A Comparative evaluation of fatigue behavior of removable partial denture alloys with and without heat treatment
Murali Ramamoorthi, Abdul Aziz Al Khuraif

Abstract
Aims: To compare the fatigue behavior of removable partial denture alloys with and without heat treatment. Material and Methods: A total of 35 specimens were casted and divided into 7 groups. The groups studied were low gold alloy, medium gold alloy, palladium alloy and cobalt chromium alloy group. One way deflection fatigue test was used to evaluate fatigue of alloys. The number of cycles required to fracture each specimen was recorded and subjected to statistical analysis. Results: More number of cycles required to fracture the heat treated noble alloys. The base metal alloy showed more fatigue resistance than low gold alloy but less than medium gold alloy and palladium alloy. Conclusion: Age hardening increases the fatigue resistance of noble alloys. Clinical Implications: The mechanical property of cast restorations can be modified by heat treatment of the alloys, and can improve the longevity of the restoration.

Key Words: Deflection Fatigue Test; Noble Alloys; Age Hardening; Heat Treatment

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Introduction
Removable partial denture retentive clasp arms must be capable of flexing and returning to original form and should satisfactorily retain prosthesis. In addition, claps should not unduly stress abutment teeth or be permanently distorted during service. In this respect gold alloys have been favored as claps compared with base metal alloys because of high yield strength and low moduli of elasticity. Noble alloys are capable of undergoing heat treatments to change their mechanical and physical properties. The heat treatments for gold alloys are generally classified into solution treatment and age hardening treatment. Age hardening is caused by several mechanisms such as phase transformation, precipitation and special decomposition of the alloy system.

The strain that is introduced by the change in crystal structure during phase transformation results in a significant increase in hardness, strength and reduction in ductility.(1) Clasps undergo permanent deformation and fatigue fracture under repeated flexures caused by denture insertion, removal and mastication. Permanent deformation and fatigue fracture are caused by the stress created in the clasp. The purpose of this in-vitro study was to compare the fatigue behavior of noble alloys with and without age hardening and base metal alloy.

Materials and Methods
The basic test specimen used was the prefabricated clasp wax pattern of dimension 15mm length and 10mm outer diameter similar to the studies done by Vallitu and Kokkonen.(2) The wax patterns were invested and casted using type IV noble alloys (Yellow Special, Pontor MPF, Ceradelta) and a cobalt chromium base metal alloy (metalloy cc) with a phosphate bonded investment. A total of five specimens for each alloy group were casted. The composition and material properties of the alloys used were shown in table-1 and table-2.

The casting procedures were determined following the manufacturer’s instructions for the alloys and investments. Heat treatment of the alloys was done based on manufacturer suggestions. Recovered castings were cleaned with airborne particle abrasion using 80 micron aluminium oxide particles.

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Manufacturer</th>
<th>Composition</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Metallor dental,</td>
<td>Au-41% Ag-44.9% Pd-1.7%</td>
<td>Phosphate bonded</td>
</tr>
<tr>
<td>special</td>
<td>Switzerland</td>
<td>Cu-11% &lt;1% Pt,Ru,Sn,Zn</td>
<td>investment</td>
</tr>
<tr>
<td>Pontor</td>
<td>Metallor dental,</td>
<td>Au-72% Ag-13.7% Pt-3.6%</td>
<td>Phosphate bonded</td>
</tr>
<tr>
<td>MPF</td>
<td>Switzerland</td>
<td>Cu-9.8% &lt;1% Zn,Ir</td>
<td>investment</td>
</tr>
<tr>
<td>Ceradelta</td>
<td>Metallor dental,</td>
<td>Pd-57.5% Ag-32% Ga-1.5%</td>
<td>Phosphate bonded</td>
</tr>
<tr>
<td></td>
<td>Switzerland</td>
<td>In-6% Sn-2% Zn-1%</td>
<td>investment</td>
</tr>
<tr>
<td>Metalloy</td>
<td>Metallor dental,</td>
<td>Co-61.5% Cr-27.5% W-8.6%</td>
<td>Phosphate bonded</td>
</tr>
<tr>
<td>CC</td>
<td>Switzerland</td>
<td>Si-1.3% &lt;1% Mn,N,Nb</td>
<td>investment</td>
</tr>
</tbody>
</table>

Table-1 Alloys studied
Results

The results were tabulated from table-3. The mean values were subjected to statistical analysis at 95% confidence level.

