RESEARCH AND EDUCATION

Effects of glass fiber mesh with different fiber content and structures on the compressive properties of complete dentures

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The midline fracture of maxillary complete dentures occurs as a result of fatigue failure by masticatory forces, and the rate is 2 to 3 times higher than that for mandibular dentures. This fracture occurs because of microcrack propagation where stress is focused. A traditional method of preventing the fracture of dentures is to reinforce them with wire and plates made of Co-Cr alloy or stainless steel. However, the poor adhesion between the denture base resin and metal reinforcement often causes them to separate at the interface, exposing the metal color and resulting in an unesthetic outcome. In addition, because of the metal mass, reinforced dentures are heavy.

Recently, glass, polyaromatic polyamide (amide), or ultrahigh molecular weight polyethylene fibers have been advocated to prevent denture fracture. Compared with metal, these fibers adhere better to the denture base resin, provide more pleasing esthetics, and result in a lighter prosthesis that is easy to repair. In addition, the mechanical properties of these dentures, such as their flexural strength and impact strength, also increase. In particular, glass fibers have been found to be more effective in increasing the flexural strength of denture base resin than aramid or nylon fibers. Because glass fibers produce a significant reinforcing effect, are less cytotoxic, and are more esthetically pleasing than other fibers, they can be used in various dental fields for posts, splints, and the reinforcement of fixed dental prostheses.

ABSTRACT

Statement of problem. No study has yet evaluated the strength of complete dentures reinforced with glass fiber meshes with different content and structures.

Purpose. The purpose of this study was to compare the reinforcing effects of glass fiber mesh with different content and structures with that of metal mesh in complete dentures.

Material and methods. Two types of glass fiber mesh were used: SES mesh (SES) and glass cloth (GC2, GC3, and GC4). A metal mesh was used for comparison. The complete dentures were made by placing the reinforcement 1 mm away from the tissue surface. A control group was prepared without any reinforcement (n=10). The compressive properties were measured by a universal testing machine at a crosshead speed of 5 mm/min. The results were analyzed with the Kruskal-Wallis test and the Duncan multiple range test (α=.05).

Results. The fracture resistance of the SES group was significantly higher than that of the control, GC4, and metal groups (asymptotic P=.004), but not significantly different from the GC2 and GC3 groups. The toughness of the SES and GC3 groups was significantly higher than that of the others (asymptotic P<.001), but not significantly different from that of the GC4 group.

Conclusions. SES and GC3, which have different structures but similar volume content, were the most effective in reinforcing complete dentures. The content of the glass fiber mesh seemed more important than the structures. (J Prosthet Dent 2015;113:636-644)
Clinical Implications
Complete dentures reinforced with between 4.35 and 4.73 vol% glass fiber mesh may help prevent denture fracture.

A complete denture can be reinforced with fibers in 2 ways: the entire denture base can be reinforced with fibers (total fiber reinforcement, TFR), or fiber reinforcement can be placed at the weak area of the denture (partial fiber reinforcement, PFR). PFR is more often used to reinforce dentures because it is easier to apply than TFR. However, if fiber mesh is applied, TFR does not present a difficult technical challenge.

Most studies regarding the effect of fiber reinforcement have been conducted by using rectangular-shaped specimens made of denture base resin. However, because complete dentures are complicated 3-dimensional structures composed of artificial teeth and a denture base, the results with these specimens cannot represent those of dentures. Some previous studies have focused on evaluating the mechanical properties of complete dentures partially reinforced with glass fibers and metal wire at the residual ridges, anterior or posterior part, and middle of the palate (PFR). However, no studies have estimated the compressive strengths of complete dentures reinforced with glass fibers covering the entire palate and the residual ridge (TFR) in comparison with metal mesh. Therefore, the reinforcing effect of glass fiber mesh on complete dentures with TFR should be evaluated.

The purpose of this study was to evaluate the reinforcing effects of glass fiber mesh with different content and structures on complete dentures and to compare the content and structures of the fiber mesh, and that the effects would not differ from those of metal mesh.

