Wear simulation effects on overdenture stud attachments

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The aim of this study was to evaluate wear effects on overdenture resilient attachments. Six commercially available attachments were investigated: ERA orange and white (EO and EW), Locator pink, white and blue (LRP, LRW and LRB) and OP anchor (OP). Five specimens were used for wear simulation while other two specimens served as controls. Fifteen thousands insertion-removal cycles were simulated. Dimensional changes and surface characteristics were evaluated using light microscopy and SEM, respectively. Sudden decrease of retentive force was characteristic for EO and EW attachments. Retentive force of Locator attachments fluctuated throughout the wear simulation period. Dimensional changes and surface wear was more expressed on plastic cores than on plastic rings of attachment males. Based on SEM analysis, some of the specimens obtained smoother surface after wear simulation. Mechanism of retention loss of resilient overdenture attachments can be only partially explained by dimensional changes and surface alterations.

Keywords: Overdenture attachment, Resilient attachment, Retentive force, Dimensional changes, Surface wear

INTRODUCTION

The advantages of mandibular overdentures over complete dentures are substantiated by many studies, which evaluate masticatory parameters, patient satisfaction and cost-effectiveness1-5). The remaining roots or implants are widely used to gain overdenture support, retention and stability6). Usually, two implants in interforaminal region are considered enough to provide adequate function of mandibular overdenture7,8). Retaining periodontally healthy roots or inserting implants may have a positive effect on residual ridges and mastication9).

Many types of overdenture attachments are employed to retain the prosthesis. Retention and stabilization of mandibular overdenture was found to be associated with patient satisfaction10). It is still disputable whether the stud or the bar attachments require more maintenance post-operatively11-13). Resilient stud attachments have gained popularity due to favorable stress distribution, simple procedure and easy aftercare14-16). However, loosening of the overdenture retentive mechanism was reported to be the most common prosthetic complication17). Therefore, routine maintenance is required to ensure successful long term outcomes12). Wear, surface alterations, plastic deformation and even breakage of attachment components resulting from functional and para-functional loads were addressed as possible causes of retention loss18). Besides objective reasons, attachment activation is also dependent on patient requests. Some authors reported that 55% of the clinician’s time would be involved in replacing retentive components19).

Many studies have addressed wear mechanisms of precision attachments20,21). Rapid loss of retentive force was accompanied by pronounced wear of metal surfaces. However, results of in vitro tests examining resilient attachments suggest that in contrast to plastic parts, metal surfaces virtually do not undergo dimensional changes or surface wear22). Many manufacturers provide different color-coded plastic parts, which suppose to ensure different levels of retention. Nevertheless, data is lacking on wear behavior and wear mechanisms of these parts. Furthermore, it is still debatable which type of material is less subjective to wear and allows maintaining constant retention of prosthesis. Few studies have investigated retentive force changes of resilient attachments during fatigue simulation23-25). However, there is little known about the relationship between retention loss, dimensional changes and surface wear patterns of these attachments26).

The objective of this study was to investigate wear of six types of commonly used overdenture attachments by measuring changes in retentive force and dimensions, and evaluating surface changes of plastic parts. The null hypothesis was that there is no difference between different types of attachments considering retentive force changes and effects of wear.

MATERIALS AND METHODS

Specimen preparation

Six commercially available attachments were investigated: ERA Overdenture orange and white (Sterngold, Attleboro, USA), Locator Root pink, white and blue (Zest Anchors, Escondido, USA), and OP anchor...
Two specimens from each group served as controls, while other five specimens were used for evaluation of retentive force, dimensional changes, and surface alterations of plastic parts. ERA and Locator attachments utilize metal females (fixed to implants or teeth) and plastic males (fixed to overdenture). Plastic males of ERA and Locator attachments provide dual retentive surfaces as plastic core and ring contact the female. While OP anchor is a traditional ball attachment with male attached to the implant or teeth and female (rubber ring) incorporated into the denture.

Females of locator attachments were prefabricated. Therefore, only ERA females and OP anchor males were cast from type IV gold alloy (Degulor M, Degussa Dental GmbH&Co., Hanau-Wolfgang, Germany) following instructions of manufacturers. Cast specimens were finished by sand blasting (ø50 µm glass beads, 0.2 MPa), and polished with silicone points (GC, Tokyo, Japan).

Metal females of ERA and Locator and males of OP anchor were glued by epoxy resin (Bond Quick 5, Konichi Co., Osaka, Japan) to the metal screws with 0° angle to their longitudinal axis. Plastic males were inserted into metal housings and rubber rings of OP anchor were embedded into metal rings by auto-polymerizing resin (Unifast Trad, GC) (Fig. 2).

