Effect of Embedded Metal Reinforcements and Their Location on the Fracture Resistance of Acrylic Resin Complete Dentures

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Keywords
Metal reinforcement location; maxillary acrylic resin complete denture; flexural load; reinforcing efficiency; flexural deflection.

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Abstract

Purpose: This study evaluated the effect of metal reinforcement and its location on the flexural load at the proportional limit (FL-PL) and the flexural deflection of maxillary acrylic resin complete dentures.
Materials and Methods: Maxillary acrylic resin complete dentures reinforced with Remanium and without reinforcement were tested. The reinforcing material was embedded in the denture base resin in the doughy state and placed (1) under the ridge lap region; (2) in the anterior region; (3) in the middle region; and (4) in the anterior and posterior regions. The FL-PL (N) and the flexural deflection (mm) at 100 N of the reinforced maxillary denture specimens were tested using a load testing machine at a 5.0 mm/min crosshead speed. The data were analyzed statistically using one-way ANOVA; Tukey's post hoc comparisons test was applied when appropriate (95% confidence level).
Results: The FL-PL of the dentures without reinforcement (909 $\pm$ 195 N) and the dentures reinforced at the ridge lap (1094 $\pm$ 176 N) and in the middle (977 $\pm$ 215 N) regions were not significantly different ($p > 0.05$). The dentures reinforced in the anterior (1348 $\pm$ 205 N) and the anterior and posterior (1190 $\pm$ 191 N) regions had a higher FL-PL than the dentures without reinforcement ($p < 0.05$) and were not significantly different from each other ($p > 0.05$). The efficiency (times) of the reinforcing material on the dentures without reinforcement was 1.08 to 1.48. The flexural deflection of the dentures without reinforcement (0.133 $\pm$ 0.014 mm), the dentures reinforced at the ridge lap (0.125 $\pm$ 0.014 mm), in the anterior (0.122 $\pm$ 0.009 mm), and in the middle (0.132 $\pm$ 0.015 mm) regions were not significantly different ($p > 0.05$), and the dentures reinforced in the anterior and posterior (0.117 $\pm$ 0.011 mm) regions had significantly lower deflection than the dentures without reinforcement ($p < 0.05$).
Conclusion: The location of the metal reinforcement affected the fracture resistance of the maxillary acrylic resin complete dentures.

Although individual denture bases may be made from metals or metal alloys, a majority of denture bases are fabricated using common polymers chosen based on availability, dimensional stability, handling characteristics, color, and compatibility with oral tissues. Conventional heat-accelerated acrylic resins are still the predominant denture base materials in use, but these materials are typically low in strength, moderately flexible, brittle on impact, and fairly resistant to fatigue failure.[1] Since complete dentures depend entirely on the soft tissue and underlying hard tissue for support, it is preferable for a denture base to be stiff and undergo little deflection during chewing.

With regard to the failure record of removable dentures, Hargreaves[2] reported that 68% of dentures had broken 3 years postplacement. Yli-Urpo et al[3] found that 28% of dentures underwent repair during the first year of use, and 39% required repair during the first 3 years of use. Denture damage most commonly occurred in maxillary complete dentures, in which breakage or fracture of the acrylic denture base was found the most often; the typical fatigue failure of maxillary complete dentures was evidenced by a midline fracture.[4,5] Vallittu et al[4] reported that the midline fracture of a maxillary complete denture ran through the notch between the two central teeth, extending partially or completely through the denture base. Another study[6] showed that midline fractures generally began either at the labial notch or in the anterior part of the denture palate. When either a notch, diastema, or both were present in the maxillary complete denture, they were involved in the fracture line. [5]

