Dental Materials Journal 2016; 35(2): 264–269

In vitro evaluation of the flexural properties of All-on-Four provisional fixed denture base resin partially reinforced with fibers

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The aim of this study was to assess the effects of partial carbon or glass fiber reinforcement on the flexural properties of All-on-Four provisional fixed denture base resin. The carbon or glass fibers were woven (3% by weight) together in three strands and twisted and tightened between the two abutments in a figure-of-"8" pattern. Four types of specimens were fabricated for the three-point loading test. The interface between the denture base resin and fibers was examined using scanning electron microscopy (SEM). Reinforcement with carbon or glass fibers between two abutments significantly increased the flexural strength and flexural modulus. SEM revealed relatively continuous contact between the fibers and acrylic resin. The addition of carbon or glass fibers between two abutments placed on All-on-Four provisional fixed denture base resin may be clinically effective in preventing All-on-Four denture fracture and can provide several advantages for clinical use.

Keywords: Flexural properties, All-on-Four, Partial fiber reinforcement, Carbon and glass fiber

INTRODUCTION

The All-on-Four treatment protocol[1,2] involves the restoration of edentulous arches with four implants, including two anterior vertically and two posterior tilted implants, which are immediately loaded by a fixed provisional denture. Satisfactory clinical outcomes have been reported in both short- and long-term follow-up studies of this protocol[3]. According to the standard All-on-Four protocol, a provisional fixed denture is delivered on the same day of implant surgery[1,2]. The denture base resin is commonly based on polymethylmethacrylate (PMMA), which has several advantages such as excellent esthetics, stability in the oral environment, and ease of repair. However, flexural fatigue has been considered as a predisposing factor for fracture[4]. Furthermore, as opposed to conventional removable denture bases, All-on-Four provisional fixed denture bases receive four abutments; most fractures occur adjacent to these abutments, where the bond between the abutment and resin matrix is considered to be weak[5]. All-on-Four provisional fixed denture fracture is one of the most common mechanical complications, with the rate ranging from 11.3 to 40.0%[5,6].

Various reinforcing materials for conventional removable denture bases have been introduced, including metal wires[7] and several types of fibers, including carbon[8], glass[9], nylon[9], aramid[9,10], and ultra-high modulus polyethylene[10] fibers. The use of metal wires is limited because of weak levels of adhesion with the resin matrix[7], fibers in the dispersed phase were difficult to manipulate and polish; therefore, none of these methods has been widely accepted. Carbon and glass fibers have been widely studied and their reinforcing effects have been documented in the past literature[7,8], the adhesion between glass fibers and the denture base resin can be enhanced by silanization[11,12].

Partial fiber reinforcement (PFR)[13] involves the accurate placement of fibers in the weak areas of the denture base. PFR is equivalent to reinforcement of the entire denture base, with superior ease of handling compared with total fiber reinforcement (TFR), where the entire denture base is reinforced with fibers.

The purpose of this *in vitro* study was to evaluate the effects of partial carbon or glass fiber reinforcement on the flexural properties of All-on-Four provisional fixed denture base resin using the three-point loading test. Two abutments at a distance of 18 mm were placed in the test specimens for clinical simulation. The interface between the acrylic resin and fibers was examined using scanning electron microscopy (SEM).

MATERIALS AND METHODS

The following materials were used in this study:

- Heat-cured acrylic resin (Vertex RS, Dentimax, Zeist, the Netherlands)
- Continuous unidirectional strands of carbon fibers (Beijing carbon fiber, Beijing, China) and glass fibers (Nanjing glass fiber, Nanjing, China)
- Silane coupling agent: γ-methylacryloyloxypropyltrimethoxysilane (KH-570, Nanjing Shuguang Chemical Group, Nanjing, China)
- Abutments (Nobel Biocare AB, Gothenburg, Sweden)

Specimen preparation

A negative dental stone mold (64×40×5 mm) was

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Received Jul 23, 2015: Accepted Oct 29, 2015
doi:10.4012/dmj.2015-243 JOI JST.JSTAGE/dmj/2015-243

prepared in a dental plaster mold using the stainless steel die technique. Two dies were placed at a fixed distance of 18 mm in the negative stone mold, and the abutments were fixed on these dies using screws.

Carbon and glass fibers were cut to a length of 15 cm, dipped into silane solution for 5 min, and air-dried at room temperature. The fibers were then woven together (3% by weight) into three strands to tame their spring-like properties, following which they were twisted and tightened between the two abutments in an "8" pattern (Fig. 1a and 1b). Both terminals of the woven fibers were maintained at a distance of about 8 mm, and the "8" pattern was fixed by a small amount of auto-cure acrylic resin (Vertex RS, Dentimax).

