Moreover, there is substantial literature that suggests that the path of insertion must be clearly established in order for retainers to exert an appropriate retentive force. However, there are very few reports with experimental designs that secure the path of insertion during repetitive insertion/removal tests.

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The objective of this study was to determine the effects of repetitive insertion/removal cycles with simulated occlusal loads on the retentive force and deformation of retainers. The null hypotheses were as follows: 1) occlusal loading has no effect on the changes in retentive force of denture retainers and 2) occlusal loading has no effect on retainer deformation during repetitive insertion/removal tests.

**MATERIALS AND METHODS**

**Abutment fabrication**

The abutment tooth design is shown in Fig. 1(a). The abutment was designed as a crown on the mandibular secondary premolar. Abutments were fabricated using CAD software (Dental system, 3shape, Copenhagen, Denmark). A guiding plane was placed on the distal proximal surface and a rest seat was placed on the distal occlusal surface according to the shape of the guide plane. Using the assumption that the clinical crown axis was perpendicular to the occlusal plane, a line parallel to the tooth axis was established as the path of insertion. A 0.25 mm undercut on the mesial buccolingual surface was placed where the clasp tip was to be located. In order to accurately place the abutment on the connector, a cylindrical knob with a diameter of 2 mm was placed on the buccolingual cusp surface. This knob was designed to be perpendicular to the path of insertion and a joint for the connector was placed on the base of the abutment tooth.

Using these conditions of the abutment tooth as data for the standard triangulated language (STL), CAD software was used to fabricate the abutment specimens. The abutment specimens were fabricated via additive manufacturing by selective laser sintering (SLS) (EOSINT M270, EOS, Krailling, Germany) and Co-Cr powder (EOS CobaltChrome SP2, EOS) (Table 1). Each specimen was heat-treated per the manufacturer’s instructions. The procedure for heat treatment was as follows: the temperature was increased to 450°C over 1 h, increased to 750°C over 45 min, then gradually cooled. The support structures were removed and the abutment specimens were blasted at a pressure of 0.6 MPa (Sand Blast FORTE, ODIC, Osaka, Japan) using alumina (ALUMINA 250μ, Denken-Highdental, Kyoto, Japan). A carborundum point was used to remove the support structures and adjust the specimens, and a silicone point was used for mirror polishing. A total of 10 abutment teeth specimens were fabricated.

**Clasp fabrication**

The retainer design is shown in Fig. 1(b). STL data of each abutment specimen was obtained using a 3D scanner (D2000, 3shape). An Akers retainer was designed for each abutment using the dental CAD software (Dental system, 3shape). The clasp arm entered the undercut region at half its length and the clasp tip was set at the 0.25 mm undercut region for both the buccal and lingual arms. The clasp design was then converted to STL data. For the clasp tang, the joint on the connector was designed using CAD software (Geomagic Freeform, 3D SYSTEMS, Rock Hill, SC, USA), and this data was combined with the clasp STL data.

Castable resin patterns (dima Print Cast, Kulzer Japan, Tokyo, Japan) of retainers were made through additive manufacturing (cara 4.0 Kulzer Japan). The resin patterns were invested with a phosphate-bonded investment material (RemaExact, DENTAURUM, Ispringen, Germany) and heated in a furnace. The invested molds were heated to 250°C at 5°C/min, held for 60 min, heated to 1,050°C at a rate of 5°C/min, and then held for 40 min. Co-Cr alloy (Remanium GM800+, DENTAURUM) (Table 1) was casted with a high-frequency centrifugal casting machine (Auto Sensor MD-201, DENKO, Chiba, Japan). After the cast clasps were blasted (Sand Blast FORTE, ODIC) with alumina, they were then minimally adjusted and polished using carborundum and silicone points per the manufacturer’s

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**Table 1** Composition and mechanical properties of the alloys used in this study

| Composition (mass%)**1** | Mechanical properties**1** | Brand Name (Manufacture) |
|--------------------------|---------------------------|--------------------------|
| **Abutment** Co: 61.8–65.8, Cr: 23.7–25.7, Mo: 4.6–5.6, W: 4.9–5.9, Si: 0.8–1.2, other | PS: 850 MPa, UTS: 1,350 MPa, EL: 3% | EOS Cobalt Chrome SP2 (EOS) |
| **Clasp** Co: 58.3, Cr: 32.0, Mo: 6.5, W: 1.5, Si: 1.0, other (C, N): <1 | PS: 720 MPa, UTS: 960 MPa, EL: 4%, EM: 230 GPa, Hv: 370 | Demanium GM800+ (Dentaaurum) |

*1: based on the nominal values from manufacture, PS: 0.2% proof strength, UTS: Ultimate tensile strength, EL: Elongation for fracture, EM: elastic modulus, Hv: Vicker's hardness
instructions. The clasps were fitted to the abutment specimens and adjustments were kept minimal to preserve the as-cast configuration. Ten clasps were made to pair with each abutment. All fabrication processes were performed by a dental technician with 26 years of experience. At the completion of all fabrication procedures, the specimens were visually inspected by three dentists.

