

RESEARCH AND EDUCATION

Fatigue resistance of a simulated single LOCATOR overdenture system



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Rehabilitation of the edentulous mandible with a single implant-retained overdenture is a well-accepted treatment with long-term effective outcomes.¹ It can successfully overcome the retention and stability problems related to conventional complete dentures.^{2,3} Moreover, it has lower treatment costs and simplified procedures and saves chairside time because parallelism between structures is not an absolute requirement.^{4,5} Several attachment systems with different retention mechanisms can be used with implant-retained overdentures. Stud attachments such as ball and socket and LOCATOR (Zest Anchors LLC) are commonly used and provide satisfactory retentive and stabilizing features.⁶ Because of their shorter height, LOCATOR stud attachments are recommended for patients with a limited

ABSTRACT

Statement of problem. The incidence of fracture in a single-implant overdenture base increases in the region adjacent to the fulcrum implant.

Purpose. The purpose of this in vitro study was to evaluate the effect of bidirectional woven electrical glass (E-glass) fiber reinforcements on the fatigue resistance of a simulated single LOCATOR-retained overdenture.

Material and methods. Test specimens with a centrally positioned metal housing for a LOCATOR stud attachment were fabricated from autopolymerizing acrylic resin. Specimens for the control group were fabricated without glass fiber reinforcements. The 4L group specimens had 4 layers of E-glass fiber weaves and were divided according to the fiber location into the following 3 subgroups: 4L-A with 4 fiber layers above the metal housing; 4L-N with 4 fiber layers adjacent to the metal housing; and 4L-A+4L-N with 4 fiber layers above and 4 fiber layers adjacent to the housing. Specimens were stored in distilled water for 1 week at 23 °C before cyclic fatigue testing at 10 000 cycles by using a staircase approach (n=12). The results were analyzed with 1-way ANOVA and the Tukey multiple comparisons post hoc analysis ($\alpha=.05$). A 2-way ANOVA ($\alpha=.05$) was conducted to detect the effect of fatigue cyclic loading and the position of the fiber layers and their interaction on the fatigue resistance.

Results. The results of the investigated compressive fatigue limits for the test groups were 190 \pm 15.9 N for the control group, 265 \pm 15.9 N for the 4L-A subgroup, 220 \pm 15.9 N for the 4L-N subgroup, and 275 \pm 15.9 N for the 4L-A+4L-N subgroup. A nonsignificant difference was found for creep values between the control group and reinforced subgroups ($P>.05$). The postfatigue flexural strength values in the 4L-A and 4L-A+4L-N subgroups were significantly higher than those in the control group ($P<.001$) and the 4L-N subgroup ($P=.004$ and $P=.005$). However, no significant difference was found in postfatigue flexural strength between the control group and the 4L-N subgroup ($P=.828$).

Conclusions. Placing 4 layers of bidirectional E-glass fiber weaves above the metal housing can increase the fatigue resistance and the postfatigue flexural strength of single LOCATOR-retained overdentures. (J Prosthet Dent 2019;122:557-63)

The author P.V. consults with Stick Tech-GC in research and development and training. Fibers used in the present study were provided by Stick Tech-GC.

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Clinical Implications

Fracture around the metal housing has been reported as the main complication in a single implant-retained overdenture. The incorporation of bidirectional E-glass fiber reinforcements in the overdenture base can improve the fatigue resistance of the prosthesis and prevent fracture.

interocclusal space.⁷ They also provide a dual retention and a self-aligning feature.⁸

Denture fractures may be caused by fatigue under repeated occlusal loads.⁹ Small flexural stresses over time may lead to a significant decrease in the flexural properties of the denture base accompanied by microcrack formation and propagation.¹⁰⁻¹⁵ Therefore, flexural fatigue resistance is a mechanical property that affects the clinical durability of the prosthesis.¹⁶