MATERIAL AND METHODS
Two types of glass fiber mesh and a metal mesh were used to reinforce complete dentures (Fig. 1A, C, E). Two glass fiber meshes, SES mesh (SES) and glass cloth (GC) with different structures, were used; GC has bigger holes and looser weave than SES (Fig. 1A, C). GC was applied with 2 layers (GC2), 3 layers (GC3), and 4 layers (GC4). The component and volume percentage of the reinforcements are presented in Table 1. SES and GC3 have similar fiber content. The SES mesh was provided in its silane-treated and preimpregnated state in resin. The glass cloth was treated with silane (γ-MPS; Dami Polychem) and impregnated with the bis-GMA-based resin fabricated in the laboratory. The aperture size of the metal mesh was 2.5 mm and its thickness was 0.3 mm.

Maxillary edentulous casts were made by pouring high-strength plaster stone (MG Crystal Rock; Maruishi Gypsum) into an edentulous rubber mold (U-402; Nissin Dental Products Inc). Two sheets of 0.5 mm thick sheet wax (Glattes Gusswachs; BEGO) were pressed on the edentulous cast, and stops were formed at both canines, the first molar areas, and the center of the palate by removing a 2 mm diameter of the wax and filling with Type 2 Class 2 pour-type denture base resin (Press LT; Retec). The fiber mesh (SES and GC) was placed over the edentulous casts covered with the sheet wax and placed into vinyl bags. The fiber mesh was conformed to the wax on the cast with suction from a vacuum device (SES 5100-G; INNO Dental). The SES was polymerized with a light-polymerization unit (Denstar-300; Denstar) according to the manufacturer’s recommendations. The GC was polymerized with a light-polymerization unit (Visio Beta Vario; 3M ESPE). The sheet wax covering the cast was eliminated with hot water. The mesh shapes adhered with stops were cut to cover the entire palate of the cast and to extend 4 mm from the residual ridge crest toward the vestibule (Fig. 1B, D).

The metal mesh was placed on the edentulous cast and hammered to form the shape of the palatal plate and residual ridge crest of the cast. After the metal mesh had been moved to the edentulous cast covered with sheet wax, it was gently hammered again. Then the metal mesh was compressed onto the cast with the vacuum device by using the procedure mentioned previously. The metal mesh was cut to the same size of the SES and GC, and the wax was removed (Fig. 1F).

To prepare the maxillary complete denture, a wax denture was made by forming the denture base with a 2 mm thickness of paraffin wax (Samjung Chemical Co) on a maxillary edentulous cast. Then U264 anterior teeth (Biotone; Dentsply Intl) and M32 posterior teeth (Endura Zero; Shofu) were aligned. The wax denture was placed into a flask (Retec Cast Mini; Retec) designed for pour-type denture base resin and then flanked with duplicating agar (Bre-Gel BG3; Bredent). After the wax denture had been removed from the flask, the artificial teeth were replaced in the agar mold. The prepared glass fiber mesh or metal mesh fixed on the edentulous cast (Fig. 2A, C, E) was replaced into the agar mold. After injecting the pour-type resin (powder 20 g/liquid 14 mL) into the flask, the prosthesis was deflashed after 1 hour (Fig. 2B, D, F). A control group without any reinforcement was also prepared. The sample size of each group was 10.

The volume content of glass reinforcements of the test specimens was measured by combustion analysis by using a furnace (Ring furnace; Seki Dental). Briefly, the weight and the density of test specimens were measured.
before and after heating at 700°C for 1 hour. The weight and density of the metal mesh were measured with a density determination kit (YDK01; Sartorius AG). The volume percentage of metal mesh was calculated from the density and weight of the metal mesh. The measured volume percentage of each reinforcement is listed in Table 1.

