Fixation of magnet assembly to denture base using alternative resins

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The fixation strengths between conventional/modified magnetic assemblies and denture base resins were evaluated using six alternative resins. Magnetic assemblies with three different undercut wings were prepared. Soft lining materials with added PMMA resin polymer, two photopolymerization denture relining resins, an experimental resin, and a temporary filling resin were used to fix the magnetic assemblies to the denture bases. As a control, a commercially available magnetic assembly without undercut wings and a conventional autopolymerized resin were also prepared. After surface treatments, the magnetic assemblies were fixed using fixation resins, and tensile strengths and attractive forces were measured using an autography. The experimental resin and the temporary filling resin showed retentive forces comparable to those of conventional autopolymerized resins. Although the experimental resin demonstrated satisfactory fixation strengths, it should be necessary to improve its mechanical strength. The temporary filling resin could be used as a permanent fixation material.

Keywords: Modified magnetic assembly, Undercut, Alternative resins, Fixation, Denture base

INTRODUCTION

Magnetic attachments have been widely used as stud attachments for root- and implant-retained overdenture rehabilitation1-3. Since a great quantity of basic and clinical research has been reported for approximately a quarter of a century, the reliability of magnetic attachments has been improved4,5. Particularly, commercially available magnetic attachments made in Japan are remarkably high performing with a small size and a great attractive force; thus, approval from the International Standardization Organization (ISO13017) was obtained in 20126.

Magnetic attachments have many advantages, including the following: 1) the attractive force is difficult to decrease, 2) the denture is easy to insert/remove, 3) the crown-root ratio is improved, 4) harmful lateral force is reduced, and 5) wider application ranges are possible7-8. It is an especially important phenomenon that the pressure burden can be decreased when the magnetic assembly is slid on the root and implant with the application of lateral forces9,10. In contrast, weakness of the mechanical strength of the denture base on the magnetic attachments and uncleanliness around the abutment teeth have been identified as disadvantages8. Consequently, complications such as the following might easily occur: 1) denture breakage, 2) removal of the magnetic assembly, 3) gingival retraction, and 4) decreased attractive force11,12. In addition, one of the problems that can be overlooked is difficulty in fixing the magnetic assembly to the denture base chairside13,14. If not adequately fixed, the attractive force will decrease greatly15.

In general, the magnetic assembly has been directly fixed to the denture base with autopolymerized polymethyl methacrylate (PMMA) resin using the brush-on technique after the magnetic assembly is placed on the keeper of the abutment tooth or implant. However, special care must be taken during the fixation because the denture may become impossible to remove from the abutment teeth or implant due to the PMMA resin's hardening within the undercut around the keeper; additionally, the attractive force of the magnetic attachment may be decreased due to displacement of the correct position between the keeper and the magnetic assembly by polymerization shrinkage of the PMMA resin15,16. To resolve this problem, custom resin and metal housings have been developed to make the procedure more effective17. Using the housings, the magnetic assembly can be fixed in the correct position on the keeper with a little autopolymerized resin, and the appropriate attractive force can be obtained. However, the housings need more space than does the conventional direct fixation method, requiring increased work in the laboratory. Easy handling in fixing the magnetic assembly has been keenly desired so that successful overdenture rehabilitation can be achieved using magnetic attachments18. As one possible solution, alternative fixation materials should be used so that the denture, including the magnetic assembly, can be removed from the keeper after it is mostly polymerized.

Moreover, the removable denture sinks slightly (approximately 100 µm) for about two weeks after delivery because the soft tissue under the denture base is deformed by masticatory loading19-21. Thus, temporary fixation materials should be used for the fixation of magnetic attachments at the time of denture delivery. After the denture is completely settled, temporary fixation materials should be exchanged for permanent ones.

Ideally, greater fixation strengths of the magnetic assembly as well as the PMMA resin and slight elasticity...
so that the denture could be removed even if the fixation resin was hardened within the undercut would be necessary properties of alternative fixation resins. However there have been no reports about any fixation resins except PMMA resin. The aim of this study has been to investigate the fixation strengths of magnetic assemblies to denture bases using alternative resins rather than conventional PMMA autopolymerized resin without housing. The magnetic assembly was modified to add several undercuts to improve mechanical retention. As alternative resins, seven temporary and permanent fixation materials were evaluated as to their fixation strengths and attractive forces after surface treatment, both initially and after repeated insertion/removals. It was null hypothesized that the temporary fixation materials as alternative resins would not influence the fixation strength of magnetic assembly and the change in the attractive force compared to conventional PMMA resin.