Metal wire[7-14] and glass fibers[8,11,13-24] are used clinically as reinforcements for acrylic resin dentures and have been investigated in several studies. In one study[14] limited to the reinforcement of in vitro denture base-shaped specimens, the researchers investigated the strengthening effect of the metal on the flexural load of maxillary complete dentures reinforced under the ridge lap surfaces of the teeth from the left second premolar to the right second premolar of the denture. The results indicated that the mean of the flexural load of the unreinforced denture was 706 N, and of the reinforced denture was 903 N. Other studies evaluated the placement of the fiber reinforcements in an acrylic resin denture. In this case, the denture base can be reinforced with fibers in two ways: the entire denture base can be reinforced with a fiber weave, or a fiber reinforcement can be precisely placed at the weak area of the denture. These reinforcements are defined as total fiber reinforcement (TFR) and partial fiber reinforcement (PFR), respectively.[25,26] If the fiber reinforcement is incorporated into the denture during repair, PFR is the reinforcement of choice, because it is easier to handle than TFR.[25] PFR can also prevent recurrent fractures in acrylic resin dentures.[26]

Placement of the fibers as near as possible to the location of the highest tensile stress in the dentures may prevent the initiation of fracture.[25] A clinical study emphasized the importance of several factors: the correct positioning of the PFR on the tensile side during mastication (perpendicular orientation to the possible fracture line), the length of the PFR, and accurate laboratory technique.[26] Some studies investigated the static strength[23] and the flexural fatigue[24] of a denture base reinforced with fiber-reinforced composites (FRC). Placing the FRC reinforcements on the tensile side resulted in considerably higher flexural strength and flexural modulus values compared with placing the same quantity of FRC reinforcements on the compression side.[23] Fiber reinforcements placed on the tensile side strengthened the test specimens more effectively against repeated bending than did fiber reinforcements located on the compression side.[24]

Some researchers have evaluated the placement of metal reinforcements in an acrylic resin denture. When a steel strengthener is used, it must be placed perpendicular to the anticipated line of stress and fracture and not coincident with that line.[7] The incorporation of two steel strengtheners several millimeters apart and perpendicular to the anticipated line of fracture produces significant resistance to flexure and reduces the likelihood of fracture of the acrylic resin denture base.[7] In studies of FRC reinforcement,[15,26] the reinforcing material was put under the ridge lap surface of the denture teeth. Therefore, in a study focused on metal reinforcement,[14] the metal was arranged similar to the placement of the FRC reinforcement. Despite the useful information gained from these previous studies on denture reinforcement, the effect of the location of the metal reinforcement on the flexural load of denture base resins has not yet been investigated in vitro.

The purpose of this study was to investigate the effect of embedded metal reinforcements and their location on the flexural load at the proportional limit and the flexural deflection of maxillary acrylic resin complete dentures. The null hypothesis was that the location of metal reinforcement would affect neither the flexural load at the proportional limit nor the flexural deflection of a reinforced maxillary acrylic resin complete denture.

Materials and methods

Maxillary acrylic resin complete dentures reinforced with Remanium (Dentaurum, Pforzheim, Germany) and without reinforcement were tested in this study. The Remanium reinforcements were placed at several locations and tested to investigate which location favorably affected the flexural load at the proportional limit and the flexural deflection. Half-round hard wire for the metal reinforcement (Remanium, 1.0-mm thick × 2.0-mm wide, Lot No. 51660)[8-14] and a denture base resin (Lucitone 199, Lot no. (P):060410, (L):0602285, Dentsply International Inc., York, PA) were selected for the study.

The surfaces of the metal reinforcements 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 seconds at a 0.3 MPa emission pressure. 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 minutes 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: 0310AA, Kuraray Medical Inc., Tokyo, Japan)[27] was applied to the sandblasted surface with a sponge pellet.

An impression of the maxillary edentulous model (G1–402, Nissin Dental Products Inc., Kyoto, Japan) was taken using elastomeric silicone material (Examix Fine injection/putty type, GC Corp., Tokyo, Japan), and a working cast was made with high-strength plaster stone (Fujirock, GC Corp.). A thermoplastic sheet (Erkodur, Erkodent Erick Kopp GmbH, Pfalzgrafenweiler, Germany) was used to form a thermoplastic denture base on a working cast by vacuum forming (Erkopress 2002, Erkodent Erick Kopp GmbH). The thickness of the thermoplastic denture base was adjusted to 2.5 mm by carefully trimming and adding wax when necessary; it was then measured with a caliper to ensure uniformity. After the artificial teeth (Real crown resin teeth anteriors, BioAce resin teeth posteriors, Shofu Inc., Kyoto, Japan) were arranged, the wax denture was invested with dental stone in a denture flask. The wax was eliminated, and the thermoplastic sheets removed. The Remanium reinforcing material was formed into a bar shape on a working cast and then embedded in the denture base resin in the doughy state and placed (1) under the ridge lap surfaces of the teeth from the left first molar to the right first molar of the denture (the ridge lap region); (2) in the anterior region of the palatal plate (the anterior region); (3) in the middle of the anteroposterior region of the palatal plate (the middle region); and (4) in the anterior and posterior regions of the palatal plate (the anterior and posterior regions) (Fig 1). The bars were equally positioned in the dentures using a jig. The reinforcing material was conventionally