### Measurement of retentive force changes
Retentive force changes were evaluated using five specimens of each type of overdenture attachment. Micromaterial testing machine (MMT-250NB-10, Shimadzu Co., Kyoto, Japan), sensor interface PCD-320 and software package PCD-30A (Kyowa Electronic Instruments Co., Tokyo, Japan) were used to simulate wear and to measure changes of retentive force simultaneously.

Screw with metal female was tightened to the end of specially designed jig. The counter part of the attachment

**Table 1** Characteristics of overdenture attachments evaluated in the study

<table>
<thead>
<tr>
<th>Attachment</th>
<th>Abbreviation</th>
<th>Manufacturer</th>
<th>Material Male</th>
<th>Material Female</th>
<th>Height and diameter (mm)</th>
<th>Retentive force indicated by manufacturer (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA Overdenture</td>
<td>EO Sterngold, Attleboro, USA</td>
<td>Nylon 66</td>
<td>Type IV gold alloy</td>
<td>3.3×4.3</td>
<td>Not available</td>
<td></td>
</tr>
<tr>
<td>ERA Overdenture</td>
<td>EW Sterngold, Attleboro, USA</td>
<td>Stainless steel with TiN coating</td>
<td>2.5×4</td>
<td>13.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locator Root (pink)</td>
<td>LRP Zest Anchors, Escondido, USA</td>
<td>DuPont Zytel 1011</td>
<td>22.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locator Root (white)</td>
<td>LRW Zest Anchors, Escondido, USA</td>
<td>NC-10 Nylon</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locator Root (blue)</td>
<td>LRB Inoue Attachments Co., Tokyo, Japan</td>
<td>Acrylonitrile-butadiene rubber</td>
<td>4.5×5</td>
<td>Not available</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 1** Schematic representation of cross sectional images of tested attachments. a: female, b: male, c: metal case, d: plastic ring, e: plastic core.
was seated on the top of the metal female. The jig with built-in shock-absorbing mechanism was attached to the load cell of wear simulation machine by means of magnetic retainer. Then the metal ring containing plastic male or rubber ring of attachment was secured to the bottom of the bath attached to the lower member of wear simulation machine. The bath was filled with 37°C demineralized water to imitate lubricating effect of saliva (Fig. 2).

Fifteen thousands insertion-removal cycles were performed using 50 mm/min speed and 2.5 mm dislodgement range (0.17 Hz). Three measurements of maximum retentive force (N) were measured and averaged initially and after each 100 cycles using 100 Hz sampling rate.

**Measurement of dimensional changes**

In order to evaluate dimensional changes 2 randomly selected specimens which underwent 15,000 insertion-removal cycles and 1 control (new) specimen were precisely centered in the plastic ring and fixed by filling it with transparent low shrinkage heat-curing epoxy resin (EpoHeat, Buehler Ltd., Lake Bluff, USA). After completion of curing specimens were attached to the specially designed jig, which allowed to cut the specimens longitudinally through the exact center with low-speed diamond saw (Isomet 1000; Buehler Ltd.) using oil irrigation (Fig. 3). The cut line was shifted outside to compensate for the thickness of the saw. Sectioned surface was polished by ultra-fine polishing paper.

Light traveling microscope (MM-60, Nikon, Tokyo, Japan) was used to measure test and control specimens. Three dimensions (mm) were evaluated: A–diameter of plastic core; B–inner diameter of plastic ring; C–inner diameter of metal housing (Fig. 4). Due to different design of OP, only inner diameter of rubber ring was possible to evaluate (B dimension). Each specimen was measured 3 times. Dimensions of the attachments after wear test were compared with the dimensions of the controls.

**Scanning electron microscopy (SEM) evaluation of surface wear**

After performing 15,000 insertion-removal cycles another two attachments were randomly selected for qualitative surface wear evaluation. Surface changes detected on plastic parts of these attachments were compared with surfaces of control specimens. For this purpose, plastic attachment parts of test and control groups were removed from the metal rings and cut by sharp blade along their longitudinal axes. Afterwards, the plastic cores were separated from the plastic rings. Therefore, wear of plastic core surface and plastic ring inner surface could be investigated. Rubber ring of OP...
anchor was cut longitudinally into two parts. Sectioned parts were prepared for the SEM evaluation according to the standard technique. Images were captured using 50, 100 and 200× magnifications using SEM equipment (S-4500, Hitachi Ltd., Tokyo, Japan) and evaluated.

