Acta Odontologica Scandinavica, 2011; 69: 215–221

ORIGINAL ARTICLE

Effect of location of glass fiber-reinforced composite reinforcement on the flexural properties of a maxillary complete denture *in vitro*

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Abstract

Objective. To evaluate the effect of the location of glass fiber-reinforced composite (FRC) reinforcement on the flexural load at the proportional limit (FL-PL) and the flexural deflection of a maxillary acrylic resin complete denture. ***Material and methods.*** Maxillary acrylic resin complete dentures strengthened with and without FRC reinforcement were tested. The polymerized FRC 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 or (4) in the anterior and posterior regions. The FL-PL and flexural deflection value at the 100-N loading point of the reinforced maxillary denture specimens were tested. ***Results.*** All of the reinforced dentures had a higher FL-PL than the denture without reinforcement but the FL-PL values of all the dentures were not significantly different from each other. The efficiency of the FRC reinforcement compared to the unreinforced denture was 1.54–1.75 times greater. All of the reinforced dentures showed significantly lower deflection compared to the unreinforced denture, but the flexural deflections of all the dentures were not significantly different from each other. ***Conclusions.*** The location of the FRC reinforcement did not affect the fracture resistance of the maxillary acrylic resin complete denture. All of the reinforced dentures had higher FL-PL and lower flexural deflection than the denture without reinforcement.

Key Words: *Flexural properties, glass fiber-reinforced composite, location, maxillary acrylic resin complete denture, reinforcement*

Introduction

The fracture of acrylic resin dentures is an unresolved problem in prosthodontics [1]. The denture that is most frequently damaged is the maxillary complete denture. Breakage or fracture of the acrylic base is found in many damaged maxillary complete dentures, and the typical fatigue failure of maxillary complete dentures may be a midline fracture [2]. Lambrecht et al. [3] reported that midline fractures generally begin either at the labial notch or in the anterior part of the denture palate. Vallittu et al. [2] also reported that a midline fracture of a maxillary complete denture ran through the notch between the two central teeth, extending partially or completely through the denture base. Furthermore, Darbar et al. [4] reported that whether a notch or diastema or both were present in upper complete dentures, they were involved in the fracture line.

To prevent clinical fracture, metal wire reinforcement has conventionally been used to strengthen acrylic resin dentures. For the past two decades, glass fibers have been employed to reinforce acrylic resin dentures. Both metal wire reinforcement [1,5–9] and glass fiber reinforcement [5,8–18] have been investigated.

With regard to 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)] [19,20]. If the fiber reinforcement is incorporated in the denture during repair, PFR is the reinforcement of choice because it is easier to handle than TFR [19]. In addition, PFR can prevent recurrent fractures in acrylic resin dentures [20].

Placement of the fibers as near as possible to the location of the highest tensile stress in dentures may prevent the initiation of fracture [19]. A clinical study [20] emphasized the importance of several factors: correct positioning of the PFR on the tensile side

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(Received 6 September 2010; accepted 24 November 2010)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2011 Informa Healthcare
DOI: 10.3109/00016357.2010.549506

during mastication, perpendicular orientation to the possible fracture line, length of the PFR, and accurate laboratory technique.

Some authors have investigated the static strength [18] and flexural fatigue [21] of denture bases reinforced with fiber-reinforced composites (FRCs). Placing FRC reinforcements on the tensile side resulted in considerably higher flexural strength and flexural modulus values compared with using the same quantity of FRC reinforcements on the compressive side [18]. Fiber reinforcements placed on the tensile side strengthened the test specimens more effectively against repeated bending than reinforcements on the compressive side [21].

Unidirectional glass fibers for reinforcement of a denture base resin have been incorporated either directly [5], after being dipped in methyl methacrylate (MMA) liquid [11–13,16,17], or after being dipped in a poly (methyl methacrylate) (PMMA)–MMA mixture [8,10,12,14,15,18]. In an earlier study [22], polymerized FRC was used to reinforce an acrylic resin denture base material; the results revealed that the flexural load of dentures reinforced with FRC was similar to that of metal-reinforced dentures; as a result, the FRC was effective for the reinforcement of acrylic dentures.

