Effects of clasp retention forces and abrasion on different cast crowns

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Statement of problem. Dental alloys have different mechanical properties compared with enamel. However, few studies have been conducted to determine the effects of the retention forces of clasps when applied on different cast crowns.

Purpose. The purpose of this study was to evaluate the retention forces of cast circumferential clasps made of cobalt-chromium alloy on complete cast crowns made of cobalt-chromium (CC group) and gold-silver-palladium (AC group) alloys, and to observe their abrasion patterns.

Material and methods. Two groups of specimens were fabricated (n=5) and subjected to repeated insertion-removal tests (100 to 15 000 cycles). The mean values of removal forces at 100, 400, 800, 1500, 4500, 7500, 10 000, and 15 000 cycles, and their corresponding change rates compared with the initial 100 cycles’ retention were determined. The differences between the 2 groups were analyzed by 2-way repeated measures analysis of variance at 100, 7500, and 15 000 cycles. The surfaces of specimens were observed with scanning electron microscopy.

Results. There were significant differences between the CC and AC groups in retention forces (P<.05). Clasp retention showed a descending trend for cobalt-chromium alloy crowns from the initial value, which decreased by 29.9% after 15 000 insertion-removal cycles. A sharp increase in retention could be observed in the AC group, which rose by 99.7% ultimately. The worn surfaces of the gold-silver-palladium crowns showed different wear patterns compared with the cobalt-chromium alloy crowns.

Conclusions. The results indicate that cobalt-chromium alloy crowns and gold-silver-palladium alloy crowns perform differently when cobalt-chromium alloy clasps are designed as retainers for partial removable dental prostheses. Crown designs should be changed, depending on the retainer and clasp materials for partial removable dental prostheses abutment teeth. (J Prosthet Dent 2014;111:493-498)

Clinical Implications
Gold-silver-palladium crowns and cobalt-chromium alloy crowns affect the retention force of cobalt-chromium alloy clasps in different ways. These results suggest that, when a tooth requires a surveyed crown for a partial removable dental prosthesis, it is important to consider matching properties of the clasp and crown.

The partial removable dental prosthesis (PRDP) is a conventional approach to replacement of missing teeth, and there are many situations in which abutment teeth are restored with fixed prostheses. For example, abutments may require crown placement to ensure appropriate contour and strength. If an abutment of a PRPD is damaged, it can be restored with a crown to prolong the service life of an existing PRPD. Therefore, it is necessary to investigate the
compatibility of clasps and crowns. It is commonly known that the retention force of a clasp is related to both the abutment’s form, such as depth and angle of the undercut, and the clasp’s material and characteristics, such as length, thickness, and cross-sectional shape. It has been reported that noble metal abutment crowns made of Type IV gold (Au) and high palladium (Pd) alloys showed higher friction coefficient values than nonmetal materials, such as human enamel or porcelain, in contact with airborne-particle abraded clasps made of cobalt (Co) chromium (Cr) alloys, which suggests that clasp designs should be changed, depending on the abutment crown materials. However, most researchers conducted 3-point bending tests to measure properties of clasps and have paid insufficient attention to metal crowns other than Co-Cr alloy crowns on the abutment teeth. Hence, it is necessary to investigate the retention force of a PRPD clasp and its variation when different alloys are used for cast crowns as abutments.

Various compositions and types of casting metal alloys are available for dental restorations. Noble alloys with 35 to 50 wt% of Au content have become an alternative to high-Au alloys for economic reasons. These alloys have a moderate elastic modulus but have increased hardness and yield strength compared with high-Au alloys. Ucar et al reported that there were no significant differences in yield strength among the Au-Pd, Pd-silver (Ag), Pd-Ag-Au, and Au-Ag-Pd alloys, although wide variation was found in percentage elongation. According to a study, Au-Pt-Pd dental alloys released 10 μg/cm² per week of metal ions or less and are the most resistant to electrochemical and chemical corrosion, more so than high-Au alloys. Clinically, the Au-Ag-Pd alloy is mostly used to fabricate fixed prostheses.