Force distribution alters when an implant-retained prosthesis is delivered.¹⁷ Stresses become more concentrated around the attachment system components,¹⁸ leading to a high risk of fractures in this area of overdenture base.¹⁹ Fracture has been reported to be a frequent complication associated with a single-implant overdenture.²⁰ High occlusal load,²¹ rigid bone-implant interface,²² and reduced thickness of the denture base adjacent to the abutment¹⁸ could explain the high incidence of fractures. Moreover, the single-implant abutment acts as a fulcrum around which the overdenture rotates under functional forces, causing a high stress concentration in the area of the housing, which may lead to overdenture base fracture.^{23,24} Also, the lack of periodontal ligaments around dental implants could facilitate attachment or denture base fracture, leading to implant failure.¹⁹

The use of glass fibers has been recommended for reinforcing denture base polymers.^{25,26} Compared with metal reinforcements, glass fibers have better esthetics and bond chemically to the resin matrix with a silane coupling agent, making them a more durable reinforcement solution.²⁵⁻²⁸ In implant-retained overdentures, they can enhance the toughness and flexural fatigue resistance of thin areas around the attachment components, which are under high stress.²⁹⁻³¹ Continuous unidirectional fiber, continuous bidirectional fiber weaves, and chopped fiber strands are the commonly used forms of denture base reinforcements.^{32,33}

The strength of the fiber-polymethyl methacrylate composites can be affected by the fiber concentration in the polymer matrix,³² fiber form,³³ orientation,³⁴ fiber adhesion to the matrix,³⁵ and the position of fibers.^{26,28} The reinforcement placed over the top of the abutment in tooth and implant overdentures has been reported to effectively reduce strains and hence the risk of

fracture.^{18,19,30} However, inadequate bonding at the interface between the metal housing and denture base resin is a weak point in the prosthetic structure that needs to be considered.³⁶ As a result, the proper location of the reinforcement is a key factor in managing mechanical complications of single implant-retained overdentures under heavy functional forces.

Therefore, the purpose of this *in vitro* study was to evaluate the effect of bidirectional woven electrical glass (E-glass) fiber reinforcements on the fatigue resistance of a simulated single LOCATOR-retained overdenture. The research hypothesis was that the location of reinforcing fiber layers would significantly affect the flexural fatigue resistance of a single LOCATOR-retained overdenture.

MATERIAL AND METHODS

Forty-eight specimens of a simulated overdenture base (65 mm in length, 5 mm in height, and 10 mm in width) were fabricated from clear autopolymerizing denture base resin (Palapress; Kulzer GmbH), with metal housings for a LOCATOR stud attachment. The powder-to-liquid ratio of the autopolymerizing resin was 10 g to 7.0 mL. The LOCATOR stud attachments selected for this study consisted of a model analog (4 mm in diameter) and a titanium housing (2.3 mm in height and 5.5 mm in diameter) with a clear inner retention insert (regular retention) (Zest Anchors LLC).

The Stick Net (SN) E-glass fiber reinforcement system (GC Corp), a bidirectional silanated E-glass fiber weave preimpregnated with porous polymethyl methacrylate, was used as the reinforcement. The single fiber weave thickness was 0.06 mm, the tensile strength was 4.78 N/mm (when the fibers are cut at a 0 to 90 degrees angulation), and the mass was 46 to 50 g/m².

Two test groups were designed for the study. The control group was fabricated without a reinforcement (n=12). The other group was fabricated by using 4 layers of woven SN fibers as a reinforcement, identified as 4L, and subdivided according to the location of fiber weaves into the following subgroups: 4L-A with 4 SN layers above the metal housing (n=12), 4L-N with 4 SN layers adjacent to the metal housing (n=12), and 4L-A+4L-N with 4 SN layers above the metal housing and 4 SN layers adjacent to it (n=12) (Fig. 1A).