<table>
<thead>
<tr>
<th>Alloy groups</th>
<th>Mean cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow special[A1]</td>
<td>38640</td>
</tr>
<tr>
<td>Yellow special age hardened</td>
<td>52840</td>
</tr>
<tr>
<td>Pontor MPF[C1]</td>
<td>66480</td>
</tr>
<tr>
<td>Pontor MPF age hardened[D1]</td>
<td>66720</td>
</tr>
<tr>
<td>Ceradelta [E1]</td>
<td>67440</td>
</tr>
<tr>
<td>Ceradelta Age Hardened[F1]</td>
<td>71520</td>
</tr>
<tr>
<td>Metalloy CC[G1]</td>
<td>44640</td>
</tr>
</tbody>
</table>

Table-3 Mean Number of cycles required to Fracture special alloy specimens

Discussion

Material failures were divided to the sudden fracture and fatigue fracture. Sudden fracture occurs when a construction was loaded until it fractures with one bend. A fracture can also occur even if the stress is considerably lower than that required for the sudden fracture. Repeated stress cycles cause microscopic cracks mainly in the tension side of the construction and after a period of time a number of cracks had increased to such of size that a sudden fracture can occur even with a low stress level. Fatigue strength of the material was defined as the highest stress that the material can withstand.

Based on the loads required to deflection noble alloys would be clinically advantageous due to low rigidity when compared to base metal alloys which was expected to have a minimum possibility of traumatic overloading to the abutment tooth during insertion and removal. It was previously claimed that the cobalt chromium alloy could withstand a stress slightly above its proportional limit without fracture over infinitely many cycles. This was not seen in this study. Cobalt chromium showed fracture at average 44640 cycles which was less than palladium and higher than gold alloys. The testing method used in this study was a deflection of 0.6 mm, obviously; the magnitude of deflection was greater than the retention undercut of the tooth used clinically. It has been suggested that for an RPD with wrought-wire clasps, an undercut of 0.25 mm provides adequate retention. Later, after testing wrought metal wire clasps, Ikebe et al reported undercuts greater than 0.5 mm are too large for base metal wires. Because of relatively high modulus of elasticity, the cobalt-chromium alloy clasp should be used in retentive undercuts of less than 0.5 mm. The results revealed that a fatigue fracture occurred in the cobalt-chromium specimen after approximately 44,640 loading cycles, in the low gold alloy specimen after 38,640 loading cycles, in the medium gold alloy specimen after 66,720 loading cycles, and
in the palladium alloy specimen after 71520 loading cycles. It can be roughly estimated that the clasp of the RPD bends 10 times per day from insertion and removal of the RPD, which means that the clasp is affected by 3600 deflections per year.(7-9) Furthermore, mastication affects bending of the clasps and should also be considered. If no wearing of the retentive undercuts of the tooth is seen, metal fatigue may fracture the yellow special alloy after 11 years, age hardened yellow special alloy 14.5 years, Pontor MPF alloy after 18.5 years, and ceradelta after 20 years and metalloy CC after 12.4 years. Age hardened yellow special shows better fatigue resistance than cobalt chromium alloy. Age hardening showed a drastic change in the properties of low gold alloy, whereas it has slight influence in the other two noble alloys studied. This hypothesis, however, requires further verification. An important factor that affects the strength of an alloy is its grain structure. Bridgeport (3) examined the grain size of cobalt-chromium alloy at different locations on the RPD and found that the grain count decreased continuously from the clasp tip towards the sprue. The grain count in a clasp cross-section has been reported to be as low as two or three. On the other hand, in a cross-section of a gold alloy clasp there can be as many as 100 grains.(8) Fatigue fracture of material is influenced by many factors including the quality of surface finish, metallographic microstructure and presence of internal defects. Although fatigue fracture can occur in a highly polished specimen, the crack initiation process is considerably facilitated by surface roughness and irregularities. Surface irregularities like cold shuts and scratches act as stress raisers and most often become the sites of fatigue crack initiation.(9)

In this study specimens were not polished. Although the quality of surface finish might have influenced the fatigue resistance of noble alloys, such conditions apparently did not affect the base alloy specimen. Although no mechanical properties are directly related to the fatigue endurance of the materials, the effects of elastic modulus and ultimate tensile strength have been postulated. Studies by different authors have shown that fractures in high stress cantilevered portion of the fixed partial denture decreased when materials with higher modulus and tensile strength were used.(2) The longevity of cast prosthesis is an important dental concern for patient as well as dentist. Based on the loads required to deflection, noble alloys would be clinically advantageous due to low rigidity when compared to base metal alloys which is expected to have a minimum possibility of traumatic overloading to the abutment tooth during insertion and removal. It was previously claimed that the cobalt chromium alloy could withstand a stress slightly above its proportional limit without fracture over infinitely many cycles. In the present study noble alloys shows better longevity than base metal alloy. Further investigations should be conducted to determine whether inherent casting defects between alloys contribute to their fatigue behavior. Specimens were subjected only to vertical directed forces, clinically the forces are multidirectional. Hence the influence of these factors should be considered in future experiments before a more accurate evaluation can be made. Finally although a sample size (N=5) was used in the current study, significant differences were found between the different groups, indicating sufficiently large effect size.

**Conclusion**

In conclusion the noble alloys showed better longevity than base metal alloy. Further investigations should be conducted to determine whether inherent casting defects between alloys contribute to their fatigue behavior. Within the limitations of the study, a) age hardened yellow special alloy shows better fatigue resistance than cobalt chromium alloy and yellow special alloy without heat treatment, and the one way deflection fatigue test is a valuable tool to study the fatigue behavior.

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