MATERIALS AND METHODS

Specimen fabrication

1. Modified magnetic assembly
To evaluate the effectiveness of mechanical retention in this study, a commercially available magnetic assembly (PHYSIO MAGNET 35, Neomax, Gunma, Japan; diameter: 3.5 mm; thickness: 0.8 mm; attractive force: approximately 5.5 N) was modified by adding three different undercut wings [wing diameter (undercut): 4.5 mm (0.5 mm), 4.8 mm (0.65 mm), and 5.5 mm (1.0 mm)] (Fig. 1). The same stainless steel (SUSXM27) alloy was used for wings and was laser-welded to the yoke of the magnetic assembly. A conventional magnetic attachment (PHYSIO MAGNET 35) of the same size without undercut wings was compared as a control.

2. Fixation materials
Table 1 shows the temporary and permanent fixation materials used in this study as alternative resins for fixing the magnetic assembly to the denture base. As a temporary fixation material, a soft lining material (SOFT LINER, GC Corp., Ltd, Tokyo, Japan) at a standard powder/liquid ratio (SL), a polymer increased to 1.5 times the manufacturer’s recommendation (1.5 SL), and two types of photopolymerization denture relining resins (TOKUSO LITE REBASE (TO), Tokuyama Dental; and MILD REBARON (RE) LC, GC Corp., Ltd) were selected for fixation. A combination of soft and hard resins, in which 40% autopolymerized PMMA resin (UNIFAST III, GC Corp., Ltd) was added to a 60% soft lining material (SOFT LINER) polymer, was also used for a temporary fixation material. As permanent fixation materials, an experimental resin (70% Polyethylene glycol dimethacrylate 23G and 30% MMA in the monomer, 20% Polybuthylmethacrylate and 80% PMMA in the polymer), a temporary filling resin (Dura Seal, Reliance Dental Mfg Co., Worth, IL, USA), and an autopolymerized PMMA resin (UNIFAST III) were used. Dura seal was selected because of its slight elasticity and appropriate solidity, and for expecting greater fixation strength and possibility of remove even if it was hardened within the undercut.

3. Fixation of the magnetic assembly
A metal primer (Alloy Primer (AP), Kuraray Co., Ltd, Tokyo, Japan) or a bonding material (Super-Bond (SB), Sun Medical Co., Ltd, Shiga, Japan) was applied on the surface of the magnetic assembly, including undercut wings, for the soft lining material. For the other fixation materials, SB was applied. Magnetic assemblies were bonded to the lower jig using a cyanoacrylate adhesive (ARON ALPHA, Toagosei Co., Ltd, Tokyo, Japan) for tensile testing. For testing repeated insertion/removal, the keeper was mounted in the lower jig, and the magnetic assembly was placed on the keeper without a cyanoacrylate adhesive. After the polymers and monomers of the fixation materials were mixed, they were applied to the magnetic assembly and poured into the housing in the upper jig (Fig. 2). The housing was placed on the magnetic assembly, and they were kept for 10 min. Two photopolymerization denture relining resins were used without photo irradiation for temporary fixation.

Measurement of fixation strengths

1. Tensile testing
Upper and lower jigs that included magnetic assemblies were mounted with fixation materials on the screw-driven autograph (EZ-S 200N, Shimadzu, Kyoto, Japan). To evaluate the fixation strength of the magnetic assembly using each temporary and permanent fixation material, tensile testing was performed at a crosshead speed of 1.0 mm/min (Fig. 3). The maximum loads when the magnetic assemblies were separated from the housing using each fixation material were recorded as the fixation strengths. Five specimens were fabricated for each condition; in
Table 1  Alternative temporary and permanent fixation materials and surface treatment materials