Before testing, the specimens were immersed in distilled water at 37°C for 50 hours. To measure the compressive properties, complete dentures were placed with the artificial teeth downward on a universal testing machine (Z020; Zwick), and load was applied to the tissue surface of the denture with a 10-mm diameter ball at a crosshead speed of 5 mm/min (Fig. 3). The maximum force that resisted fracture was recorded as fracture resistance in newtons. The elastic modulus was determined from the straight line of the slope of the stress-strain curve. The area under the stress-strain curve was

Figure 1. Photographs of each reinforcement before (left) and after (right) forming. A, SES mesh preimpregnated with resin (SES). C, Glass cloth without preimpregnation as supplied (GC). E, Metal mesh. B, D, F, Reinforcements of SES, GC, and metal conformed to edentulous cast were cut to cover entire palate and extended 4 mm from residual ridge crest. Arrows indicate stops.
automatically calculated into toughness with software (testXpert 11.0; Zwick) connected to the universal testing machine. The end of the test was determined either by fracture or when the load dropped 30% from the maximum load.10

The fracture lines of all specimens were observed with the naked eye. After analyzing the failure aspects of all specimens, the failure mode was classified into 1 of 3 patterns according to the fracture line. In Pattern A, the complete denture was completely fractured into 2 parts. In Pattern B, the denture was not fractured completely, with fractures only at the loaded area and the posterior midline area. In Pattern C, the fracture occurred only at the loaded area.

The compressive test data were evaluated with statistical software (IBM SPSS Statistics v22; IBM Corp). Fracture resistance, elastic modulus, and toughness were analyzed by the Kruskal-Wallis test, and the Duncan multiple range test was used to identify differences among groups ($\alpha=.05$). To evaluate the effect of the fiber content on the compressive properties, the control group and all GC groups were analyzed with the same methods. For the assessment of the difference of fiber structure on the compressive properties, the control group, SES, and GC3 group were analyzed as before.

### RESULTS

The means and standard deviations of compressive properties are listed in Table 2. The fracture resistance of the SES group was significantly higher than that of the control, GC4, and metal groups ($\chi^2=17.458, df=5, \text{ asymptotic } P=.004$) but was not significantly different from the GC2 and GC3 groups (Fig. 4A). For the elastic moduli, no significant differences were found among the groups ($\chi^2=7.642, df=5, \text{ asymptotic } P=177$) (Fig. 4B). The toughness of the SES and the GC3 groups was higher than in the other groups ($\chi^2=25.057, df=5, \text{ asymptotic } P<.001$) but was not significantly different from the toughness of the GC4 group (Fig. 4C).

The SES and GC3 group with different structure showed higher fracture resistances (asymptotic $P=.004$) and toughness (asymptotic $P<.001$) than the control group (Table 3). However, the SES and GC3 groups were not significantly different from each other. In the GC groups with different fiber content, no significant differences were found in fracture resistance (asymptotic $P=.135$). The toughness of GC3 was higher than GC2 (asymptotic $P<.001$) but was not significantly different from GC4. Detailed statistical information is described in Table 3.

The failure modes of all specimens are listed in Table 4. The control group showed both complete fractures (A) and incomplete fractures at the loaded area with a fracture line at the posterior midline (B). All reinforcement groups demonstrated incomplete fractures (Fig. 5).

### DISCUSSION

The purpose of this study was to evaluate the reinforcing effects of glass fiber mesh with different content and structures on complete dentures. For fracture resistance, the SES group was highest, but it was not significantly different from the GC2 and GC3 groups. For toughness, the SES and GC3 groups were higher than the other groups but were not significantly different from the GC4 group. The findings of this study show that SES and GC3 are the most effective reinforcements of complete dentures, both in fracture resistance and toughness. The null hypothesis was rejected because the fracture resistances and toughness were significantly different among the SES group, all GC groups, and the metal group.

The structure of SES and GC were different in the study. Figures 1A, 1C show that the aperture dimensions of the GC were larger than those of the SES, and the weave was different. SES and GC3, which have similar fiber content but different structures, did not show significant differences either in fracture resistance or toughness. The fiber content was different among the GC groups, and the content increased from GC2 to GC3 to GC4. Among the GC groups, which have same fiber structure with different fiber content, the toughness was significantly different. As a result, the difference in structure did not affect the fracture resistance or toughness, while the fiber content affected the compressive properties. Therefore, fiber content can be considered more important than structure. The results show that the most effective