The polymer: monomer ratio was 1.5 g: 1.0 mL for polymerization according to the manufacturer's instructions. Then, the mixture was slightly overfilled into the negative stone mold, which was shaken and allowed to stand for approximately 6 min until a thin film formed on the surface of the mixture. The mold was then placed into the injection system maintained at 2.5 bar and 50±5°C for 30 min.

After deflasking, the surfaces of the test specimens were polished with silicon carbide grinding papers (400, 600, and 800 grit) in a grinding machine (MP-2B, Laizhou Instrument Manufacturing, Shandong, China). Then, they were cut to a final dimension of 64×10×3.3 mm according to ISO20795-1:2008. The size of each specimen was verified at three locations on each side using a vernier caliper.

The test specimens were stored in a water bath at 37°C for 50 h before testing.

A total of 40 specimens were fabricated and divided into the following four groups containing 10 specimens each.

Group A: Specimens without abutments and fiber reinforcement (plain group)

Group B: Specimens with two abutments and no fiber reinforcement (abutments only group)

Group C: Specimens with two abutments and carbon fiber reinforcement (abutments and carbon fiber reinforcement group)

Group D: Specimens with two abutments and glass fiber reinforcement (abutments and glass fiber reinforcement group)

Three-point loading test

The flexural strength and flexural modulus of the specimens were measured using a universal test machine (3367, Instron, Norwood, MA, USA) according to ISO 1567 standards at a crosshead speed of 5.0 mm/min and a span length of 50 mm (Fig. 2). The loading point is located in the middle of the specimen that corresponded to the jointing point of the "8" pattern for the fiber reinforcement specimen. All specimens were tested at three bending points until failure occurred and the results were calculated using a computer program (Instron Bluehill® Lite, Instron). The flexural strength and flexural modulus were calculated using the following formulae:

$$S=3FL/2BH^2$$

$$E=F_1L^3/4BH^3D_1$$

Where S is the flexural strength, E is the flexural modulus, F is the maximum load at break (N), L is the distance between two supports, B is the width of the specimen, H is the thickness of the specimen, and D_1 is the deflection (mm) corresponding to the force at point F_1 (N) in the linear region of the load-deflection curve.

SEM

The fracture surfaces were treated by gold-sputtering, following which three specimens from the fiber reinforcement groups were randomly selected for SEM (JSM-5600LV, Jeol, Tokyo, Japan). The cross-sectional view of the fractured segment was examined to characterize the interface between the fibers and denture base resin and analyze the degree of fiber impregnation by the resin.

Statistical analysis

Data were statistically analyzed using one-way ANOVA

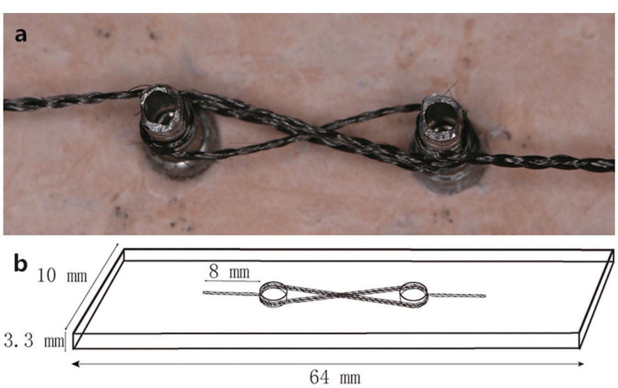

Fig. 1 Schematic image of the specimens evaluated in this study.

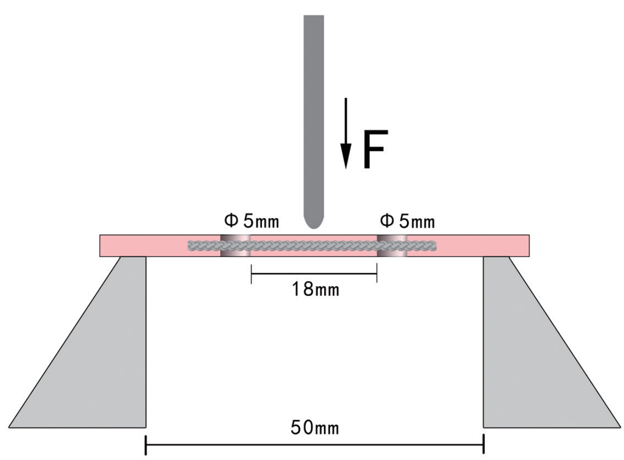

Fig. 2 Schematic diagram of the three-point loading test.

with SPSS software (SPSS17.0, SPSS, Chicago, IL, USA). A *p*-value of ≤0.05 was considered statistically significant.

