Flexural strengths of reinforced denture base resins subjected to long-term water immersion

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ABSTRACT

Objective This study evaluated the flexural strengths of reinforced denture base resins subjected to long-term water immersion.

Materials and methods Acrylic denture base resin reinforced with metal wire or glass fiber-reinforced composite (FRC), and without reinforcement were tested. Bar-shaped specimens were fabricated. Half of the specimens were stored in 37°C distilled water for 50 hours (h), the other half were stored in 37°C distilled water for 180 days (d) before testing. Ten specimens were fabricated per group for each reinforcement/water immersion period combination. The ultimate flexural strength and flexural strength at the proportional limit of reinforced denture base resin were tested.

Results The 180 d bulk specimen possessed significantly lower ultimate flexural strength compared with the 50 h bulk specimen (p<0.05). The ultimate flexural strength of the 50 h metal, 50 h FRC, 180 d metal and the 180 d FRC reinforcement specimens were not significantly different from each other (p>0.05). The 180 d bulk specimen had a significantly lower flexural strength at the proportional limit compared to the 50 h bulk specimen. The 180 d reinforced specimens of metal and FRC were not significantly different from each of the 50 h specimens.

Conclusion The flexural strengths of a reinforced denture base resin did not change after long-term water immersion.

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Introduction

Removable denture bases have been conventionally fabricated using polymethyl methacrylate resins. These materials are typically low in strength, moderately flexible, brittle on impact and fairly resistant to fatigue failure.[1] Therefore, the fracture of these dentures is an unresolved problem in prosthodontics.[2]

Metal wire reinforcements are used to strengthen acrylic resin dentures in order to prevent clinical fracture. Recently, glass fibers have been employed to reinforce acrylic resin dentures so as to prevent a denture fracture. Regarding glass fiber reinforcement, the denture base can be reinforced with fibers in two ways: the entire denture base can be reinforced with a fiber weave [total fiber reinforcement (TFR)] or a fiber reinforcement can be placed precisely at the weakest region of the denture [partial fiber reinforcement (PFR)].[3,4] If the fiber reinforcement is incorporated into the denture during repair, PFR is the reinforcement of choice because it is easier to handle compared to TFR.[3] In addition, PFR can prevent recurrent fractures in acrylic resin dentures.[4] The reinforcing effect of metal wire [5–8] and glass fiber reinforcement [5,8–14] for acrylic denture base resins, have previously been investigated. These studies showed that both types of reinforcements had a reinforcing effect for the flexural strengths of acrylic denture base resins.

Polymethyl methacrylate absorbs small amounts of water when placed in an aqueous environment. This water exerts significant effects on the mechanical and dimensional properties of the processed polymer.[15] Although absorption is facilitated by the polarity of polymethyl methacrylate molecules, a diffusion mechanism is primarily responsible for the ingress of water. As water molecules penetrate the polymethyl methacrylate mass, they occupy positions between polymer chains. Consequently, the affected polymer chains are forced apart. The introduction of water molecules produces two important effects. First, it causes a slight expansion of the polymerized mass. Second, water molecules interfere with the entanglement of polymer chains and thereby act as plasticizers.[15]

A previous study[16] investigated the equilibrium strengths of acrylic denture base resins subjected to long-term water immersion. In the study, water immersion
affected the strength of most denture polymers studied, and the flexural strengths at the proportional limit of the heat-polymerized acrylic denture base resin gradually decreased following water immersion. Likewise, another study [17] reported that long-term water immersion decreased the ultimate flexural strength and the flexural strength at the proportional limit of heat-polymerized acrylic denture base resins. These studies addressed the flexural strength of denture base in bulk. The data presented are sufficiently reliable to estimate the clinical performance of acrylic denture base resins. As mentioned earlier, the flexural strengths of reinforced acrylic denture base resins have been investigated,[5-14] and these studies estimated the effect of reinforcement on the flexural strengths of reinforced acrylic denture base resins after water immersion, ranging from 50 h to 2 weeks. Clinically, an estimation of the effect of long-term water immersion on the flexural strengths of reinforced acrylic denture base resins is beneficial. However, the flexural strengths of reinforced acrylic denture base resins that are subjected to long-term water immersion have not yet been investigated. It was hypothesized that the performance of reinforced acrylic denture base resins will be different from the performance of the bulk denture base resins after long-term water immersion. The purpose of this study was to investigate the flexural strengths of reinforced acrylic denture base resins subjected to long-term water immersion.