### Table 1. Information and volume percentage of reinforcements of complete denture used

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>Brand Name</th>
<th>Manufacturer</th>
<th>Component</th>
<th>Vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fiber</td>
<td>SES</td>
<td>SES 1108</td>
<td>INNO Dental Co Ltd</td>
<td>E-glass</td>
<td>4.35 (0.33)</td>
</tr>
<tr>
<td>reinforcement</td>
<td>GC2</td>
<td>Glass cloth</td>
<td>HanKuk Fiber Co</td>
<td>E-glass</td>
<td>3.11 (0.13)</td>
</tr>
<tr>
<td></td>
<td>GC3</td>
<td>R 326</td>
<td>HanKuk Fiber Co</td>
<td>E-glass</td>
<td>4.73 (0.18)</td>
</tr>
<tr>
<td></td>
<td>GC4</td>
<td></td>
<td>HanKuk Fiber Co</td>
<td>E-glass</td>
<td>6.22 (0.21)</td>
</tr>
<tr>
<td>Metal</td>
<td>Metal</td>
<td>Denture mesh</td>
<td>World Dental</td>
<td>Cu-Zn (Au plated)</td>
<td>2.36 (0.25)</td>
</tr>
</tbody>
</table>

*GC2, 2 layers of glass cloth (GC); GC3, 3 layers of GC; GC4, 4 layers of GC.*
content of glass fiber mesh for reinforcing complete dentures appears to be between 4.35% to 4.73%, which corresponds to the SES and GC3 content.

Interestingly the standard deviations of the glass fiber-reinforced groups (SES and all GC groups) were smaller than those of the control and the metal group in fracture resistance and toughness (Figs. 4A, 4C; Table 2). Fiber reinforcements not only increased the compressive properties but also decreased the standard deviation in fracture resistance and toughness. However, the standard deviation of elastic modulus seemed not to be affected by the fiber reinforcement.

Factors that can affect the mechanical properties of fiber reinforcement are the types of fiber, the diameter and length of the fiber, the content and ratio of fiber to resin, the location and orientation of the fiber, and the preimpregnation of fibers. In this study, the content of glass fibers affected the mechanical properties of complete dentures. GC3 (4.73 vol%), which contained more fiber content, showed higher toughness

**Figure 2.** Fabrication procedure of complete dentures. A, C, E, Edentulous cast located with conformed reinforcements of SES glass mesh (SES), glass cloth (GC), and metal mesh. B, D, F, Complete denture with reinforcement of SES, GC, and metal.
than GC2 (3.11 vol%) despite having the same structures. SES mesh was supplied in a preimpregnated state with resin. Because glass cloth was supplied without preimpregnation, it was impregnated with an experimental bis-GMA-based resin that was fabricated in the laboratory. However, no significant differences were found in compressive properties between the preimpregnated SES and GC groups. Solnit and Vallittu reported that preimpregnating the reinforcing fibers improved the overall strength of the fiber-reinforced composite.

Unexpectedly, the glass fiber mesh groups displayed higher fracture resistance and toughness than the metal group. The fracture resistance of the SES group was significantly higher than that of the metal group, and the toughness of the GC3 group was significantly higher than that of the metal group. Tsue et al. reported similar results to those in this study. Although the study evaluated the compressive strength of complete dentures with partial reinforcement, the glass fiber groups showed significantly higher compressive strengths than the metal group. One study likewise reported that a metal-reinforced group was not significantly different from the control group in rectangular-shaped specimens; however, glass weave displayed higher fracture resistance than controls. If we infer the reason, the volume of the metal mesh was 2.36 vol%, which was lower than that of the glass reinforcement contents (3.11 to 6.22 vol%) in this study. The reason may be that the volume content of metal mesh was lower than that of glass fiber mesh. In addition, poor bonding between metal and denture base resin could account for the lower mechanical properties of the metal group. The good bonding of the reinforcement with the polymer matrix is important to increase the strength of the complete denture as a composite material. In this study, the SES and GC groups were silane treated and impregnated with unfilled resin before being incorporated into the denture base. Some reports suggest that silane treatment is effective for bonding each fiber with the polymer matrix. The impregnation of the reinforcing fibers with unfilled resin allowed good bonding with the highly viscous denture base resin. However, because the metal mesh received no surface treatment, no chemical bonds were formed with the resin matrix. The obvious conclusion is that good bonding between the reinforcing medium and the denture base resin is essential to achieve reinforcement.