The test specimens were fabricated as in a previous study.³⁷ For fabricating the control group specimens, the metal housing for the LOCATOR stud attachment was centrally placed in a polyvinyl siloxane laboratory putty mold (Lab Putty; Coltène) (5.2×10.2×65.2 mm), and then a mixture of acrylic resin was poured to fill the mold. For preparing the fiber-reinforced test specimens for the 4L group, SN fiber sheets were cut using scissors into equal layers (60 mm in length and 9 mm in width) and wetted for approximately 10 minutes with a

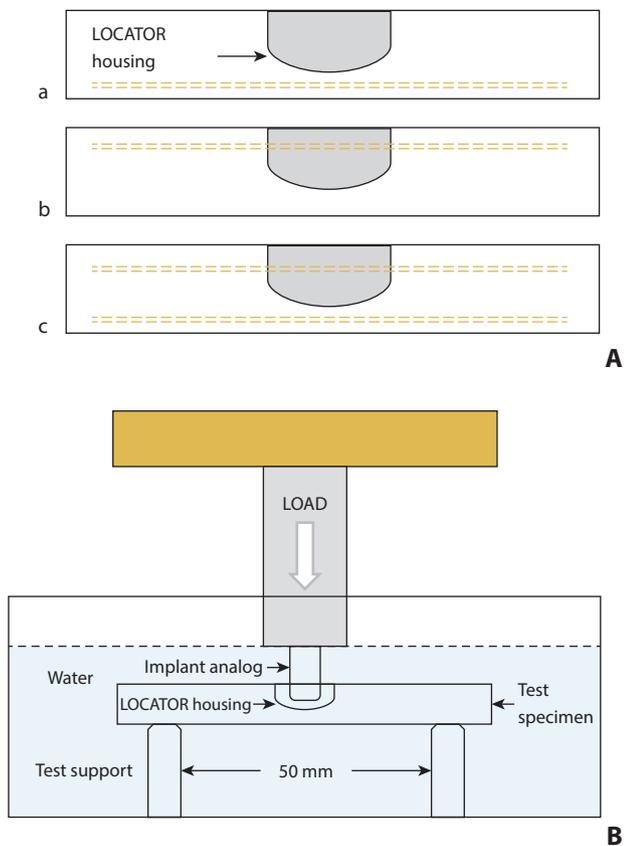


Figure 1. A, Fiber position (orange double dashed lines) in specimens: (a) above metal housing (4L-A), (b) adjacent to metal housing (4L-N), and (c) above and adjacent to metal housing (4L-A+4L-N). B, Flexural fatigue test arrangement in water.

powder-liquid mixture of autopolymerizing acrylic resin (Palapress; Kulzer GmbH) between 2 plastic sheets. The fibers and resin matrix become nearly transparent when they are fully wetted. To prepare the specimens for the 4L-A subgroup, the mold with the housing in the middle was partially filled with a 4-mm layer of acrylic resin. Four layers of wetted SN fiber weaves were then placed above each other and finally covered with another layer of acrylic resin mix. To fabricate the 4L-N subgroup specimens, a hole with a diameter less than 5.5 mm was made in the middle of 4 fiber sheets by using an explorer (LM 5-8 Si; LM-DENTAL) to displace the fibers laterally and create a space for placing the metal housing with a degree of friction. The housing and surrounding wetted fiber weaves were then centrally placed together in the mold and covered with a denture base resin mix. To prepare 4L-A+4L-N subgroup specimens, procedures for fabricating the subgroup 4L-N specimens were repeated in addition to placing 4 layers of SN fiber weaves above the metal housing and covering them with a layer of acrylic resin.

The specimens were then covered with glass plates and polymerized in distilled water maintained at $55 \pm 2^\circ\text{C}$ under an air pressure of 300 kPa for 15 minutes in a pneumatic