Regarding the reinforcement location in maxillary acrylic resin complete dentures, clinical studies [19,20] showed that an unidirectional glass fiber reinforcement should be placed close to the ridge lap surfaces of the incisors. In two studies strictly relating to the reinforcement of denture base-shaped specimens *in vitro*, Polyzois et al. [1] estimated the fracture load of denture bases reinforced with metal at ≈3–4 mm below and palatal to the corresponding crest of the ridge, and discussed the interesting effect on the fracture process of placing a metal wire in the anterior part of a maxillary denture. A previous study [22] investigated the strengthening effects of metal or FRC 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. However, the optimal location of the reinforcing material (either metal or FRC) with regard to producing the most favorable flexural load of maxillary complete dentures has not been investigated yet. Therefore, in a previous study [23], the effect of the location of metal reinforcement on the flexural load of maxillary complete dentures was estimated. As a result, it was found that (1) the location of the metal reinforcement affected the fracture resistance of the maxillary acrylic resin complete denture, and (2) dentures reinforced in the anterior region and in the anterior and posterior regions had higher flexural load at the proportional limit than dentures reinforced at the ridge lap and in the middle regions.

Furthermore, since a complete denture is entirely dependent for support on the soft tissue and underlying hard tissue, an estimation of the flexural deflection of the denture base, as well as an estimation of flexural load, is clinically important. It is preferable for the denture base to be stiff and to undergo little deflection during chewing. The relationship between the location of the FRC reinforcement and the flexural deflection of a maxillary complete denture has not yet been investigated.

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

Material and methods

Silanized E-glass fibers (20-μm diameter; Asahi Fiber Glass Co., Tokyo, Japan), dimethacrylate resin [urethane dimethacrylate (UDMA)–triethyleneglycol dimethacrylate (TEGDMA)] and a denture base resin [Lucitone 199, Lot No. (P):060410, (L):0602285; DENTSPLY International Inc., York, PA] were selected for this study. UDMA (Lot No. SH-500B; Negami Chemical Industrial Co. Ltd., Ishikawa, Japan) and TEGDMA (NK-Ester; Lot No. 0925X; Shin-Nakamura Chemical Co. Ltd., Wakayama, Japan) were mixed at a ratio of 1:1. As a light initiator (0.7 wt.%), camphorquinone [(CQ); Lot No. J5CTB; Tokyo Kasei Co. Ltd., Tokyo, Japan] and 2-dimethylaminoethyl methacrylate [(DEAM); Lot No. IY80A; Tokyo Kasei Co. Ltd) were used at a ratio of 1:2.

A maxillary acrylic resin complete denture reinforced with FRC was investigated. As a control, a maxillary acrylic resin complete denture without reinforcement was tested.

The glass fibers were impregnated with the dimethacrylate resin liquid and then packed in a stainless-steel mold (1.0-mm thick; 5.0-mm wide). The highly filled bar-shaped specimens containing glass fibers were cured in the mold under a glass cover for 1 min with a light-curing unit (Visio Alfa; 3M ESPE, Seefeld, Germany), removed from the mold, and post-cured with another light-curing unit (UniXS II; Heraeus Kulzer, Wehrheim, Germany) for 3 min.

Combined precision impressions of the maxillary edentulous model (G1-402; Nissin Dental Products Inc., Kyoto, Japan) were made with elastomeric silicone material (Examix Fine injection/putty type; GC Corp., Tokyo, Japan), and a working cast was fabricated with high-strength plaster stone (Fujirock; GC Corp.). Thermoplastic sheets (Erkodur; Erkodent Erick Kopp GmbH, Pfalzgrafenweiler, Germany) were used to form thermoplastic denture bases on a working cast by vacuum forming (Erkopress 2002; Erkodent Erick Kopp GmbH). The thickness of the thermoplastic denture bases was adjusted to 2.5 mm by carefully trimming and adding wax when necessary; they were 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 dentures were invested with dental stone in denture flasks. The wax was eliminated and the thermoplastic sheets removed. The polymerized FRC was used as reinforcing material (Figure 1) and was formed into a bar shape on a working cast. The FRC reinforcement was 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); or (4) in the anterior and posterior regions of the palatal plate (the anterior and posterior regions) (Figure 2). The denture base resin was heat-polymerized according to the manufacturer's instructions.