The abutment and clasp specimens were tested as a set. A total of 10 specimens were divided into 2 groups of 5, where each group was labeled as the load and non-load group.

**Repetitive insertion/removal test**
The abutment tooth and clasp were fixed to the connector with auto-curing resin (UNIFAST III, GC, Tokyo, Japan) using a jig. The fixed jig was attached to a testing device (TDC-YKp, Japan Mecc, Tokyo, Japan) that performs both repetitive insertion/removal and cyclic loading (equivalent to occlusal force) (Fig. 2). Two types of repetitive insertion/removal tests were conducted: one where an insertion load was applied during the mounting of the clasp (non-load group), and another where a load equivalent to occlusal force was applied in addition to the insertion load (load group).

The load to mount the clasp on the abutment teeth was measured at 49 N and the load equivalent to occlusal force was measured at 196 N. The loads were applied on the artificial tooth closest to the abutment tooth. In the load group, 5 occlusal loads with 1 s-intervals were applied between every insertion/removal cycle. The insertion/removal cycles were performed at a cross-head speed of 1,800 mm/min (Fig. 3). The tests were performed in 37°C distilled water.

**Measurement of retentive force**
A universal testing machine (Autograph AG-X/R, Shimadzu, Kyoto, Japan) was used to measure the retentive force. For the insertion/removal test, the jig was attached to the universal testing machine in order to standardize the direction of insertion/removal.

The clasp and abutment were mounted on to the jig. At a crosshead speed of 50 mm/min, a load of 14.7 N was applied for 20 s then removed. Retentive forces were measured before the start of repetitive insertion/removal cycle tests as the initial retentive force, and then every 1,000 cycles, 10 times for a total of 10,000 cycles. Ten measurements were carried out each time. At the beginning of every measurement, the jig was checked between the abutment or the clasp for looseness. Specimens which displayed looseness in the fixation area of the jig were excluded from the test.

**Measurement of deformation**
After the insertion/removal test, specimens were examined for deformation using a 3D scanner (ATOS core200, GOM, Braunschweig, Germany). The clasp was coated with titanium oxide powder (Pure scan powder, 3Dent Mater J 2021; - -)

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Fig. 2 Testing device.
(a) The repetitive insertion/removal testing device (TDC-YKp), (b) The layout of frontal design

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Fig. 3 A line graph (conceptual diagram) of loading conditions for two experimental groups, where the vertical axis is load and the horizontal axis is time.
Quest, Tokushima, Japan) for measurement accuracy. Measurements were taken before the insertion/removal tests and again after 10,000 cycles. STL data was obtained for both measurements.

STL data before and after repetitive insertion/removal testing were superimposed using a 3D modeling tool (GeomagicStudio 2014, 3D SYSTEMS) in order to perform deviation analysis. The data was superimposed using the best fit method and the root mean square of deviation (RMSD) was calculated. The surfaces of some specimens were observed under a field emission scanning electron microscope (FE-SEM; SU6600, Hitachi, Tokyo, Japan) before and after repetitive insertion/removal tests.

Statistical analysis
For each group, one-way analysis of variance (ANOVA) was used to analyze changes in retentive force according to the number of insertion/removal cycles. This analysis was followed up with Bonferroni’s multiple comparison test. Student’s t-test was also used to compare the retentive force between two groups every 1,000 cycles. In order to analyze the degree of clasp deformation, Mann–Whitney’s U-test was used to compare the RMSD values between each group. The significance level was set as 5%. (SPSS ver.25, IBM, Armonk, New York, USA).

RESULTS

Changes in retentive force
Figure 4 shows the changes in retentive force of the clasp and abutment tooth after the repetitive insertion/removal test with or without cyclic loading (load and non-load groups). The initial retentive forces in the load and non-load groups were 9.9±0.6 N and 11.2±2.3 N, respectively (mean value±standard deviation). There was no significant difference between the initial retentive forces (Student’s test, p>0.05). The retentive forces in both load and non-load groups decreased after the repetitive insertion/removal test. Statistically significant differences in retentive forces in both load and non-load groups were observed between the number of insertion/removal cycles (ANOVA; p<0.05). In the multiple comparison test, significant differences between the initial retentive force and the retentive force after 1,000–10,000 cycles were examined in the load group, while significant differences between retentive forces less than 1,000 cycles and after 2,000–10,000 cycles were examined in non-load group (Bonferroni’s multiple comparison test; p<0.05). With the exception of the group that underwent 1,000 cycles, no significant differences in retentive force were observed between the load and non-load groups (Student’s t-test; p<0.05).