Table 1. Methods for analyzing staircase test data

Load (L)	Stress Level (I)	Failures (N), $N = \sum n_i$	$A = \sum i \cdot n_i$	$B = \sum i^2 \cdot n_i$
Control group				
130	0	0	0	0
160	1	3	3	3
190	2	3	6	12
		N=6	A=9	B=15
4L-A Subgroup				
200	0	0	0	0
230	1	2	2	2
260	2	4	8	16
		N=6	A=10	B=18
4L-N Subgroup				
170	0	0	0	0
200	1	5	5	5
230	2	1	2	4
		N=6	A=7	B=9
4L-A+4L-N Subgroup				
220	0	0	0	0
250	1	4	4	4
280	2	2	4	8
		N=6	A=8	B=12

polymerizing unit (Ivomat type IPR; Ivoclar Vivadent AG). The specimens were wet-ground successively with finer grades of silicon carbide abrasive papers from P300 to P1200 (LaboPol-21; Struers A/S) to the predetermined dimensions ($5 \times 10 \times 65$ mm) and then stored in distilled water at room temperature ($23 \pm 1^\circ\text{C}$) for 7 days before testing.

Compressive fatigue limits (CFLs) at 10 000 cycles were determined for the test groups according to the staircase approach. The test was performed using a universal testing machine (Model LRX; Lloyds Instruments Ltd) at a crosshead speed of 60 mm/min and a frequency of 0.5 Hz in a water bath at 37°C . An implant analog was used for load application at the LOCATOR metal housing (Fig. 1B). In this “up and down” method, specimens were sequentially tested so that the first specimen was tested at the initial stress level detected from preliminary data. The stress level for the next specimen was increased or decreased according to the survival or failure of the first specimen. The magnitude of load by which the level was changed was 30 N. Data analysis was based on the failure versus nonfailure events. The CFL and its standard deviation³⁸⁻⁴⁰ were calculated according to the following equations:

$$\text{CFL} = X_o + d(A/N \pm 1/2)$$

$$S = 0.53 \cdot d,$$

where X_o is the lowest load level at which failure occurs, d is the fixed load increment (30 N) used in the sequential test, and S is the standard deviation. A , N , and B are explained in Table 1.³⁸⁻⁴⁰ The specimens that survived the 10 000 cycles

Table 2. Cyclic fatigue limit (CFL) values in Newtons (N) of tested groups at 95% confidence intervals

Group	Subgroup	CFL	Standard Deviation (SD)	Standard Error (SE)	T Value	Confidence Interval (CI)	Lower Limit	Upper Limit
Control	-	190	15.9	4.59	2.20	10.09	179.91	200.09
4L	4L-A	265	15.9	4.59	2.20	10.09	254.91	275.09
	4L-N	220	15.9	4.59	2.20	10.09	209.91	230.09
	4L-A+4L-N	275	15.9	4.59	2.20	10.09	264.91	285.09

Table 3. Mean flexural strength (FS) and creep values of tested groups

Test Condition	After 10 ⁴ Cycles				Without 10 ⁴ Cycles				1-Way ANOVA
	Group	Control	4L (4 layers of SN fiber)		Controlx	4Lx (4 layers of SN fiber)			
Subgroup	-	4L-A (4 layers of SN fiber above the metal housing)	4L-N (4 layers of SN fiber adjacent to the metal housing)	4L-A+4L-N (4 layers of SN fiber above the metal housing and 4 layers of SN fiber adjacent to the metal housing)	-	4L-Ax (4 layers of SN fiber above the metal housing)	4L-Nx (4 layers of SN fiber adjacent to the metal housing)	4L-A+4L-Nx (4 layers of SN fiber above the metal housing and 4 layers of SN fiber adjacent to the metal housing)	
FS (MPa) Mean ±SD	53 ±8 ^a	74 ±15 ^b	57 ±5 ^a	74 ±12 ^b	92.4 ±13.9 ^c	116 ±7.3 ^d	106 ±11.7 ^{dc}	117 ±6 ^d	<.001
Creep (mm) Mean ±SD	0.7 ±0.1	0.7 ±0.2	0.8 ±0.1	0.8 ±0.2	-	-	-	-	.192

SD, standard deviation; SN, Stick Net. $P < .05$ considered significant. Same superscripted lowercase letters indicate groups not statistically significantly different when compared by Tukey multiple comparisons post hoc analysis ($P > .05$).

were then statically loaded to evaluate the flexural strength after fatigue testing, that is, postfatigue flexural strength (PFFS). A 95% confidence interval analysis was conducted for the CFL values of the tested groups. Also, creep values were collected from the test machine and analyzed.