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

The flexural load at the proportional limit (FL-PL) was measured in newtons using a load testing machine (AGS-J; Shimadzu Co., Tokyo, Japan) at a crosshead speed of 5.0 mm/min. A flexural load was applied to each maxillary complete denture with a 25-mm diameter ball attachment (Figure 3). The downward load applied 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 [22–25]. The FL-PL and the flexural deflection value (millimeters) at the 100-N loading point were both determined from each load–deflection graph (Figure 4).

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

When failure occurred, the failure mode was inspected for all specimens. The failure of the denture was classified into three categories based on the fracture lines: (1) complete midline fracture; (2) partial midline fracture; and (3) along the reinforcement.

Results

The one-way ANOVA revealed significant differences ($P < 0.05$) in the FL-PL of the maxillary dentures, which were attributed to the various reinforcement locations. All of the reinforced dentures had a higher FL-PL than the denture without reinforcement but the data for the dentures were not significantly different. The efficiency of the FRC reinforcement compared to that of the unreinforced denture was 1.54–1.75 times greater (Table I).

The one-way ANOVA revealed significant differences ($P < 0.05$) in the flexural deflection value at the 100-N loading point of the maxillary dentures, which were attributed to the various reinforcement locations. All of the reinforced dentures showed significantly lower deflection compared to the unreinforced denture and were not significantly different from each other (Table II).

The modes of failure of all dentures are given in Table III, and representative failure modes are shown in Figure 5. The dentures without

a

b

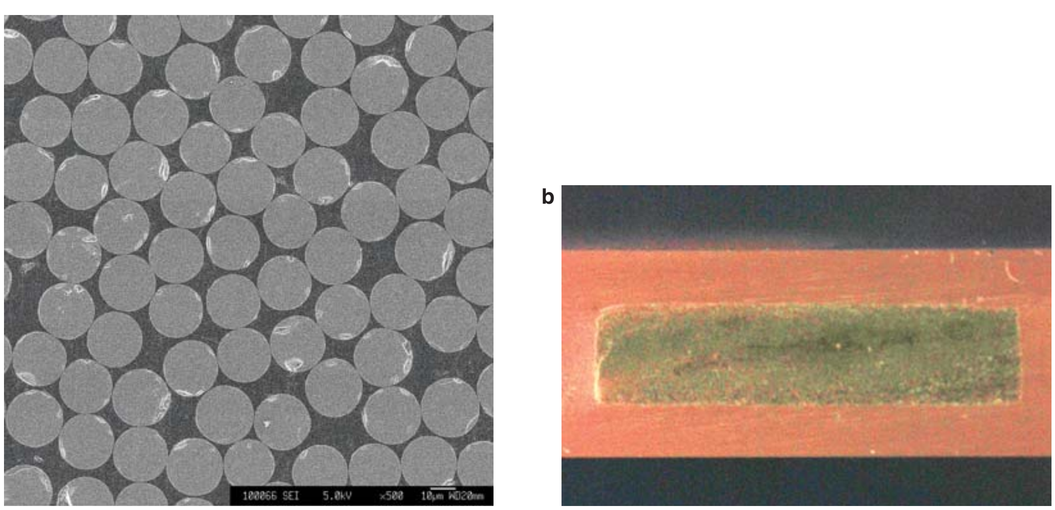

Figure 1. (a) Scanning electron micrograph (original magnification ×500) of cross-section of polymerized FRC reinforcement. (b) Representative cross-section of a denture reinforced with FRC.