**Materials and methods**

A denture base resin (Acron, GC Corp., Tokyo, Japan, Lot no. (P):1011193, (L):1010272), 1.0 mm diameter round wire (Sun-Cobalt Clasp-Wire, Dentsply-Sankin K.K., Tochigi, Japan, Lot No. E700370) and glass fiber-reinforced composite (everStick C&B, GC Corp., Tokyo, Japan, Lot no.:1406101) were selected for this study. A denture base resin reinforced with a metal reinforcement or a glass fiber-reinforced composite (FRC) reinforcement was subjected to 180 day (d) water immersion. As a control, a denture base resin without reinforcement was tested. The surfaces of the metal reinforcements (1.0 mm diameter round wire, 30 mm long) were sandblasted with 50 μm grain-sized alumina (Aluminous Powder WA 360, Pana Heraeus Dental Inc., Osaka, Japan) using a grit blaster (Micro Blaster, Comco Inc., Burbank, CA) for 10 s at an emission pressure of 0.3 MPa. The nozzle was positioned at a right angle approximately 10 mm from the surface of the metal reinforcement. The sandblasted metal reinforcement was then cleaned in distilled water for 10 min in an ultrasonic cleaner (Bransonic 2510 J-MTH, Branson Ultrasonics Corp., Danbury, CT). Immediately after the cleaned metal reinforcement was dried, a metal conditioner (Alloy Primer, Lot:1G0005, Kuraray Medical Inc., Tokyo, Japan) was applied to the sandblasted surface with a sponge pellet. An FRC reinforcement (1.5 mm diameter round, 30 mm long) in prepreg state was cured with a light-curing unit (G-light Prima II, GC Corp., Tokyo, Japan) for 3 min.

Denture base resin specimens with reinforcement (none, metal, FRC) were then fabricated. The specimens were heat-polymerized and fabricated according to the manufacturer’s instructions in gypsum molds with cavities (65 mm long × 10 mm wide × 2.5 mm high). The reinforcement was embedded in the denture base resin in the doughy state and placed longitudinally in the center of the specimens. Each specimen was polished with 600-grit SiC paper. The accuracy of the dimensions was verified with a micrometer at three locations for each dimension to within a 0.05-mm tolerance for width and height. Half of the specimens were stored in 37°C distilled water for 50 h, and the other half were stored in 37°C distilled water for 180 d before testing. Ten specimens were fabricated per group for each reinforcement/water immersion period combination.

The specimens were fractured using a load testing machine (AGS-J, Shimadzu Co., Tokyo, Japan). The ultimate flexural strength and the flexural strength at the proportional limit [16,18–21] of the specimens were tested. Each specimen was placed on a 50 mm-long support for three-point flexural testing (Figure 1). A vertical load was applied at the midpoint of the specimen at a crosshead speed of 1 mm/min [22] on a load testing machine.

The ultimate flexural strength (MPa) was calculated according to the following formula:

\[
\text{Ultimate flexural strength} = \frac{3Fl}{2bh^2}
\]

**Figure 1. Schematics of specimens. (A) specimen without reinforcement, (B) specimen reinforced with metal wire reinforcement, (C) specimen reinforced with FRC reinforcement.**
where $F = \text{the maximum load (N)}$, $l = \text{the span distance (50 mm)}$, $b = \text{the width (mm) of the specimen}$, and $h = \text{the height (mm) of the specimen}$. The flexural strength at the proportional limit (MPa) was calculated according to the following formula:

$$\text{Flexural strength at the proportional limit} = \frac{3F_1l}{2bh^2}$$

where $F_1 = \text{the load (N) at the proportional limit}$. The load at the proportional limit was determined from each load/deflection graph (Figure 2).

All the tests were performed under uniform atmospheric conditions of $23.0 \pm 1 ^\circ C$ and $50 \pm 1\%$ relative humidity.