After fatigue and postfatigue testing procedures, the specimens were examined visually to detect failure modes. Failure modes were classified as either the fracture path was arrested at the fibers or the test specimen was fractured into 2 pieces.

The fracture surfaces of representative specimens were evaluated using a scanning electron microscope (JSM 5500; JEOL Ltd). The selected specimens were wet-ground (LaboPol-21; Struers A/S) with silicon carbide paper of decreasing abrasiveness (1000-, 1200-, 4000-grit) and then gold sputter coated before the scanning electron microscope examination.

Statistical analysis of the PFFS and creep values for the test groups was carried out with 1-way ANOVA, followed by a Tukey multiple comparisons post hoc analysis ($\alpha = .05$). The previous analyses were also used to compare the PFFS values of the tested specimens with the static flexural strength values of similar specimens previously tested under static dry loading conditions without exposure to cyclic loading before static testing.³⁷ They were named as the controlx group and 4Lx group with 3 subgroups 4L-Ax, 4L-Nx, and 4L-Ax+4L-Nx. A 2-way ANOVA ($\alpha = .05$) was conducted to detect the effect of fatigue cyclic loading, the position of the fiber layers, and their interaction on the flexural strength. All

analyses were conducted using a statistical software program (IBM SPSS Statistics, v21; IBM Corp).

RESULTS

The results of the investigated CFL were 190 ± 15.9 N for the control group, 265 ± 15.9 N for the 4L-A subgroup, 220 ± 15.9 N for the 4L-N subgroup, and 275 ± 15.9 N for the 4L-A+4L-N subgroup. The 95% confidence interval values showed an overlap between the 4L-A and 4L-A+4L-N subgroups, which indicates that they are statistically similar. All the others are statistically different at $P < .05$ as shown in Table 2.

The PFFS and creep values of the tested groups are presented in Table 3. The 1-way ANOVA revealed a statistically significant difference in the PFFS values ($P < .001$) and non-significant differences in creep values between the control group and reinforced subgroups ($P > .05$). The post hoc Tukey HSD test indicated significantly higher PFFS values in the 4L-A and 4L-A+4L-N subgroups than those in the control group ($P < .001$) and the 4L-N subgroup ($P = .004$ and $P = .005$). Also, no significant difference was found in the PFFS values between the control group and the 4L-N subgroup ($P = .828$) or between the 4L-A and 4L-A+4L-N subgroups ($P > .05$).

The flexural strength values with and without 10 000 cycles were compared among the groups with 1-way ANOVA, and a statistically significant difference ($P < .001$) was found. The post hoc Tukey HSD test showed that all the uncycled specimens had significantly higher

Table 4. Fracture mode of test specimens for investigated groups

Group	Subgroup	Fracture Behavior			
		Fracture Arrested at Fibers		Specimen Fractured Into 2 Pieces	
		Postfatigue Static Loading	Cyclic Loading	Postfatigue Static Loading	Cyclic Loading
Control	–	–	–	6/12	6/12
4L (4 layers of SN fibers)	4L-A	–	–	6/12	6/12
	4L-N	6/12	6/12	–	–
	4L-A+4L-N	6/12	6/12	–	–

SN, Stick Net.

flexural strength values than those exposed to cyclic loading before static testing ($P<.001$) as shown in Table 3.

The 2-way ANOVA showed that the cyclic loading and fiber position both significantly affected the flexural strength ($P<.001$). However, the interaction between the 2 factors was not significant ($P=.467$).

The fracture modes are presented in Table 4. Visual examination revealed that all specimens of the control group fractured into 2 pieces (Fig. 2). In group 4L, all the specimens of the subgroup 4L-A fractured into 2 pieces (Fig. 3A). However, in subgroups 4L-N and 4L-A+4L-N, the fracture was arrested at the fiber layers placed adjacent to the metal for all test specimens (Fig. 3B, C).