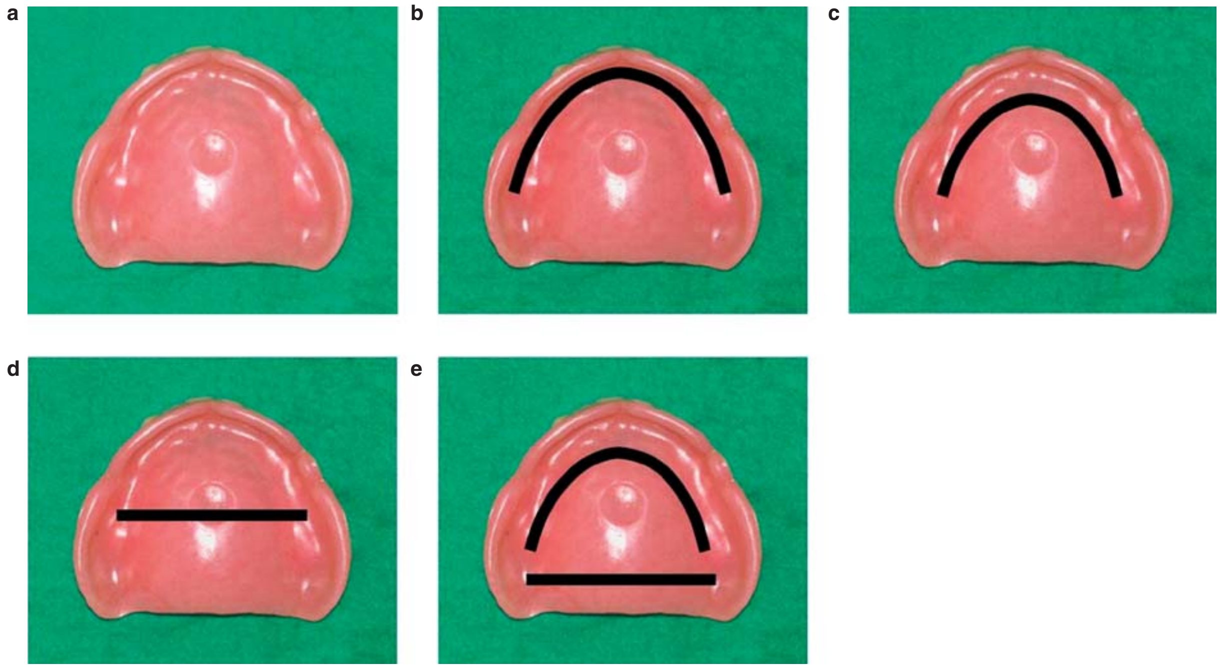

Figure 2. Location of FRC reinforcement of the maxillary complete denture: (a) without reinforcement, (b) the ridge lap region, (c) the anterior region, (d) the middle region, (e) the anterior and posterior regions.

reinforcement all had complete midline fracture. The fracture lines of most of the dentures reinforced in the ridge lap region and those of all the dentures reinforced in the anterior and the anterior and posterior regions occurred along the reinforcement. All of the dentures reinforced in the middle region showed partial midline fracture.

Discussion

The null hypothesis of this study was not rejected, and the location of the FRC reinforcement did not affect the FL-PL or the flexural deflection of the reinforced maxillary acrylic resin complete denture.

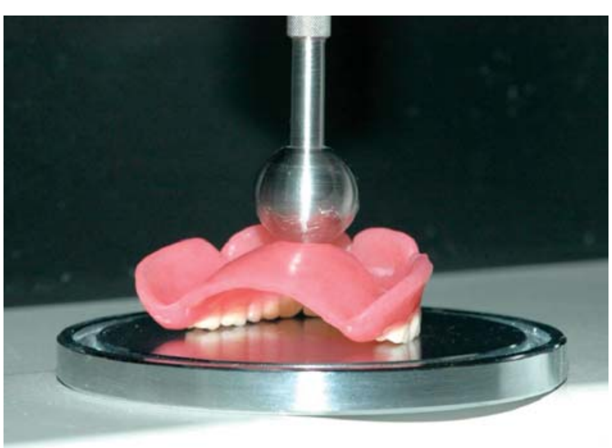

Figure 3. Flexural load testing equipment.