Cr-containing base metal casting alloys are the principal materials used in the fabrication of PRPD frameworks because of their strong mechanical properties and relatively low cost. There are several available Cr alloy systems, including Co-Cr alloy, Co-Cr-nickel (Ni) alloy, and Ni-Cr alloy. Their hardness increases with higher Cr content and decreases with higher Ni content. Co-Cr-molybdenum alloys are popular because of their higher hardness and lower allergy risk than Ni-based alloys. Although they generally do not contain carbon when used for complete cast restorations, carbon is frequently added to improve hardness and yield strength when they are to be used for PRPD frameworks. These substances are more rigid and fatigue resistant than noble alloys.

The purpose of this in vitro study was to evaluate the retention forces of a frequently used cast circumferential clasps (Co-Cr alloy) applied to crowns made from Au-Ag-Pd and Co-Cr alloys, and to observe the abrasion between them. The null hypothesis was that there would be no difference in the retentive forces and abrasion patterns of Co-Cr alloy cast circumferential clasps applied to Au-Ag-Pd and Co-Cr alloys crowns during fatigue cycles.

### MATERIAL AND METHODS

The crown of a mandibular right first molar typodont model tooth (500 A; NISSIN) was prepared for an abutment tooth with an occlusal rest seat (spoon shaped, 2.5 × 2.5 × 1 mm). A cylindrical wax sprue (4.0 mm; Dentaurum), which served as retainers in the fatigue test, were connected to the long axis of the crown. Wax circumferential clasps were fabricated with occlusal rests by using preformed semicircular wax clasp profiles (MK; Dentaurum). The lower edge of the wax clasp profile was securely placed along the undercut line of each die to ensure the same length and identical location of clasps. Cylindrical wax sprues (4.0 mm; Dentaurum), which served as retainers in the fatigue test, were connected to the upper surfaces of the rests, parallel to the long axes of the crowns, by using a surveyor. Each specimen was airborne-particle abraded (120# Al₂O₃, 0.2 MPa, 45 seconds) and electrolytically polished (sulfuric acid 53%, glycercol 25%, water 13%, ethanol 8%, Co dichloride 0.001 to approximately 0.01%, 2, 6 minutes). The composition and manufacturers of metals used for specimen fabrication in this study are listed in Table I.

The internal porosity of the clasps was examined with dental radiographs (70 kV, 25 mAs; Instrumentarium Imaging). The external defects were detected by visual observation with the aid of dental loupes

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition (wt%)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-Ag-Pd alloy</td>
<td>Au 40; Pd 3.8; Ag 47; other 9.2</td>
<td>BioZZ40, Beijing Rulin Jinye Co Ltd</td>
</tr>
<tr>
<td>Co-Cr alloy</td>
<td>Co 60; Cr 24; W 9; Mo 5</td>
<td>Shanghai Chang Ping Material Co</td>
</tr>
<tr>
<td>Co-Cr alloy</td>
<td>Co 64; Cr 28.6; Mo 5; Si 1; Mn, C</td>
<td>Wironit S, BEGO</td>
</tr>
</tbody>
</table>

Au, gold; Ag, silver; Pd, palladium; Co, cobalt; Cr, chromium; W, tungsten; Mo, molybdenum; Mn, manganese.

*a-Co-Cr alloy was used to fabricate crown specimens.*
accuracy of the clasps was determined by using silicone rubber (Afinis Precious regular body; Coltène/Whaledent) under the same dental loupes. A specimen would be excluded if the key parts (clasp arm, outer surface of abutment, and the joint of abutment and its retainer) were defective or if the silicone rubber remained at the location where the clasp and crown contacted.

Specimens were divided into 2 groups according to crown type: CC (Co-Cr alloy crowns–Co-Cr alloy clasps) and AC (Au-Ag-Pd alloy crowns–Co-Cr alloy clasps). Each group contained 5 pairs of specimens. The fatigue test was conducted by using a universal testing machine (Electroforce 3100; Bose Corp) under dry-air condition. The clasps were placed on the abutment teeth, which ensured that the occlusal rests were completely in contact with the rest seats and attached to the testing machine with the help of a clamping apparatus (Fig. 1). Each cycle consisted of the clasp being moved on and off the abutment, parallel to the long axis of the crown. The test was performed at 1 Hz for 15 000 cycles, which simulated 10 years of clinical use (inserting and removing the PRPD 4 times a day). The maximum values of the displacement forces were recorded in N. The test was terminated if a specimen fractured. The mean (standard deviation) values of force measurements at 100, 400, 800, 1500, 4500, 7500, 10 000, and 15 000 cycles were recorded. The differences of retention values between both groups were examined by using 2-way repeated measures ANOVA at 3 time points: initial 100 cycles, 7500 cycles, and 15 000 cycles (which represented baseline, middle, and final measurements). The change rates of retention values at key cycles compared with the initial 100 cycles’ retention were calculated by using the formula 

\[ P_Y = \frac{(Y_i - Y_0)}{Y_0} \times 100\% \]

where \( P_Y \) is the change rate, \( Y_i \) is the retention force and \( Y_0 \) is the mean retention value in the first 100 cycles. Statistical significance was set at \( \alpha = .05 \).