Statistical analysis
Descriptive statistics were used to calculate means and standard deviations for the maximum retentive force and dimensional changes. Multiple comparisons were made by one-way ANOVA and Scheffe post-hoc tests. Retentive force values and dimensions before and after wear simulation were compared by paired-samples t-test. The level of statistical significance was set at $p<0.05$.

RESULTS
All attachments tested in the study had significantly different ($p<0.05$) mean values of maximum retentive force. As a result of wear simulation, retentive force and dimensions have changed, though some of these changes were not statistically significant.

Maximum retentive force changes before and after wear simulation are presented in Fig. 5 and Table 2. As for EO and EW sudden decrease of retentive force followed by more constant period (retentive force of around 3N) was characteristic. EO and EW attachments retained only 22–23% of their initial retentive force. Retentive force values for LRP, LRW and LRB alternated: after initial decrease, moderate increase in retentive force was recorded. However, at the end of the test retentive force of Locator attachments decreased from 21% to 62%. Most sensitive to wear simulation among Locator attachments was LRB. Unexpectedly, retentive force of OP increased slightly throughout all testing period, though this change was not statistically significant. Results of multiple comparisons after wear simulation are presented in Table 2.

Dimensional changes of plastic parts and metal housings of attachments were analyzed at the end of fatigue test (Table 3). As for dimension A (diameter of plastic core) wear effects were evident with all types of attachments. Decrease in this dimension was found to be up to 5%. Diameter of inner plastic ring (dimension B) decreased in all groups except EW (0.01 mm increase). Wear simulation induced only minimal changes in inner diameter of metal cases (dimension C).

SEM examination revealed surface characteristics before and after wear simulation (Fig. 6). Wear on both plastic core and inner surface of plastic ring were detected in EO, EW, LRW, LRP and LRB attachments. Wear effects were more notable on surfaces of plastic cores (Fig. 6a–b; 6i–j) than on plastic rings (Fig. 6c–h). After wear simulation scratches along the path of insertion were seen on inner surfaces of plastic rings. Relatively smoother surfaces were obtained by EO and EW, whereas particle loss and irregular surface were characteristic changes for Locator attachment. As for OP attachments, loose particles that could be seen on the surface initially were lost after wear simulation.

DISCUSSION
Proper support, retention, stability, long time service, ease of maintenance, and reasonable cost are among the big number of requirements overdenture attachments have to fit to. Therefore, so far there is no any straightforward advice on which type of overdenture attachment is superior. Despite the popularity of resilient overdenture attachments, there are a limited number of studies, which have related retentive force changes and wear effects. There is clinical and research
Fig. 5  Graphical representation of retentive force changes (N) during axial loading (15,000 cycles).

Table 2  Changes of retentive force before and after fatigue simulation (Standard deviations are indicated in parentheses). ERA orange and white–EO and EW, Locator pink, white and blue–LRP, LRW and LRB, OP anchor–OP

<table>
<thead>
<tr>
<th></th>
<th>Before (N)</th>
<th>After (N)</th>
<th>Abs. change (N)</th>
<th>Change (%)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO</td>
<td>12.63 (1.4)</td>
<td>2.86 (0.5)</td>
<td>9.77</td>
<td>22.64</td>
<td>0.000</td>
</tr>
<tr>
<td>EW</td>
<td>13.12 (3.3)</td>
<td>2.89 (0.7)</td>
<td>10.23</td>
<td>22.03</td>
<td>0.001</td>
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<tr>
<td>LRP</td>
<td>15.20 (6.9)</td>
<td>11.95 (3.5)</td>
<td>3.25</td>
<td>78.62</td>
<td>0.359</td>
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<tr>
<td>LRW</td>
<td>16.61 (2.2)</td>
<td>10.28 (3.9)</td>
<td>6.33</td>
<td>61.89</td>
<td>0.075</td>
</tr>
<tr>
<td>LRB</td>
<td>16.50 (9.4)</td>
<td>6.24 (6.1)</td>
<td>10.26</td>
<td>37.82</td>
<td>0.062</td>
</tr>
<tr>
<td>OP</td>
<td>3.15 (0.6)</td>
<td>3.70 (0.2)</td>
<td>−0.55</td>
<td>117.46</td>
<td>0.144</td>
</tr>
</tbody>
</table>

* — bars connect not significantly different groups after wear simulation (p<0.05).