Denture base plastics typically exhibit considerable plastic deformation before fracture. Plastic deformation beyond its proportional limit permanently alters the dimensions of a denture and is not clinically acceptable; therefore, some studies [22,23,26–30] evaluated the resistance of denture polymers to plastic deformation under a flexural load. In this study, the FL-PL of an acrylic resin maxillary denture was evaluated.

Michael et al. [31] reported that the maximum bite strength of complete denture wearers averaged 156 N over a range of 98–209 N. Based on this report, 100 N was arbitrarily chosen for the present study because it is at the lower end of the range; thus, the flexural deflection was evaluated at the 100-N loading point.

In a previous study [22], the reinforcing effect of FRC on an acrylic resin bar-shaped specimen was similar to that of metal (Remanium). However, compared with another earlier study [23], the reinforcing effect of FRC on a maxillary acrylic resin complete denture specimen was different from that of metal. The location of the metal reinforcement affected the fracture resistance of the maxillary acrylic resin complete denture, and dentures reinforced in the anterior region and in the anterior and posterior regions had higher FL-PL than an unreinforced denture [23]. However, the location of the FRC reinforcement in the present study did not affect the fracture resistance of the maxillary acrylic resin complete denture, perhaps due to differences in the stiffness of the reinforced denture. The denture reinforced with metal in the anterior and posterior regions underwent significantly lower deflection than the unreinforced denture, but the dentures reinforced with metal at

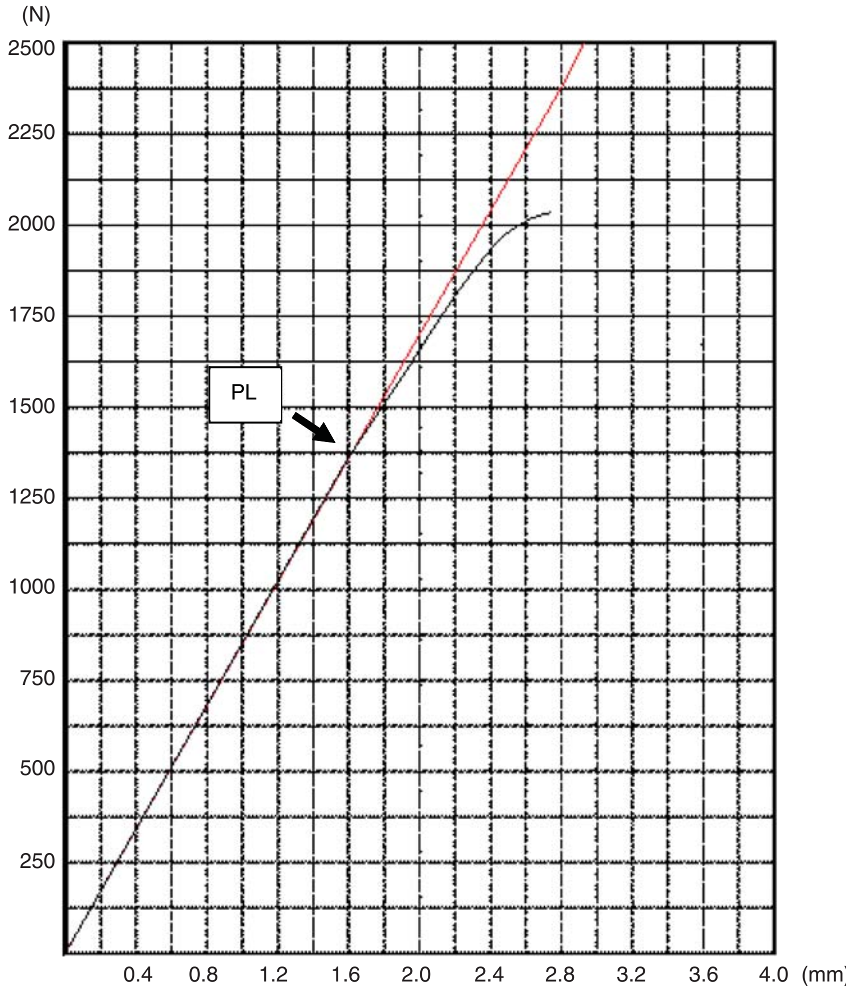

Figure 4. Representative load–deflection graph. PL = proportional limit.