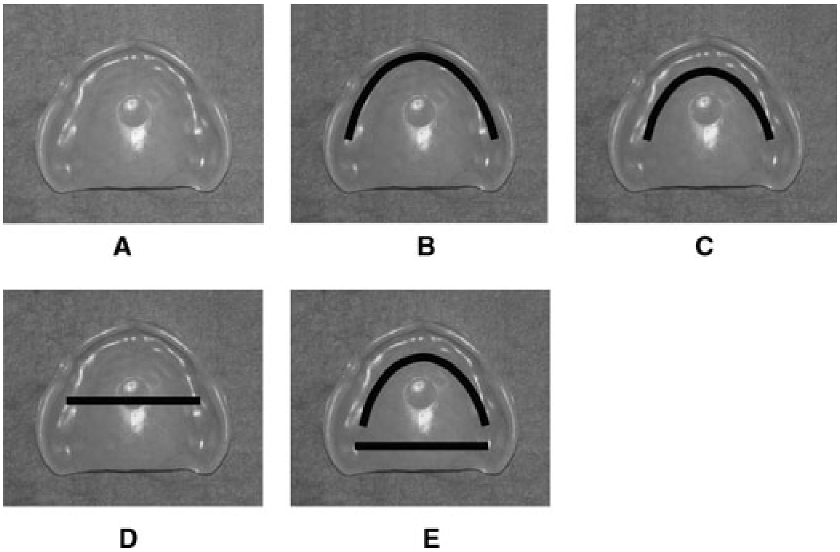

Figure 1 Location of metal reinforcement of the maxillary complete denture. (A) without reinforcement, (B) ridge lap region, (C) anterior region, (D) middle region, (E) anterior and posterior regions.

packed, and the resin was heat polymerized according to the manufacturer's instructions.

Ten specimens were fabricated for each group. All dentures were stored in 37°C distilled water for 50 hours before testing.

The flexural load at the proportional limit (FL-PL) (N) was measured using a load testing machine (AGS-J, Shimadzu Co., Tokyo, Japan) at a 5.0 mm/min crosshead speed. A flexural load was applied to each maxillary complete denture with a 25-mm diameter ball attachment (Fig 2). The application of the downward load along the midline of the tissue surfaces of the denture was designed to be equivalent to the upward load on both sides, combined with unyielding support in the center of the plate.[14,28,29] The FL-PL (N) and the deflection (mm) at 100 N were both determined from the load-deflection curve. When failure occurred, the failure mode was determined for all specimens and classified based on the fracture lines: (1) complete midline fracture, (2) partial midline fracture, (3) along the reinforcement, and (4) other.

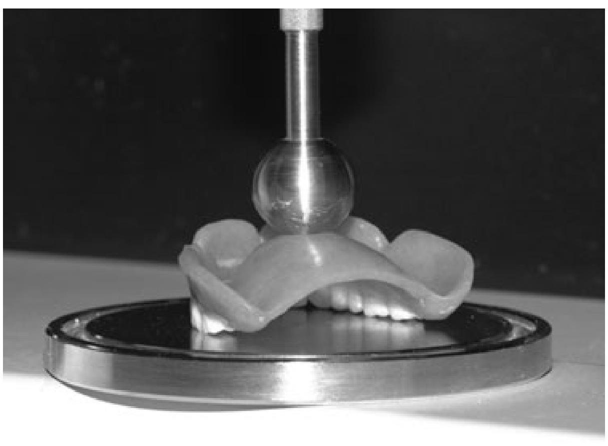

Figure 2 Flexural load testing equipment.