Table 3  Dimensional changes of attachment parts before and after wear simulation. ERA orange and white–EO and EW, Locator pink, white and blue–LRP, LRW and LRB, OP anchor–OP

<table>
<thead>
<tr>
<th></th>
<th>EO</th>
<th>EW</th>
<th>LRP</th>
<th>LRW</th>
<th>LRB</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>A</td>
<td>Before (mm)</td>
<td>2.02</td>
<td>0.00</td>
<td>2.06</td>
<td>0.00</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>After (mm)</td>
<td>1.97</td>
<td>0.03</td>
<td>2.00</td>
<td>0.00</td>
<td>2.07</td>
</tr>
<tr>
<td></td>
<td>Abs. change (mm)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Change (%)</td>
<td>97.52</td>
<td>99.01</td>
<td>94.66</td>
<td>97.64</td>
<td>100.00</td>
</tr>
<tr>
<td>B</td>
<td>Before (mm)</td>
<td>3.54</td>
<td>0.00</td>
<td>3.54</td>
<td>0.00</td>
<td>3.81</td>
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<tr>
<td></td>
<td>After (mm)</td>
<td>3.51</td>
<td>0.01</td>
<td>3.55</td>
<td>0.00</td>
<td>3.76</td>
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<td>Abs. change (mm)</td>
<td>0.03</td>
<td>−0.01</td>
<td>0.05</td>
<td>0.00</td>
<td>0.08</td>
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<tr>
<td></td>
<td>Change (%)</td>
<td>99.15</td>
<td>100.28</td>
<td>98.69</td>
<td>97.91</td>
<td>99.21</td>
</tr>
<tr>
<td>C</td>
<td>Before (mm)</td>
<td>4.51</td>
<td>0.00</td>
<td>4.48</td>
<td>0.00</td>
<td>4.56</td>
</tr>
<tr>
<td></td>
<td>After (mm)</td>
<td>4.50</td>
<td>0.03</td>
<td>4.52</td>
<td>0.01</td>
<td>4.52</td>
</tr>
<tr>
<td></td>
<td>Abs. change (mm)</td>
<td>0.01</td>
<td>−0.04</td>
<td>0.04</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Change (%)</td>
<td>99.78</td>
<td>100.89</td>
<td>99.12</td>
<td>99.78</td>
<td>100.44</td>
</tr>
</tbody>
</table>
evidences that retentive properties of overdenture attachments tend to change with time. Wear-induced loss of retention in attachment-retained dentures poses a major clinical problem; thus, routine maintenance is required to ensure successful long-term outcomes\textsuperscript{27}. Some studies have shown that, in contrast to metal parts, only plastic parts of resilient attachments were affected by wear\textsuperscript{22}. As wear of resilient overdenture attachments adversely affects function, maintenance aspects, and patient satisfaction the burden of maintenance of plastic parts is paramount for the clinician. The choice of an attachment type essentially depends on which design provides the least wear, i.e. long functional life.
In this study 15,000 of continuous insertion-removal cycles in axial direction were used to simulate wear of overdenture attachments. Different authors tried to relate simulated insertion-removal cycles with in vivo service years. According to Besimo and Guarneri 10,000 insertion-removal cycles in vitro corresponds with a time in use of about 9 years. Gamborena et al. considered that 5,500 placement-removal cycles can simulate 3 years of in vivo wear based on an average of five placements and removals daily. However, overdenture attachment parts have to be replaced more often than in vitro studies indicate. Therefore, 15,000 cycles were used in this study, as it is believed to be sufficient number of cycles to achieve changes in attachment retention and to simulate wear. Wear of attachments appears mainly through friction between the matrix and patriarch. As film of saliva between corresponding parts of attachment acts as a protective layer and lubricant that modifies wear, specimens were immersed in demineralized water at 37°C.

After 15,000 insertion-removal cycles all attachments, except OP, exhibited loss in retention. However, decrease in retention of EO and EW was pronounced (87–88%) and statistically significant. ERA attachments have several types of color-coded plastic males, which are classified from having "light retention" (white) to "most retention" (red). Stronger retention is gained through oversizing the plastic males. The EO and EW are considered as having "weak retention". As different plastic males are made from the same material, similar wear patterns could be expected for other color-coded males. The study comparing wear behavior of ERA attachments have reported similar decrease in retentive force (85–88%) for all types of plastic males. Maximum retentive force for both ERA attachments decreased rapidly. This continued until approximately 2000 cycles when ERA attachments obtained more constant retentive force which unchanged till the end of the test. Retention of EO and EW after wear simulation was 2.86 N and 2.89 N respectively. There was no statistically significant difference between EO and EW at the end of the test.