the ridge lap, in the anterior and in the middle regions did not display lower deflection than the unreinforced denture [23]. Nevertheless, the dentures reinforced with FRC at all locations in this study showed significantly lower deflection compared to the unreinforced denture. This finding may be due to the chemical bonding of the FRC reinforcement to the acrylic resin, while the metal reinforcement did not bond completely to the acrylic resin. Thus, the dentures reinforced with metal were not completely stiff, indicating that the location of the metal reinforcement affected the fracture resistance of the maxillary acrylic resin complete denture. Conversely, FRC reinforcement was incorporated into the denture base; as a result, the reinforced dentures were stiff regardless of the location of the reinforcement. As mentioned earlier, 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 [2]. In the present study, the flexural

Table I. FL-PL of the maxillary acrylic resin denture reinforced at several locations and the reinforcing efficiency of the reinforcement material compared to the dentures without reinforcement ($n = 10$).

Location of reinforcement	FL-PL (N); mean (SD)	Reinforcing efficiency
Without reinforcement	908.5 (194.6)	1
Ridge lap region	1442.8 (123.2)[a]	×1.59
Anterior region	1589.9 (219.0)[a]	×1.75
Middle region	1396.9 (148.9)[a]	×1.54
Anterior and posterior regions	1496.6 (64.9)[a]	×1.65

[a]Denotes no significant difference ($P > 0.05$).

Table II. Flexural deflection at the 100-N loading point of the maxillary acrylic resin denture reinforced at several locations ($n = 10$).

Location of reinforcement	Flexural deflection (mm); mean (SD)
Without reinforcement	0.133 (0.014)
Ridge lap region	0.093 (0.004)[a]
Anterior region	0.100 (0.006)[a]
Middle region	0.102 (0.007)[a]
Anterior and posterior regions	0.093 (0.007)[a]

[a]Denotes no significant difference ($P > 0.05$).

Table III. Failure mode of dentures.

Location of reinforcement	Complete midline fracture	Partial midline fracture	Along the reinforcement
Without reinforcement	10		
Ridge lap region	2		8
Anterior region			10
Middle region		10	
Anterior and posterior regions			10

load was applied to the maxillary complete denture but it seems that, in the initial stage of the fracture, tensile stress occurred at the notch between the two central teeth of the denture. At that stage, the denture reinforced with FRC was stiff, and the stiffness affected the fracture resistance; as a result, the FL-PL increased. Placement of the fibers as near as possible to the location of the highest tensile stress in dentures may prevent the initiation of fracture [19], but the location of FRC reinforcement may not affect the FL-PL when the reinforced denture is stiff.

In this study, the efficiency of the FRC reinforcement compared to that of the unreinforced denture was 1.54–1.75 times greater. In a previous study [23], the efficiency of the metal reinforcement at the location showing the significantly highest reinforcing effect was 1.31–1.48 times greater. From these data, it has been suggested that FRC reinforcement with the highest reinforcing effect compares favorably with metal reinforcement.

With regard to failure mode, the previous study [23] indicated that the location of the metal reinforcement to prevent midline fracture was effective at maintaining the flexural load of the maxillary acrylic resin complete denture. In the present study, the dentures reinforced with the FRC did not undergo midline fracture, and the location of the FRC reinforcement resisting the midline fracture was likewise effective at sustaining the flexural load.