Deformation of clasp retainer
Figure 5 shows typical color charts from STLs of load and non-load groups before and after repetitive insertion/removal cycle test. Slight changes were observed at the clasp tip for both groups according to the color chart. The median RMSD value of the load group was 2.0×10⁻² mm, the minimum value was 1.8×10⁻² mm, and the maximum value was 3.4×10⁻² mm. The median RMSD value of the non-load group was 1.4×10⁻² mm, the minimum value was 1.1×10⁻² mm, and the maximum value was 1.5×10⁻² mm. Significant differences in the RMSD values between the load and non-load group were observed (Mann–Whitney U test; p<0.05, Fig. 6).

In the SEM images (Fig. 7) of the clasp following repetitive insertion/removal tests, a gap was observed at...
Fig. 6 Comparison of RMSD of clasp between load and non-load group.

Fig. 7 SEM images of the clasps before and after repetitive insertion/removal with or without cyclic loading tests. White arrows indicated gap between clasp and abutment tooth. (a) Before repetitive insertion/removal test, (b) After repetitive insertion/removal test with loading (Load group), (c) After repetitive insertion/removal test without loading (Non-load group)

DISCUSSION

Test method
In clinical settings, denture retainers undergo occlusal stress in addition to repetitive insertion/removal cycles. The occlusal forces that are loaded on the denture are transmitted to the abutment tooth through the retainer of the RPD. This highlights the importance of the retainer in denture design as it dictates the path of insertion while simultaneously transmitting occlusal forces to the abutment tooth. Many studies involving repetitive insertion/removal of clasps have been reported\cite{4-6,10-15}, however, there are few reports that have also considered the effects of occlusal loading on the retentive force of retainers. In this study, cyclic loading was performed in addition to repetitive insertion/removal cycles in order to identify additional factors that may affect the retention force of clasps. Previous papers have reported that Aker’s clasp made of silver-palladium-copper-gold alloy\cite{4}, cobalt-chromium alloy\cite{4,5,7}, and titanium alloy\cite{6} have displayed retentive forces between 10–15 N and this value is similar the retentive forces derived in this study. Retentive force gradually decreased with the number of repeated insertion/removal cycles. In this study, retention decreased during early stages then stayed constant until 10,000 cycles with little deformation. The retention of the clasp largely depended on the elastic modulus of materials since elastic deformation occurs during insertion/removal of the clasp. The elastic modulus of casted cobalt chromium alloy in this study was 230 GPa, which is larger than that of titanium alloys (108 GPa), type 4 gold alloy and silver-palladium-copper-gold alloy (<100 GPa). A retainer made of cobalt chromium alloy, which has a large elastic modulus, can undergo cyclic loading with a smaller displacement compared to retainers made with other materials. Since cyclic loadings and occlusal forces showed small clasp deformation that was within the range of the elastic deformation, it can be concluded that no obvious deformation was observed in this study. The cyclic load of 196 N was selected in reference to a study that studied the occlusal forces of elderly individuals over 80 years of age\cite{8}.

Fig. 8 SEM image of the abutment tooth surface after repetitive insertion/removal test. White arrows indicated scratch marks with repetitive insertion/removal.
Change in clasp retention and form
A previous study reported that the initial retentive force of Co-Cr cast clasps on natural teeth and cast crowns were 13.0±4.0 N and 11.3±2.1 N respectively. The retentive forces were similar to the initial retentive force of in this study. After repetitive insertion/removal and cyclic loading tests, the retentive forces of clasps in the load group and non-load group decreased significantly after 1,000 cycles and 2,000 cycles respectively. When compared to the retentive force of clasps in the non-load group, the retentive forces in the load group showed a decrease in retentive force at earlier stages. The retentive force in the load group showed no significant changes from 2,000 to 10,000 cycles, suggesting that occlusal load affected clasp retention during early stages of loading. Despite these changes, the minimally required retentive forces for clasps were maintained even after 10,000 cycles.