DISCUSSION

The results of the study confirmed the hypothesis that the location of reinforcing fiber layers significantly affects the flexural fatigue resistance of a single LOCATOR-retained overdenture. Implant-retained overdentures are exposed to fatigue stress in function. Previous studies have reported that correct placement of a sufficient amount of well-impregnated glass fiber reinforcements can significantly increase fracture load values and interrupt the fracture propagation in the denture base.^{18,31} Moreover, the fiber reinforcement should be placed in locations associated with highest tensile stresses.¹⁵ High tensile stresses were recorded on the top surface and next to the abutments for a single implant-retained overdenture⁴¹ and two²⁴ implant-retained overdentures. From the mechanical point of view, attachment systems place stresses on the overdenture base. Also, they transmit functional forces to the implant, increasing the risk of complications.^{19,23}

One characteristic feature of unsplinted LOCATOR stud attachments is stress breaking, which has been reported to reduce lateral forces and implant loading. However, such resiliency was found to be associated with tensile deformation in the denture base area around attachments.⁴² These deformations may not only lead to denture base fracture but can also transmit compressive stresses to the bone, causing ridge resorption.⁴³

The present study showed that the position of the fiber significantly affected PFFS values. Placing 4 layers of bidirectional woven E-glass fiber weaves as the reinforcement



Figure 2. Fractured specimen of control group (top view).

only above or both above and adjacent to the metal housing resulted in the highest increase in cyclic fatigue limits and PFFS values as seen in subgroups 4L-A and 4L-A+4L-N; however, both subgroups were not significantly different from one another. Placing the fibers closer to the side of tensile stresses was proven to be more effective in reinforcing the denture base resin against repeated bending than the fiber reinforcements being placed on the side of compression stresses.¹⁵ Takahashi et al¹⁹ reported that reinforcing an implant overdenture on the top of copings can effectively decrease the denture base strains and stress transmission to the underlying implants and tissues. Gonda et al¹⁸ also reported that reinforcing the denture base above the copings reduced the strain values on mandibular telescopic overdentures. Metal reinforcements inserted in single-implant overdenture bases can also provide better stress distribution throughout the prosthesis instead of concentrating it around the implant housing and reduced the tensile stresses around the housing portion of the implant by 61.8%.⁴¹

Placing the SN fiber reinforcement next to the LOCATOR attachment significantly increased the CFL but did not significantly increase PFFS values. However, it was successful in inhibiting the crack propagation and limiting it to only a partial fracture of the test specimens (Fig. 3B). A previous study¹⁹ showed that strains and deformation of the denture base around the implant copings were not significantly reduced by fiber