The data were analyzed statistically using one-way ANOVA (STATISTICA, StatSoft Inc., Tulsa, OK), and Tukey's post hoc comparison (STATISTICA) was applied when appropriate (95% confidence level). All tests were performed under uniform atmospheric conditions of 23.0 ± 1°C and 50 ± 1% relative humidity.

Results

Oe-way ANOVA revealed significant differences ($p < 0.05$) in the FL-PL of the maxillary dentures, attributed to the various reinforcement locations. The dentures reinforced in the anterior, and the anterior and posterior regions had a higher FL-PL than the dentures without reinforcement (Table 1). The efficiency (times) of the reinforcing material on the unreinforced denture was 1.08 to 1.48 (Table 1).

One-way ANOVA of the maxillary dentures revealed significant differences ($p < 0.05$) in the flexural deflection at 100 N, attributed to the various reinforcement locations. The dentures reinforced in the anterior and posterior regions underwent significantly lower deflection than the dentures without reinforcement (Table 1).

The modes of failure of all the dentures are provided in Table 1, and the representative failure modes are shown in Figure 3. The dentures without reinforcement and those reinforced in the ridge lap region all showed complete midline fracture. The fracture lines of most of the dentures reinforced in the anterior and the anterior and posterior regions occurred along the reinforcement. All dentures reinforced in the middle region showed partial midline fracture.

Discussion

The null hypothesis of this study was rejected—the location of the metal reinforcement affected the flexural load at the proportional limit, as well as the flexural deflection of the reinforced maxillary acrylic resin complete denture. Stresses higher than

Table 1 Flexural load at proportional limit (FL-PL) of maxillary acrylic resin dentures reinforced at several locations, reinforcing efficiency (times) of the reinforcing material on the denture without reinforcement, flexural deflection (mm) at 100 N of the maxillary acrylic resin denture reinforced at several locations, and failure mode of dentures (N = 10).

Location of reinforcement	FL-PL (N), mean (SD)	Reinforcing efficiency	Flexural deflection, mean (SD)	Failure mode (n) CMF/PMF/RF/Other**
Without reinforcement	909 (195) a*	1	0.133 (0.014) a*	10/0/0/0
Ridge lap region	1094 (176) a,b	1.20	0.125 (0.014) a,b	10/0/0/0
Anterior region	1348 (205) c	1.48	0.122 (0.009) a,b	2/0/8/0
Middle region	977 (215) a,b	1.08	0.132 (0.015) a,b	0/10/0/0
Anterior and posterior regions	1190 (191) b,c	1.31	0.117 (0.011) b	0/0/9/1

*similar letters denote no significant differences ($p > 0.05$).
**CMF = Complete midline fracture; PMF = Partial midline fracture; RF = Along the reinforcement.

the proportional limit for acrylic denture base polymers typically initiate permanent plastic deformation before fracture. Plastic deformation beyond its proportional limit permanently alters the dimensions of a denture, which is not clinically acceptable. Some studies[30-34] have evaluated the resistance of denture polymers to plastic deformation under a flexural load. In this study, the flexural load at the proportional limit of an acrylic resin maxillary denture was investigated.

As mentioned earlier, in a previous study[14] strictly related to the reinforcement of denture base-shaped specimens, the FL-PL of an unreinforced denture was 706 N, and that of a denture reinforced at the ridge lap region was 903 N. In this study, the FL-PL of an unreinforced denture and the FL-PL of a denture reinforced at the ridge lap region were 909 N and 1094 N, respectively. Although the present values were different from the previous study's values, the efficiency of the reinforcement at the ridge lap region was 1.20 in this study, similar to the reinforcing efficiency found at the ridge lap in the previous study (1.28).[14] In this study, the reinforcement efficiency values in the anterior and the anterior and posterior regions were 1.48 and 1.31, respectively, similar to the value of FRC reinforcement in the earlier study.[14]

The maximum bite force of complete denture wearers averages 156 N, in a range of 98 to 209 N.[35] In this study, 100 N was chosen because it is at the lower end of the range, and thus, the flexural deflection was evaluated at the 100 N loading point. The flexural deflection of the dentures without reinforcement, those reinforced at the ridge lap, in the anterior, and in the middle regions were not significantly different; however, the dentures reinforced in the anterior and posterior regions displayed significantly lower deflection compared to the unreinforced denture, which means that the stiffness increased in the dentures reinforced with two metal reinforcements. This finding suggests that one-metal reinforcement may not be enough to maintain the stiffness of reinforced dentures.