Using these findings, the first null hypothesis that occlusal loading has no effect on the retentive force of denture retainers was rejected. Assuming that denture placement and removal was repeated 4 times a day, 1,000 cycles of insertion/removal corresponds to approximately 250 days of denture use. This indicates that the retentive force of retainers decreases within the first year of denture placement. These results can be considered to be more realistic from a clinical perspective compared to past reports which did not account for occlusal loading. The non-load group also showed a decrease in retentive force in earlier stages compared to some previous reports. This was most likely due to a disparity in factors such as the shape and form of the clasp and abutment tooth, or the duration of load at which the clasps were mounted. In addition, the reduction of clasp retention after 250 days suggests the timing that dentists should check for looseness and compatibility of dentures with clasp. These changes in the retentive force of clasp could provide evidence to suggest how often patients should see their dentist for their long-term use of dentures.

The RMSD value of the load group was larger than that of the non-load group, indicating that the clasp deformation was greater in the load group. SEM image (Fig. 7) also showed that the gap at the clasp tip was slightly larger in the load group when compared to the non-load group. A significant difference was indicated between the RMSD values, and thus the second null hypothesis that occlusal loading has no effect on retainer deformation was rejected.

The results of the color chart suggested that clasp deformation increased with loading cycles and that differences in wear behavior existed between the buccal and lingual clasp arms. Several papers have reported the influence of clasp shape on permanent deformation, as well as wear behavior on the inner surface of the clasp and abutment surface. Tanaka et al. investigated wear behavior of crowns and clasps made of silver-palladium-copper alloy, and then reported that adhesive wear occurs as a result of repetitive insertion/removal of a clasp from the abutment tooth. In wear mechanism between different metals, Kanbara et al. reported that abrasive wear occurs between metals varying in hardness. These researches suggested that the wear behavior between the crown and clasp with repeated insertion/removal and cyclic loading will vary depending on their respective materials and conditions.

In this study, wear marks were macroscopically confirmed on the guiding lines and areas where the clasp tip came in contact with the abutments, and on the inner surfaces of clasps in the undercut area. In the non-load group, the SEM images (Fig. 8) revealed wear marks on areas of the crown that came in contact with the clasp tip of the lingual arm. Therefore, even though the undercut levels at the clasp tip were all the identical, overall differences in the degree of clasp deformation by loading and differences between the buccal and lingual clasp arms occurred at differences in survey line height on the buccal and lingual surfaces of the abutment tooth. In other words, clasp deformation due to repetitive insertion/removal and cyclic loading affects the contact point between the abutment tooth and clasp arm.

Obvious clasp deformities are often observed in clinical settings, however no obvious deformities were observed in this study, suggesting that deformation occurred on a microscopic level. This was largely due to the fact that the path of insertion/removal was strictly limited. In addition, since no loosening was detected on the jig during the measurement of retentive force, the motion of the clasp during cyclic loading was slight rotational movement along the fulcrum on a plane where the guide plane and the proximal plate came in contact. The rotational stress was the most concentrated in the area from the base plate to the clasp tang, leading to permanent deformation and a subsequent shift in the positioning of the clasp tip with respect to the abutment. Repetitive insertion/removal cycles eventually led to significant levels of clasp deformation in this manner.

The retainers used in this study were designed to have sufficient width and thickness from the proximal plate to the clasp tang in order to ensure that only slight elastic deformation would occur. This design was effective, as the retainers were happened to only slight permanent deformation. Considering the limited resolution of the 3D scanner used in this study, it is necessary to suggest that a more comprehensive approach or higher resolution equipment be utilized in order to accurately measure deformation in future analyses.

The clasps in this study were designed using gold-platinum alloy and based on the Ney Surveyor Manual, which has been the most widely used in the past. The types of dental materials and their production methods have diversified with the development of CAD/CAM technology, therefore, it is necessary to reevaluate the design of conventional clasps with respect to appropriate undercut levels. Therefore, further analysis is required to study the gap between the abutment tooth and clasp before and after testing.
CONCLUSIONS

The effects of repetitive insertion/removal cycles with simulated occlusal loads on the retentive force and deformation of Akers clasp were examined. Within the limitations of this study, the following conclusions were observed.

1. The retentive forces of Akers clasp decreased with repetitive insertion/removal cycles regardless of occlusal loading.
2. A decrease in retentive force occurred after 1,000 cycles of insertion/removal in the load group and after 2,000 cycles of insertion/removal in the non-load group.
3. The Akers clasp showed significant deformation after cycles of repetitive insertion/removal with occlusal loading.

A significant decrease in retentive force with clasp deformation was observed in early stages of repetitive insertion/removal in the load group with simulated occlusal loads. This suggests that functional loads should always be considered when evaluating the retention force of denture retainers.