Two-way analysis of variance (ANOVA) (STATISTICA, StatSoft Inc., Tulsa, OK) was applied to study the differences among the reinforcement and the effect of the water immersion period. One-way ANOVA (STATISTICA) and the Newman–Keuls post-hoc test ($\alpha = 0.05$) (STATISTICA) was also used when appropriate.

Results

The two-way ANOVA revealed significant differences in ultimate flexural strength because of the reinforcement variable, and the interaction between the reinforcement and the water immersion period ($p < 0.05$). As there was a significant difference resulting from the interaction between the two variables, the one-way ANOVA and the Newman–Keuls post-hoc comparison were applied to the reinforcement/water immersion period combination. The results are depicted in Table 1. The 180 d bulk specimen possessed significantly lower ultimate flexural strengths compared with the 50 h bulk specimen ($p < 0.05$). The ultimate flexural strength of the 50 h metal reinforcement specimen, the 50 h FRC reinforcement specimen, the 180 d metal reinforcement specimen and the 180 d FRC reinforcement specimen were not significantly different from each other ($p > 0.05$).

The two-way ANOVA revealed that there were significant differences in the flexural strength at the proportional limit, caused by the variables of the reinforcement and the effect of water immersion period ($p < 0.05$); there was no significant difference in the flexural strength at the proportional limit because of the interaction between the reinforcement and the water immersion period. The descending order of flexural strengths at the proportional limit according to the reinforcement, arranged in terms of statistical significance, was: FRC reinforcement specimens ($68.7 \pm 9.3 \text{ MPa}$) > metal reinforcement specimens ($59.8 \pm 7.0 \text{ MPa}$) > without reinforcement specimens ($54.2 \pm 6.1 \text{ MPa}$), where the numbers in parentheses denote mean and standard deviations. Individual flexural strengths at the proportional limit of the reinforcement/water immersion period combination specimens were analyzed using one-way ANOVA (Table 1). The 180 d bulk specimen had a significantly lower flexural strength at the proportional limit compared to the 50 h bulk specimen. The 180 d reinforced specimens of metal and FRC were not significantly different from each of the 50 h specimens.

![Figure 2. Representative load/deflection graph. PL: the load at the proportional limit, Max: the ultimate load.](image)

Table 1. Mean and standard deviations (SD) of ultimate flexural strength and flexural strength at the proportional limit of the reinforced denture base resins after 50 h and 180 d water immersion ($n = 10$).

| Reinforcement | Water immersion | Ultimate flexural strength (MPa); Mean (SD) | Flexural strength at proportional limit (MPa); Mean (SD) |
|---------------|-----------------|---------------------------------------------|-----------------------------------------------------|
| None          | 50 h            | 112.5 (14.1)$^{a}$                          | 58.2 (3.4)$^{b}$                                     |
| Metal         | 50 h            | 123.1 (12.8)$^{b}$                          | 62.7 (5.2)$^{b}$                                     |
| FRC           | 50 h            | 130.8 (16.3)$^{b}$                          | 68.9 (4.4)$^{a}$                                     |
| None          | 180 d           | 91.0 (18.9)                                 | 50.1 (5.6)                                          |
| Metal         | 180 d           | 137.9 (25.7)$^{b}$                          | 56.8 (7.6)$^{b}$                                     |
| FRC           | 180 d           | 117.8 (19.2)$^{b}$                          | 68.5 (12.8)$^{a}$                                    |

$a,$ $b$ or $c$ denotes groups that were not significantly different from each other ($p > 0.05$).
Discussion