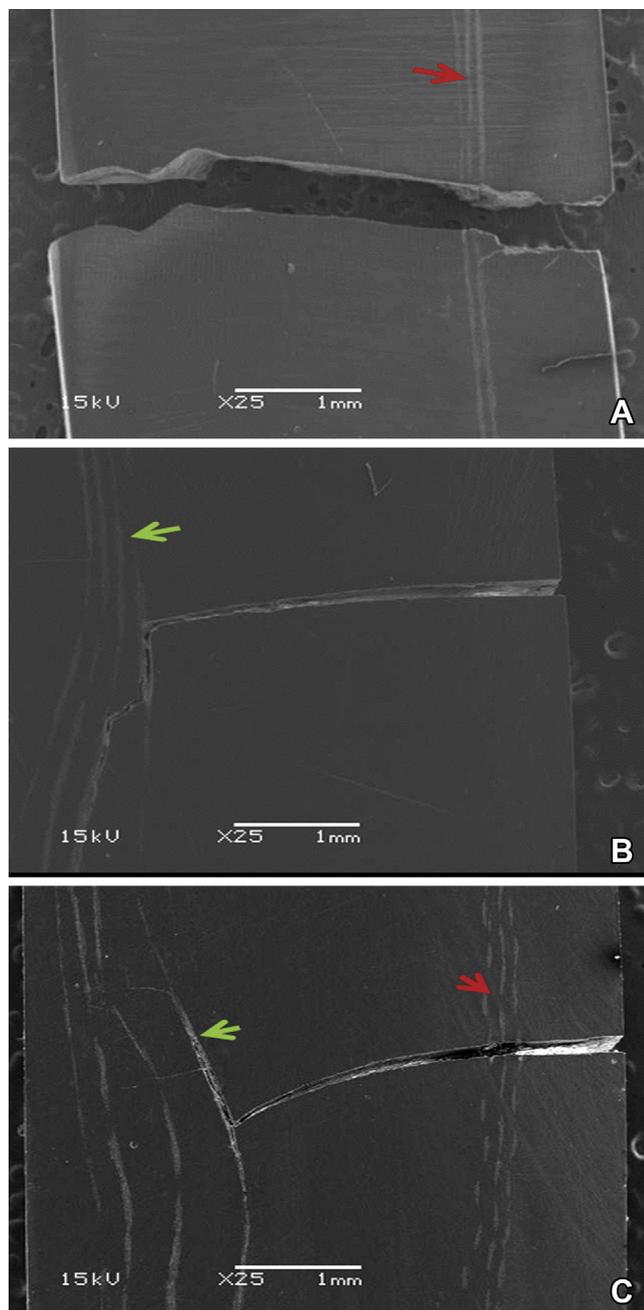


Figure 3. Scanning electron micrograph of fracture path for 4L group and schematic drawing demonstrating fiber position (red and green arrows) in specimen. A, Subgroup 4L-A with SN fiber above metal housing (red arrow). B, Subgroup 4L-N with SN fiber adjacent to metal housing (green arrow). C, Subgroup 4L-A+4L-N with SN fiber above metal housing (red arrow) and SN fiber adjacent to metal housing (green arrow). Original magnification $\times 25$.

reinforcements placed on the sides of the implant coping. Accordingly, as the side reinforcement around the abutment reduced the deformation to a certain limit, it may be used in situations with insufficient space between the abutment and denture teeth for placing the top reinforcement. A similar finding was detected by Rached

et al,³¹ who found that the strengthening capacity of fibers placed on the compression side of an implant-supported overdenture simulation model was less than that of fibers placed at the middle section of the specimen.

The nonsignificant decrease in creep values may be due to the low fiber volume of SN fiber weaves. This low fiber volume may not efficiently increase the fracture modulus (γ), which is directly proportional to the fiber concentration that results in transmitting stresses to the adjacent denture base material.^{29,41}

The 2-way ANOVA showed that cyclic loading and fiber position both significantly affect the flexural strength ($P < .001$). However, the interaction between the 2 factors was not significant ($P = .467$). A comparison of the flexural strength values of cycled and uncycled specimens showed that the flexural strength was significantly affected by fatigue cycling. A similar effect was reported in a previous study of denture base resin's flexural and fatigue strength.⁴⁴ Another cause for low flexural strength values of the cycled specimens might have been the water saturation of fibers.⁴⁵ However, denture base polymers with properly silanated glass fibers do not weaken in water even over several years.⁴⁶

Heat formation could affect the results of fatigue testing. To avoid that effect in the present study, the frequency of loading the specimens was kept low (0.5 Hz), and the test specimens were immersed in water during testing.¹⁵

The in vitro model used in this study may not simulate the failure modes and clinical stress conditions exactly. The number of fatigue cycles might also have been low as a previous study showed that 10 000 fatigue cycles have little impact on the flexural strength of some tested materials.⁴⁴

CONCLUSIONS

Within the limitation of this in vitro study, the following conclusions were drawn:

1. Placing 4 layers of bidirectional E-glass fiber weaves above the metal housing can increase the fatigue resistance and the PFFS of single LOCATOR-retained overdentures.
2. Placing fibers adjacent to the metal housing does not reinforce the specimens significantly after cyclic loading.
3. Placing the fiber reinforcement adjacent to the metal housing does not significantly improve the flexural strength of specimens already reinforced with fibers above the metal housing.

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