<table>
<thead>
<tr>
<th>Fixation materials</th>
<th>Trade name</th>
<th>Abbreviation</th>
<th>Lot</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft lining material</td>
<td>SOFT LINER</td>
<td>SL, 1.5SL</td>
<td>1303072</td>
<td>GC, Tokyo, Japan</td>
</tr>
<tr>
<td>Photopolymerization denture relining</td>
<td>TOKUSOLITE REBASE</td>
<td>TO</td>
<td>0050003P</td>
<td>Tokuyama Dental, Tokyo, Japan</td>
</tr>
<tr>
<td></td>
<td>MILD REBARON</td>
<td>RE</td>
<td>1311141</td>
<td>GC, Tokyo, Japan</td>
</tr>
<tr>
<td>Combination of soft and hard resins</td>
<td>40% Uni fast III</td>
<td>SHR</td>
<td>1406161</td>
<td>GC, Tokyo, Japan</td>
</tr>
<tr>
<td></td>
<td>60% SOFT LINER</td>
<td></td>
<td>1303072</td>
<td></td>
</tr>
<tr>
<td>Experimental resin</td>
<td>PMMA resin adjusted</td>
<td>ER</td>
<td>140146</td>
<td></td>
</tr>
<tr>
<td>Temporary filling resin</td>
<td>Dura Seal</td>
<td>DS</td>
<td>0120140210</td>
<td>RELIANCE, Worth, IL, USA</td>
</tr>
<tr>
<td>Autopolymerized PMMA resin (conventional resin)</td>
<td>UNI FAST III</td>
<td>—</td>
<td>1406161</td>
<td>GC, Tokyo, Japan</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface treatment materials</th>
<th>Trade name</th>
<th>Abbreviation</th>
<th>Lot</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding material</td>
<td>Super-Bond</td>
<td>SB</td>
<td>GG1</td>
<td>Sun Medical, Shiga, Japan</td>
</tr>
<tr>
<td>Metal primer</td>
<td>Alloy Primar</td>
<td>AP</td>
<td>00358A</td>
<td>Kuraray, Tokyo, Japan</td>
</tr>
<tr>
<td>No treatment</td>
<td>—</td>
<td>Non</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2  Fixation of magnetic assembly for each test.

Fig. 3  Autography used for tensile testing.

total, 180 specimens were prepared.

2. Repeated insertion/removal testing
To evaluate the resistance to removing the magnetic assembly from the denture base as compared to the conventional PMMA resin, the specimens were measured using permanent fixation materials. As with tensile testing, upper and lower jigs were mounted on the repeated insertion/removal testing machine designed by Tsurumi University School of Dental Medicine (JM100-T, Japan Mecc., Tokyo, Japan) (Fig. 4). Similar to insertion/removal of the denture, repeating the tensile and compressive motions (crosshead speed: 950 mm/min.) was performed for up to 10,000 cycles. After 10,000 cycles, the magnetic assembly was bonded to the keeper using cyanoacrylate adhesive. The fixation strengths were measured using the tensile testing
Measurement of attractive forces
The initial attractive force of the magnetic attachment using a permanent fixation material was determined for the mean of the attractive force during the first 10 insertion/removal cycles. To evaluate changes in the attractive force, the averages of the attractive forces during each cycle from 1 to 10, namely, during the 1,001–1,010, 2,001–2,010, 3,001–3,010, 4,001–4,010, and each 1,000-cycle skip up to the 10,001–10,010 cycle, were measured and calculated. Eleven sets of average data, including initial attractive forces, were compared for each fixation material.

Statistical analysis
The data of fixation strengths and attractive force were analyzed with the SPSS statistical package (Version 12.0, SPSS Inc., Tokyo, Japan). After 2-way ANOVA and Tukey’s multiple comparison test were performed at a significance level of α=0.05.

RESULTS
Fixation strength
Table 2 depicts the fixation strengths of the magnetic assembly with three undercut wings using a temporary fixation material. Of the surface treatments of the magnetic assembly that used soft lining material in the standard P/L ratio and 1.5 times the amount of polymer, Super-Bond tended to have higher fixation strengths without significant differences than did the Alloy Primer and without a primer (p>0.05). Although all modified magnetic assemblies without surface treatment demonstrated significantly higher fixation strengths than did those without undercut (p<0.05), three different undercuts showed similar fixation strengths (p>0.05). Polymer at 1.5 times the amount demonstrated fixation strengths 1.2–1.5 times higher than those that used the standard P/L ratio. Of the 4.8-mm and 5.5-mm wings, a combination of soft and hard resins displayed significantly greater fixation strengths than did those for TOKUSO REBASE and MILD REBARON LC (p<0.05). Two photopolymerization denture relining resins showed similar fixation strengths in spite of the undercut wings (p>0.05).