The surfaces of retention arm tips (0.2 cm in diameter) and the corresponding parts of the abutments were observed with scanning electron microscopy (×1000, S-4800; Hitachi) before and after the insertion-removal test.

![Clasps placed on abutment tooth for insertion-removal test.](image1)

**Mean changes in retention forces required to dislodge clasps of CC and AC groups at 100, 400, 800, 1500, 4500, 7500, and 15 000 cycles (bars indicate standard deviation).**

**Figure 1**
RESULTS

No specimens fractured during the test. Clasp retention altered with repeated insertion and removal (Fig. 2). Mean values of removal forces at 100, 400, 800, 1500, 4500, 7500, 10,000, and 15,000 cycles are recorded in Table II, and their corresponding change rates are compared with the initial force. In the CC group, mean force values decreased with cycles, whereas they increased in the AC group. Two-way repeated measures ANOVA revealed significant differences in retention values among different groups (Table III).

Representative scanning electron micrographs of clasps and crowns are shown in Figures 3, 4. Before the fatigue tests, the inner faces of Co-Cr alloy clasps were relatively smooth, except for some pits and protuberances (Figs. 3A, 4A). After 15,000 cycles of insertion and removal, Co-Cr alloy clasps exhibited grooves that were predominantly parallel to the sliding direction (Fig. 3B). Oval white patches were visible on the Co-Cr clasps in the AC group (see arrow in Fig. 4B). Irregular scratches were observed on the crowns (Figs. 3C, 4C). Shallow grooves as well as irregular-shaped pits appeared on Au-Ag-Pd alloy crowns after the fatigue test (see arrow in Fig. 4D).

DISCUSSION

Based on the results, the null hypothesis was rejected because differences were found in the retentive forces and abrasion patterns of Co-Cr alloy cast circumferential clasps applied to Au-Ag-Pd and Co-Cr alloys crowns during fatigue cycles.

Molars are ideal abutment teeth for PRPDs with good support and retention ability. Ahmad et al. found that 70% of PRPD retention is provided by molar abutments. Cast metal crowns are used extensively for molar restorations. In this study, the mandibular right first molar was chosen for the experiment. Given that the mesial contour of the crown is more concave at the cervical third than the distal, the occlusal rest seat distally and clasp tips mesially were designed to ensure clasp tips away from gingival margins, which benefit the periodontal health of abutments. When the occlusal rest was fully seated, the clasp was closely adapted to the abutment crown with restricted path of insertion.

Retention forces for cast clasps for PRPD should be approximately 5 N, provided by an undercut depth for Co-Cr clasps of 0.25 mm. Mahmoud et al. reported that Co-Cr clasps could survive more than 10^6 loading cycles without fracture under a 0.25-mm deflection. In the present study, there was no clasp fracture for either group. The initial retention forces were slightly higher than 5 N. The present test was conducted in a dry condition outside the oral environment, which may have contributed to the observed results because the lubricant action of saliva will reduce the coefficients of friction.

With repeated insertion and removal, different crowns affected clasp retention in different ways. According to the 2-way repeated measures ANOVA, clasp retention values in different test cycles were significantly influenced by groups (Table III). Co-Cr clasps lose their retention compared with the initial values on Co-Cr alloy crowns (Fig. 2), which decreased by 29.9% after 15,000 insertion-removal cycles. It did not meet clinical requirements at the end of testing when considering that the retention force was smaller than 5 N at 15,000 cycles (Table II). In contrast with the above result for the CC groups, an