The hypothesis of this study was accepted, and the performance of reinforced denture base resin differed from the performance of the bulk denture base resin after long-term water immersion. The strength of a reinforced denture base resin is dependent on the bulk strength, on the reinforcement, and on the bonding between reinforcement and denture base resin. The flexural strengths of the present bulk denture base resin were established in earlier studies,[16,17] namely, the ultimate flexural strength and the flexural strength at the proportional limit of the bulk denture base resin significantly decreased after 180 d water immersion; therefore, it became weak. Although the exact mechanism through which a denture base resin reaches water saturation is unknown, the present study clearly demonstrated the effect of water immersion on the strengths of bulk denture base resin. As the denture polymers are immersed in water, soluble constituents, such as unreacted monomers, plasticizers, and initiators leach out.[16,23,24] Microvoids are then formed, which become filled with water molecules by inward diffusion. Both the outward leakage of the soluble constituents and inward diffusion of water are time-dependent processes. Therefore, the relative amount of these molecules within the denture base resin changes over time until equilibrium is reached. To different extents, water, plasticizers, and unreacted monomers adversely affect the strength of the polymer because these molecules facilitate the movement of the polymer chains to a varying degree. Hence, the strength of a denture polymer at a given time after water immersion is affected by the relative amount of those molecules present.[16] From the result of the present study, the tendency of the flexural strengths of a bulk heat-polymerized acrylic denture base resin seems to decrease after long-term water immersion.

The decrease in ultimate flexural strength means a weakening of the denture base resin. A decrease in the flexural strength at the proportional limit represents a decrease in resistance to plastic deformation of the denture base resin.[16,18–21] In the present study, the ultimate flexural strength and the flexural strength at the proportional limit of reinforced specimens did not change after 180 d water immersion; nevertheless, the flexural strengths of the bulk specimen decreased after 180 d water immersion. This meant that the reinforced denture base did not become weak and maintained its resistance to plastic deformation after 180 d water immersion. The reason would be because reinforcements were not affected by water absorption and they bonded to denture base resin. In the present study, metal and FRC reinforcements were used. Metal wire was not affected by water absorption, and a previous study [25] reported that the flexural strength of the bulk FRC did not change after 180 d water immersion. Furthermore, it seemed that metal wire reinforcement was bonded to denture base resin because of surface treatment of metal wire using a metal conditioner and FRC reinforcement was bonded chemically to the acrylic denture base resin and got entangled in the denture base resin. Therefore, reinforced denture base resins were most likely to keep their flexural strengths after 180 d water immersion. With regard to flexural strengths at the proportional limit of reinforced denture base resin after 180 d water immersion, denture base resin reinforced with FRC was higher than that with metal reinforcement. The reason may be due to differences in the degree of bonding between reinforcement and denture base resin, because a previous study [26] reported that FRC reinforcement bonds chemically to the acrylic denture base resin and is incorporated into the denture base, but metal reinforcement does not bond completely to the acrylic denture base resin.

The effect of reinforcement on acrylic denture base resin could be explained by the result of the present study. With regard to the ultimate flexural strength of the 50 h specimens in the present study, the bulk specimen, the metal reinforcement specimen and the FRC reinforcement specimen were not significantly different from each other ($p > 0.05$). The flexural strength at the proportional limit of the 50 h bulk specimen was not significantly different from that of the 50 h metal reinforcement specimen and the flexural strength at the proportional limit of the 50 h metal reinforcement specimen was not significantly different from that of the 50 h FRC reinforcement specimen ($p > 0.05$). Therefore, it seemed that there was no clear difference clinically between the strengths of the bulk denture base resin and the strengths of the reinforced denture base resin in 50 h water immersion. However, the bulk denture base resin was fatigued after 180 d water immersion. As mentioned earlier, reinforcements used in the present study; metal wire and FRC, did not change after long-term water immersion. Thus, the existence of a stable material, and reinforcement in the denture base resin was effective for flexural strengths. In other words, the role as a reinforcement was not only the improving flexural strengths of a denture base resin, but also the resistance to fatigue of a denture base resin. In this study, a bundle of FRC was used as a reinforcement. A previous study [8] reported that the thickness of an FRC reinforcement in a bar-shaped acrylic denture base specimen affected the reinforcing effect in the flexural strength after 50 h of water immersion. Therefore, it seems that the diameter of the reinforcing material
would affect flexural strengths of reinforced denture base resins subjected to long-term water immersion.

The present study estimated the ultimate flexural strength and the flexural strength at the proportional limit of acrylic denture base resin reinforced with metal wire reinforcement or FRC reinforcement after 180 d water immersion. It may be concluded that the flexural strengths of a reinforced denture base resin did not change after long-term water immersion. The results of the present study suggested that long-term water immersion does not affect the flexural strengths of acrylic resin dentures reinforced with metal wire or FRC reinforcement.

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Declaration of interest
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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