Figure 5 shows the fixation strengths of magnetic assemblies using permanent fixation material, both initially and after 10,000 cycles. The fixation strengths of a temporary filling resin (Dura Seal) with a 4.5-mm undercut wing and conventional PMMA resin could not be measured because the magnetic assembly was separated from the lower jig without failure between the magnetic assembly and the fixation resin. Without the undercut wing, the temporary filling resin demonstrated higher fixation strengths than did the experimental with a 8 (temporary and permanent fixation materials) by 4 (amount of undercuts including control), 1-way ANOVA and Tukey’s multiple comparison test were performed at a significance level of α=0.05.

Table 2  Fixation strengths of magnetic assembly with three undercut wings using temporary fixation materials (Mean (SD), Unit: N)

<table>
<thead>
<tr>
<th>Fixation material</th>
<th>Surface treatment</th>
<th>0 mm (Control)</th>
<th>4.5 mm</th>
<th>4.8 mm</th>
<th>5.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL</td>
<td>SB</td>
<td>8.7 (2.2)a</td>
<td>11.7 (3.9)a</td>
<td>11.4 (1.8)a</td>
<td>11.2 (3.1)a</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>6.9 (2.4)a</td>
<td>9.9 (4.0)a</td>
<td>9.9 (3.7)a</td>
<td>10.4 (0.8)a</td>
</tr>
<tr>
<td></td>
<td>Non</td>
<td>5.3 (1.4)</td>
<td>8.4 (1.7)a</td>
<td>8.6 (1.5)a,b</td>
<td>9.6 (1.3)a,b</td>
</tr>
<tr>
<td>SL</td>
<td>SB</td>
<td>9.8 (1.9)a</td>
<td>12.0 (3.7)a</td>
<td>13.6 (1.0)a,b</td>
<td>17.1 (2.2)a</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>8.5 (1.9)a</td>
<td>10.8 (2.5)a,b</td>
<td>12.6 (2.1)a,b,c</td>
<td>13.7 (3.4)a,b,c</td>
</tr>
<tr>
<td></td>
<td>Non</td>
<td>6.3 (2.2)a</td>
<td>9.9 (4.3)a</td>
<td>11.4 (3.3)ac</td>
<td>12.2 (3.5)ac</td>
</tr>
<tr>
<td>TO</td>
<td>SB</td>
<td>8.6 (0.8)a</td>
<td>8.7 (1.0)a</td>
<td>9.4 (0.4)a,b</td>
<td>10.4 (0.6)b</td>
</tr>
<tr>
<td>RE</td>
<td>SB</td>
<td>8.0 (1.8)a</td>
<td>8.1 (1.5)a</td>
<td>9.5 (0.6)a</td>
<td>9.9 (0.9)a</td>
</tr>
<tr>
<td>SHR</td>
<td>SB</td>
<td>9.2 (2.0)a</td>
<td>10.9 (0.8)a</td>
<td>14.1 (1.3)</td>
<td>17.7 (0.9)</td>
</tr>
</tbody>
</table>

*a Same superscript letters in same raw indicate no significant difference (p>0.05).
Changes in attractive forces
Figures 6 and 7 show changes in the attractive forces of the magnetic attachments when using permanent fixation materials with and without the undercut wing, respectively. Without the undercut wing, the magnetic assembly was removed in one of five experimental resin specimens. There were no significant differences in the attractive forces with and without undercuts ($p>0.05$). Conventional acrylic resin and temporary filling resins showed greater constant attractive forces (within 4 N to 5 N) up to 10,000 insertion/removal cycles. Although the initial attractive force of the experimental resin was similar to the others both with and without the undercut wing, a remarkable decrease was shown at 1,000 cycles, keeping constant attractive forces at 2,000 cycles.

DISCUSSION
Fixation strengths would depend on both the adhesive strength and the mechanical retention between the magnetic assembly and the fixation materials (29,30). In the present study, application of a conventional metal primer and Super-Bond was examined to investigate the effectiveness of the adhesive strength. Using soft lining material, Super-Bond’s fixation strength tended to be higher than that of the metal primer. However, interface failure was observed between soft lining material and the magnetic assembly or Super-Bond. To increase mechanical retention, three sizes of undercut wings were added to the commercially available magnetic assembly (PHYSIO MAGNET 35) in this study. Fixation strengths increased when temporary fixation materials were used with undercut wings, and cohesive failure was observed. However, no contribution was elucidated by undercut wings when permanent fixation resins were used. Placing wings requires more space within the denture base on the keeper. When using a magnetic assembly without wings, a temporary filling resin would be recommended in cases with little space for dentures. Alternatively, photopolymerization denture relining resins are used without photoirradiation for temporary fixation. After completely settled, it will be completely polymerized by photoirradiation. These results confirm that, with undercut wings, these materials could be used for the temporary fixation of magnetic assemblies until dentures settle.