REFERENCES

1) Singh BP, Gauthier G, Rompre P, De Grandmont P, Emami EA. 30-year follow-up of partial removable dental prostheses in a university dental school setting. J Prosthodont 2016; 25: 544-549.
2) Planned partials: the combined edition of the Ney surveyor book. JM Ney Company, Hartford, CT, USA 1963 p.23-34
3) Mothopi-Peri M, Owen CP. Guide-plane retention in designing removable partial dentures. J Prosthodont 2018; 31: 145-148.
4) Nakanishi M, Hotta H, Takemoto S, Yoshinari M, Yamashita S. Change in the retentive force of Akers clasp for zirconia crown by repetitive insertion and removal test. J Prosthodont Res 2019; 63: 447-452.
5) Torii M, Naka T, Takahashi K, Kawamura N, Shimpo H, Ohkubo C. Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling. J Prosthodont Res 2018; 62: 342-346.
6) Shimpo H. Effect of arm design and chemical polishing on retentive force of cast titanium alloy clasps. J Prosthodont 2008; 17: 300-307.
7) Cheng H, Xu M, Zhang H, Wu W, Zheng M, Li X. Cyclic fatigue properties of cobalt-chromium alloy clasps for partial removable dental prostheses. J Prosthodont 2010; 104: 389-396.
8) Tatematsu M, Mori T, Kawaguchi T, Takeuchi K, Hattori M, Morita I, et al. Masticatory performance in 80-year-old individuals. Gerodontology 2004; 21: 112-119.
9) Carr AB, Brown DT. McCracken’s Removable Partial Prosthodontics. 13th Edition ed. St. Louis, Missouri, USA: ELSEVIER, 2016; 83-88.
10) Arda T, Arikan A. An in vitro comparison of retentive force and deformation of acetal resin and cobalt-chromium clasps. J Prosthodont 2005; 94: 267-274.
11) Nakata T, Shimpo H, Ohkubo C. Clasp fabrication using one-process molding by repeated laser sintering and high-speed milling. J Prosthodont Res 2017; 61: 276-282.
12) Tamrous F, Steiner M, Shahin R, Kern M. Retentive forces and fatigue resistance of thermoplastic resin clasps. Dent Mater 2012; 28: 273-278.
13) Tokue A, Hayakawa T, Ohkubo C. Fatigue resistance and retentive force of cast clasps treated by shot peening. J Prosthodont Res 2013; 57: 186-194.
14) Rodrigues RC, Ribeiro BF, de Mattos Mda G, Bezzen OL. Comparative study of circumferential clasp retention force for titanium and cobalt-chromium removable partial dentures. J Prosthodont 2002; 88: 290-296.
15) Schweiger J, Güth JF, Erdelt KJ, Edelhoff D, Schubert O. Internal porosities, retentive force, and survival of cobalt-chromium alloy clasps fabricated by selective laser-sintering. J Prosthodont Res 2020; 64: 210-216.
16) Frank RP, Nicholls JL. A study of the flexibility of wrought wire clasps. J Prosthodont 1981; 45: 259-267.
17) Ghani F, Mahood M. A laboratory examination of the behaviour of cast cobalt-chromium clasps. J Oral Rehabil 1990; 17: 229-237.
18) Vallittu PK, Kokkonen M. Deflection fatigue of cobalt-chromium, titanium, and gold alloy cast denture clasp. J Prosthodont 1995; 74: 412-419.
19) Sato Y, Abe Y, Yuasa Y, Akagawa Y. Effect of friction coefficient on Akers clasp retention. J Prosthodont 1997; 78: 22-27.
20) Ahmad I, Sherriff M, Waters NE. The effect of reducing the number of clasps on removable partial denture retention. J Prosthodont 1992; 68: 928-933.
21) Kanbara T, Sekine H, Homma S, Yajima Y, Yoshinari M. Wear behavior between zirconia and titanium as an antagonist on fixed dental prostheses. Biomed Mater 2014; 9: 025005.
22) Tasaka A, Kato Y, Odaka K, Matsunaga S, Goto TK, Abe S, et al. Accuracy of clasps fabricated with three different CAD/CAM technologies: Casting, milling, and selective laser sintering. Int J Prosthodont 2019; 32: 526-529.
23) Tasaka A, Shimizu T, Kato Y, Okano H, Ida Y, Higuchi S, et al. Accuracy of removable partial denture framework fabricated by casting with a 3D printed pattern and selective laser sintering. J Prosthodont Res 2020; 64: 224-230.