| Table II. Retention force values and change rates of different groups at different cycle numbers |
|---------------------------------|---------------------------------|
| No. Cycles | CC Group | AC Group |
| Retention Force, N, mean (SD) | Change Rate (%) | Retention Force, N, mean (SD) | Change Rate (%) |
|---|---|---|---|---|
| 100 (approx. 1 mo of use) | 7.02 ± 1.36 | 7.74 ± 1.16 | 7.02 ± 1.36 | 7.74 ± 1.16 |
| 400 (approx. 3 mo of use) | 6.72 ± 1.44 | -4.3 | 10.92 ± 2.07 | 41.1 |
| 800 (approx. 0.5 y of use) | 6.58 ± 1.34 | -6.3 | 11.72 ± 2.63 | 51.4 |
| 1500 (approx. 1 y of use) | 6.37 ± 1.44 | -9.3 | 13.57 ± 3.44 | 75.3 |
| 4500 (approx. 3 y of use) | 6.06 ± 1.32 | -13.7 | 14.83 ± 2.27 | 91.6 |
| 7500 (approx. 5 y of use) | 5.69 ± 1.31 | -18.9 | 15.60 ± 3.71 | 101.6 |
| 10,000 (approx. 7 y of use) | 5.52 ± 1.31 | -21.4 | 15.70 ± 3.67 | 102.8 |
| 15,000 (approx. 10 y of use) | 4.92 ± 1.31 | -29.9 | 15.46 ± 3.58 | 99.7 |

SD, standard deviation; approx, approximately.

| Table III. Two-way repeated measures ANOVA of retention forces in AC and CC groups at 100, 7500, and 15,000 cycles |
|--------------------|--------------------|------------------------|--------------------|------------------------|
| Degrees of Freedom | Sum of Squares | Mean Square | F | P |
| Group | 1 | 373.6 | 373.7 | 33.5 | <.001 |
| Cycle | 2 | 62.4 | 31.2 | 11.4 | .001 |
| Group × cycle | 2 | 150.9 | 75.5 | 27.7 | <.001 |
| Between-subject error | 8 | 89.2 | 11.152 | |
| Within-subject error | 16 | 43.5 | 2.722 | |
| Total | 5 | | | |

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3 Scanning electron microscopy of contact surfaces of CC group. A, Cobalt (Co)–chromium (Cr) alloy clasp before test. B, Co-Cr alloy clasp after test. C, Co-Cr alloy crown before test. D, Co-Cr alloy crown after test (original magnification ×1000).

increase in force values was observed in the AC group (Fig. 2). The mean retention values doubled after the middle period of the test (Table II). The standard deviation values were greater in AC group specimens compared with CC group specimens (Fig. 2). This probably came from the surface finishing process of crown specimens. The percentage elongation and hardness represent the burnishability of a material. Au-Ag-Pd alloy, with lower hardness and higher ductility than Co-Cr alloy, is more prone to uneven dimensional changes during the finishing process. Other researchers also reported similar findings. Rodrigues et al postulated that the increases in force values were caused by prolonged cold working of the clasps and the strictly defined insertion path. Bridgeman et al hypothesized that the increase in delta values was due to work hardening of the metal. Nevertheless, no solid explanation of this phenomenon has yet been published. The differences between retention force change curves of the 2 groups also may be derived from some other factors, such as microstructural phases or mechanical properties as well as the wear and fatigue behaviors of these 2 casting alloys. The scanning electron microscopy showed the irregularly shaped pits on the Au-Ag-Pd alloy crown (arrow in Fig. 4D) and the oval white patches on the clasp (Fig. 4B), which were rarely observed in the CC group (Fig. 3). X-ray diffraction and metallographic testing should be performed in the future to determine the actual reasons of this difference.

It should be noted that this study was conducted in a dry-air condition, which was different from the oral environment. Saliva, hard metal debris, and electrochemical reactions between different metals could affect the outcomes of attrition and retention force values. Moreover, this study only involved certain alloy compositions. Different proportions of elements may affect mechanical properties of alloys and, consequently, their friction behavior. Furthermore, this study is limited to macroscopic property of these dental materials. Further research is needed to study the clinical conditions of clasps applied on different metal crowns and to explore the element exchange between the clasps and crowns, for example, by using energy dispersive x-ray spectroscopy to reveal microscopic friction characteristics.

CONCLUSIONS

Under the experimental conditions in this study, Co-Cr alloy crowns and Au-Ag-Pd alloy crowns performed in different ways when Co-Cr alloy circumferential clasps were applied on them. Crown designs should be changed, depending on the PRDP retainer (clasp) materials.

REFERENCES


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