Regarding the experimental resin, polyethylene glycol (PEG) dimethacrylate 23G and polybutylmethacrylate were prepared for flexibility and expanded the polymerization time. Ideally, the experimental resin will gradually harden as the denture settles, and it will finally be polymerized similarly to conventional PMMA resin when the denture is completely settled. However, in this study, the magnetic assembly was removed from the housing in one of five specimens that used the experimental resin during insertion/removal cycles of up to 10,000. Thus, the mechanical property of the experimental resin should be improved for rigid fixation if the experimental resin is used as a permanent fixation material.

Of course, permanent fixation materials exhibited greater fixation strengths than did temporary ones. Particularly, the fixation strengths of magnetic assemblies using temporary filling resin, even without

resin ($p<0.05$). Even the experimental resin without the undercut wing exhibited higher fixation strengths than did those of the temporary fixation resins ($p<0.05$).
undercut, showed approximately 50 N even after 10,000 insertion/removal motions. To the contrary, the attractive force of the magnetic attachment was a constant of 5.5 N. Therefore, the magnetic assembly would be kept in the denture base by new fixation procedures using a temporary filling resin.

All of the fixation resins used in this study have more porous structures as compared to the PMMA resin; thus, it would become unclean around the keeper. However, less water absorption of the temporary filling materials and the photopolymerization denture relining resins was confirmed as compared to the others. From the viewpoint of oral hygiene, a temporary filling resin would be a better alternative fixation material. Careful maintenance is needed constantly to keep conditions clean around the fixation regions. Alternatively, a coating material for the temporary filling resin should be developed to protect from water absorption.

Providing and keeping higher attractive forces constant for magnetic attachments are the most important characteristics of fixation materials. The attractive force when using a temporary filling resin was comparable to that with conventional PMMA resin. Until 10,000 insertion/removal motions, temporary filling resin and conventional PMMA resin demonstrate a constant attractive force (approximately 4 to 5 N) without removing the magnetic assembly. These phenomena would be realized with little displacement of the magnetic assembly on the keeper when using a temporary filling resin. Also, removal of the magnetic assembly and decreased attractive force are disadvantages of the magnetic attachment that could be prevented by using a temporary filling resin. In conclusion, using a temporary filling resin can be recommended as a permanent fixation material similar to conventional PMMA resin.

The limitation of this study was that only the fixation strengths and changes in the attractive forces were examined. Hygienic properties and pressure displacement of the magnetic assembly using all fixation materials should be compared to PMMA resin. Additionally, little is known about the polymerization period, hardening speed, and flexibility of the fixation materials. Due to the settling of dentures, the polymerization period and the hardening speed should be arranged to improve the new fixation resin. It seems likely that clinicians’ stress levels during the fixation of magnetic assemblies must be decreased remarkably by using alternative resins that enable the removal of the denture after the fixation resin is completely polymerized, instead of using conventional autopolymerized PMMA resin.

CONCLUSIONS

For easy handling while fixing the magnetic assembly to the denture base, alternative commercially available resins, including experimental resins, were evaluated and compared to the conventional acrylic resin. Within the limitations of this study, the following conclusions can be drawn:

1. Applying Super-Bond to the magnetic assembly as a surface treatment tended to increase the fixation strengths of the temporary fixation materials.
2. By adding undercut wings to the magnetic assembly, fixation strengths tended to be increased when temporary fixation materials were used.
3. Although the experimental resins demonstrated satisfactory fixation strengths, improving the mechanical strengths is necessary because the magnetic assembly was removed from the housing in one of five specimens.
4. Temporary filling resin showed comparable fixation strengths to conventional resins; thus, they could be used as permanent fixation materials for magnetic attachments used in this study.

REFERENCES

6. ISO 13017: 2012(E), Dentistry magnetic attachments.