The fracture of the maxillary acrylic resin complete denture generally started at the notch between the two central teeth, and the fractured dentures without reinforcement showed midline fracture, as did the fractured dentures reinforced at the ridge lap

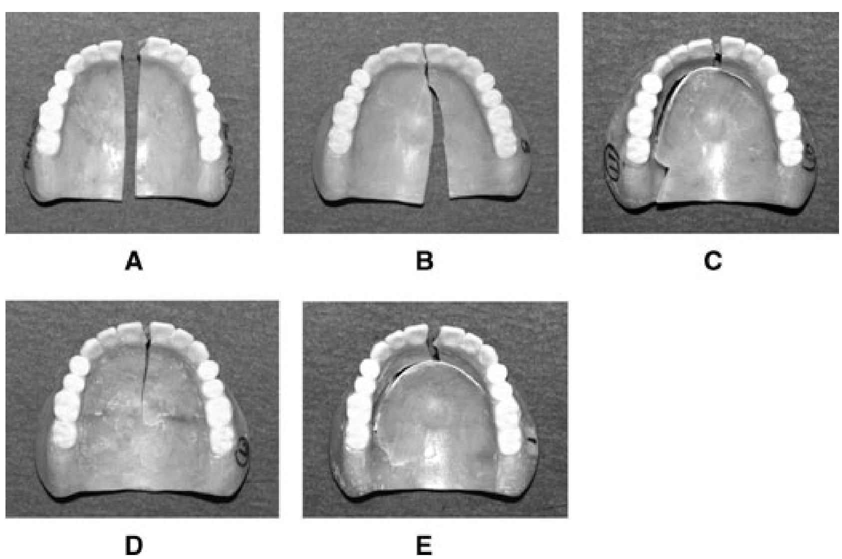

Figure 3 Representative failure modes of dentures. (A) without reinforcement, (B) ridge lap region, (C) anterior region, (D) middle region, (E) anterior and posterior regions.

region. The location of reinforcement did not have a beneficial effect, which may have been due to the fact that the reinforcing material placed at the ridge lap region was located just under the starting point of the fracture; the fracture line of the dentures then ran through the notch, extending completely through the denture base. As mentioned earlier, a clinical study emphasized the importance of the correct positioning of the PFR on the tensile side during mastication (perpendicular to the possible fracture line) and of the length of the PFR.[26] Moreover, the PFR in the earlier study was inserted close to the ridge-lap surface of the maxillary complete denture incisors, and there were no fractures in the denture base for 2 years and 8 months.[26] FRC 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. Therefore, the location of the metal reinforcement at the ridge-lap region did not produce a reinforcing effect. In contrast, the reinforcing materials in the anterior and the anterior and posterior regions were placed close to the starting point of the fracture. The fracture line of the dentures ran through the notch, stopped at the reinforcement, and then continued along the reinforcement; therefore, the reinforcements at these locations were effective. Because the reinforcing material placed in the middle region was not close to the starting point of the fracture, the fractured denture showed a partial midline fracture, and the middle region was not reinforced. This study indicated that the metal reinforcement placed so that it resisted midline fracture was effective against the flexural load of the maxillary acrylic resin complete denture.

Conclusions

Under the conditions of the present experiment, the following conclusions may be drawn:

(1) The location of the metal reinforcement affected the fracture resistance of the maxillary acrylic resin complete denture.
(2) The dentures reinforced in the anterior region and the anterior and posterior regions had higher flexural load at the proportional limit than the dentures without reinforcement ($p < 0.05$).
(3) The dentures reinforced in the anterior and posterior regions showed significantly lower deflection compared to the others ($p < 0.05$).

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