For failure mode, the cracks were initiated at the loading point, and no fracture occurred at the incisal notch. Fracture of dentures occurs in the area of stress concentration. In the test mode of this study, the load was applied...
to the midpalatal area of the internal side of the denture. However, if the load had been applied on both axes of the posterior teeth, resulting in flexure of dentures, a different failure mode would have occurred. In this study, all reinforced groups displayed partial fractures only at the loaded area or in the posterior midline. A previous study regarding the reinforcing effects of complete dentures partially reinforced (PFR) with metal at the ridge lap region or middle region demonstrated complete or partial midline fracture.24 Another study revealed partially reinforced dentures with glass fiber fractured along the reinforcement.26 In this study, the complete dentures were fully reinforced with the reinforcement (TFR) to cover the entire palate and over 4 mm from residual ridge crest in all experimental groups. Therefore, TFR is effective in preventing the fracture of dentures. Because maxillary complete dentures are subject to flexural forces occurring on the axis of both posterior teeth in mouth, the reinforcement should be placed to resist the flexural forces. Therefore, glass fiber meshes should be applied with TFR, and either the warp or weft should be located perpendicular to the midline of the complete denture. The warp means the tightly stretched lengthwise core of a fabric, while the weft is woven between the warp threads to create various patterns.

Until now, the test for evaluating the mechanical properties of a complete denture has been limited with regard to the relevance to the dentures in the patient’s mouth. Clinically, complete dentures are located on flexible soft tissues, and the load is applied to both molar areas during chewing, resulting in denture flexing in the case of bilateral occlusion. Therefore, a new test method to measure the strengths of dentures designed to simulate clinical conditions seems to be necessary.

In summary, glass fiber mesh was more effective than metal mesh in reinforcing the fracture resistance and toughness of complete dentures. The content of the glass fiber reinforcement was more important than the structure, and the most effective content was found to be a volume ratio of 4.35% to 4.73%.

### Table 3. Effect of structure and content of fiber meshes on ranking of fracture resistance and toughness (Kruskal-Wallis test)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Fracture Resistance Ranking</th>
<th>Toughness Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Control a</td>
<td>$\chi^2=10.965$ a</td>
<td>$\chi^2=16.312$ a</td>
</tr>
<tr>
<td></td>
<td>SES b</td>
<td>$df=2$ b</td>
<td>$df=2$ b</td>
</tr>
<tr>
<td></td>
<td>GC3 b</td>
<td>Asymptotic P=.004 b</td>
<td>Asymptotic P&lt;.001 b</td>
</tr>
<tr>
<td>Content</td>
<td>Control - a</td>
<td>$\chi^2=5.567$ b</td>
<td>$\chi^2=22.825$ b</td>
</tr>
<tr>
<td></td>
<td>GC2 -</td>
<td>$df=3$ c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GC3 -</td>
<td>Asymptotic P=1.35 c</td>
<td>Asymptotic P&lt;.001 c</td>
</tr>
<tr>
<td></td>
<td>GC4 -</td>
<td>Asymptotic P&lt;.001 c</td>
<td></td>
</tr>
</tbody>
</table>

*No significant differences among groups with Kruskal-Wallis test ($\alpha=.05$).

### Table 4. Failure modes of complete denture classified according to location and propagation of fracture lines

A: Complete fracture 6
B: Incomplete fracture, loaded area and posterior midline 4 6 5 6 4 7
C: Incomplete fracture, loaded area 4 5 4 6 3

A, B, and C are demonstrated in Figure 5.
CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. SES and GC3 increased the fracture resistance and toughness of complete dentures.
2. Glass fiber mesh was more effective than metal mesh.

3. The content of the glass fiber mesh was more important than the structure, and between 4.35 and 4.73 vol% was the most effective in reinforcing complete dentures.

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