Initially, LRP, LRW and LRB attachments had very variable retentive force (SD: 2.2–9.4 N) to compare with EO, EW and OP (SD: 0.6–3.3 N). This tendency could be noticed after wear simulation as well. After wear simulation Locator attachments preserved from 38% to 79% of initial retentive force. The highest decrease in retention was noticed for LRB, while LRP preserved most of its retention. There was no statistically significant difference between LRW and LRP at the end of the test. Retention of LRP and LRW attachments after wear simulation were close to that indicated by the manufacturer. In contrast to this, retention of LRW after wear simulation was approximately two times less (10.3 N) comparing with manufacturer’s data (22.2 N). Results indicate that different color coded males may not necessarily provide significantly different retention. Retentive force of OP was considerably lower initially, but after wear simulation no statistically significant difference was found between retention of OP and EO groups. Lower retentive force of OP could be attributed to the relatively soft rubber ring.

As level of retention of ERA and Locator attachments is achieved through different sizes of males, dimensional changes of them can influence retentive properties. Plastic cores (dimension A) underwent wear in all groups of attachments (Table 3). However, the dimensional changes of plastic cores were not correlated with retentive force changes (p>0.05). For example, highest decrease in retention was characteristic for EW and EO groups, but the plastic cores underwent similar dimensional changes as Locators. Plastic ring of male is designed to provide guiding surfaces and stability for ERA attachments. In turn, plastic ring of Locator engages undercuts on female supplementing retention from plastic core. Unexpectedly, dimensions of the inner diameter of the plastic ring (dimension B) decreased up to 2.1%. Expected increase in dimension B was recorded only in EW group. It is difficult to relate dimensional changes of diameter of inner plastic rings with changes of retentive force, because appropriate space is provided between plastic male and metal housing to ensure resiliency (e.g. 0.4 mm in ERA attachments). Decrease of inner diameter of rubber ring in OP group was found. This finding can partially explain the slight increase in retention of OP during wear simulation. Minimal changes of inner diameter of metal housings (in the range of 0.9%) were characteristic for all attachment groups. These changes most probably had negligible influence on retentive force changes.

Along with friction, water absorption and/or thermal expansion can contribute to the dimensional changes of plastic parts as well. Shock absorbing jig was used in this study to prevent plastic deformation of resilient parts. Conversely, in vivo functional and parafunctional movements can lead to plastic deformation of attachment, resulting in clinically detectable reduction of retentive forces or even breakage of attachment.

According to results of SEM analysis, distinct surface wear patterns were characteristic for the different types of attachments (Fig. 6). Wear effects on ERA’s core (Fig. 6a,b) were more visible than on the inner surface of the plastic ring (Fig. 6c,d). Inner surface of the plastic ring before wear simulation was finely grained (Fig. 6c) and later became smoother with small lines orientated along the path of insertion (Fig. 6d). As for Locator attachments surface initially had smooth character with obscure lines orientated perpendicularly to the longitudinal axis which most probably were formed during manufacturing process (Fig. 6e,g). However, few surface irregularities and defects were also detected at the baseline (Fig. 6i,k). As a result of wear Locator attachments produced surface with more irregularities and particle loss (Fig. 6j). Different wear patterns of ERA and Locator attachments could be explained by different types of nylons used to fabricate plastic males. Though wear effects were relatively more expressed on Locator plastic males retentive force decreased less than with ERA attachments. Therefore, relationship between...
qualitatively evaluated surface wear and retentive force was not observed.

Smoothed surfaces of OP attachment (Fig. 6l) could partially explain gain in retentive force recorded during wear simulation.

Disagreement between clinical findings and in vitro fatigue tests indicates that wear cannot be adequately simulated using currently available in vitro approach. Minimal displacement of overdenture in three dimensions during function, implant angulation, effects of denture cleaners, foods, ageing of plastic males and fatigue of metal parts were addressed as possible causes of this disagreement. Currently, due to extreme complexity of simulation of clinical conditions, results of in vitro experiments should be taken as guidance.

CONCLUSIONS
Within the limitations of this study the following conclusions may be drawn:
1. After 15,000 insertion-removal cycles resilient attachments lost from 21% to 80% of their initial retentive force;
2. Dimensional changes of plastic cores and plastic rings were more expressed than that of metal housings ranging from −2.5% to 0.4%;
3. Based on SEM analysis wear of plastic cores was evident, whereas only minor scratching and smoothening of the surfaces of inner plastic rings were visible;
4. Change in retentive force of overdenture attachments can be only partially explained by dimensional changes and surface alterations;
5. Different color-coded plastic males do not necessarily provide significantly different levels of retention;
6. Further studies are needed to investigate wear mechanisms of overdenture attachments more properly.

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