In this study, the FRC was fabricated using a UDMA–TEGDMA matrix. The preimpregnation resin of some commercially available FRCs is composed of 2,2-bis[4-(2-hydroxy-3-methacryloxypropoxy) phenyl] propane (Bis-GMA) or PMMA [18,21]. It seems that the FRC matrix affects the bonding to acrylic denture base resin; however, this point should be further investigated. In addition, the main factor causing the denture fracture was fatigue of the denture base resin, although fatigue failure does not require strong biting forces [21]. In the present study, the static loading test was applied. It will be necessary to estimate the durability of acrylic resin dentures using a dynamic test because the bonding of a FRC reinforcement to a denture base resin plays an even more important role.

This study indicated that unidirectional glass FRC reinforcement was preferable to the metal reinforcement of a maxillary acrylic resin complete denture; the increase in stiffness of the resin denture affected its fracture resistance.

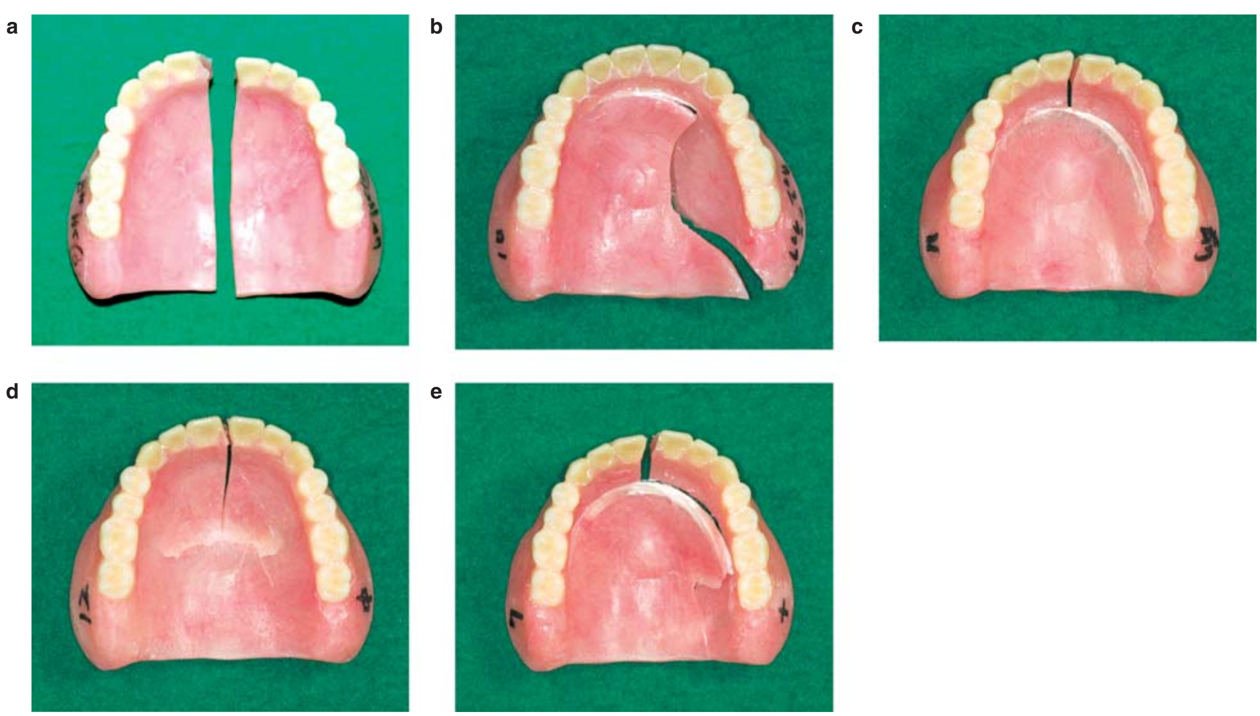

Figure 5. Representative failure modes of dentures: (a) without reinforcement, (b) the ridge lap region, (c) the anterior region, (d) the middle region, (e) the anterior and posterior regions.

Conclusions

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

(1) The location of the glass FRC reinforcement did not affect the fracture resistance of the maxillary acrylic resin complete denture.
(2) All of the reinforced dentures had higher FL-PL and lower flexural deflection compared to the dentures without reinforcement.

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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