RESULTS

Flexural strength

The flexural strength of Group B specimens was significantly lower than that of Group A specimens, while that of Groups C and D specimens was significantly higher than that of Groups A and B specimens (Fig. 3).

Flexural modulus

The flexural modulus of the Groups A and B specimens was comparable, while that of the Groups C and D specimens was significantly higher than that of the Groups A and B specimens. Moreover, the flexural modulus of the Group C specimens was significantly higher than that of the Group D specimens (Fig. 4).

Fracture points and failure modes

Group A: All fracture points occurred between the two supports of the three-point loading test. The failure modes were all completely fractured.

Group B: All fracture points occurred at the interface between resin and abutments. One specimen had two fracture points. The failure modes were all completely fractured.

Group C: One fracture point occurred between two abutments and the others occurred at the interface between resin and abutments. The failure modes were partially resin or fibers fractured that were in eight specimens and completely fractured in two specimens.

Group D: Two fracture points occurred between two abutments and the others occurred at the interface between resin and abutments. The failure modes were partially resin or fibers fractured that were in seven specimens and completely fractured in three specimens (Fig. 5).

SEM revealed relatively continuous contact between the carbon or glass fibers and the denture base resin, with few empty spaces (Figs. 6a, 6b, 7a and 7b).

The amount of adhered particles on the surface of the glass fibers was lesser than that on the surface of the carbon fibers (Figs. 6c and 7c).

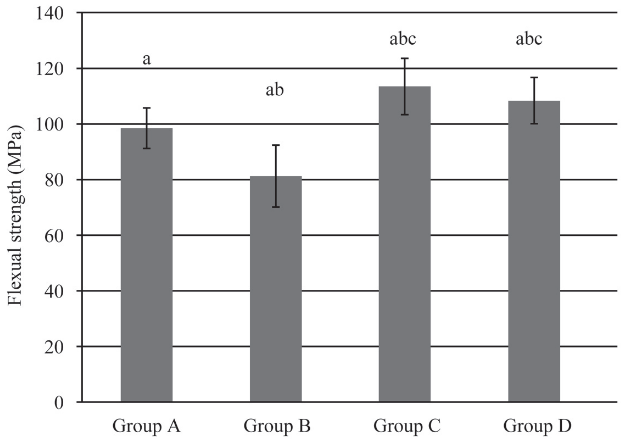

Fig. 3 Flexural strength in the four groups.
The superscripts with the same letters show results that were not significantly different according to one-way ANOVA.

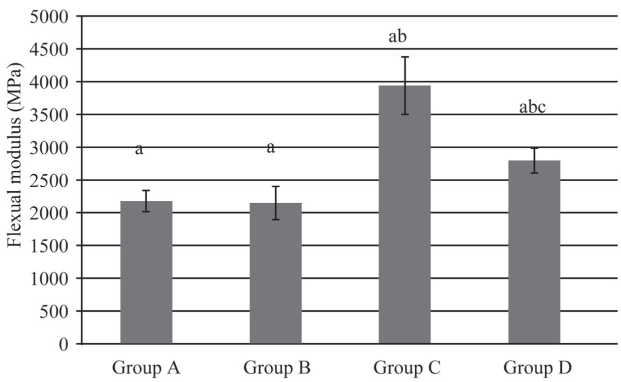

Fig. 4 Flexural modulus in the four groups.
The superscripts with the same letters show results that were not significantly different according to one-way ANOVA.

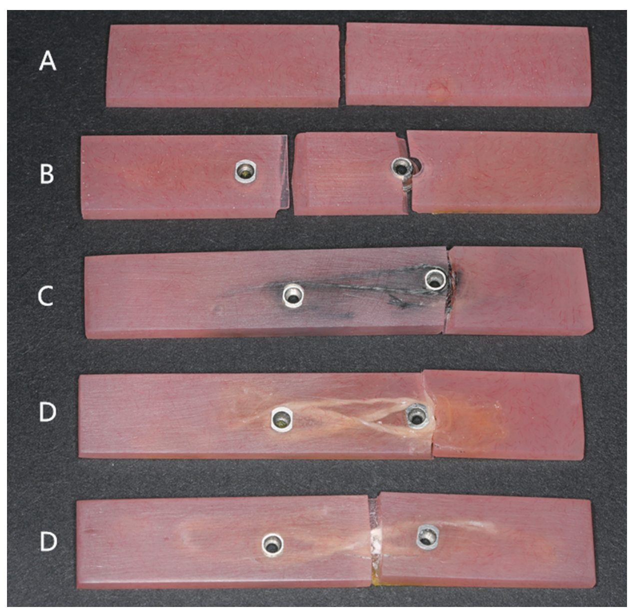

Fig. 5 Fracture points and failure modes of the four groups.

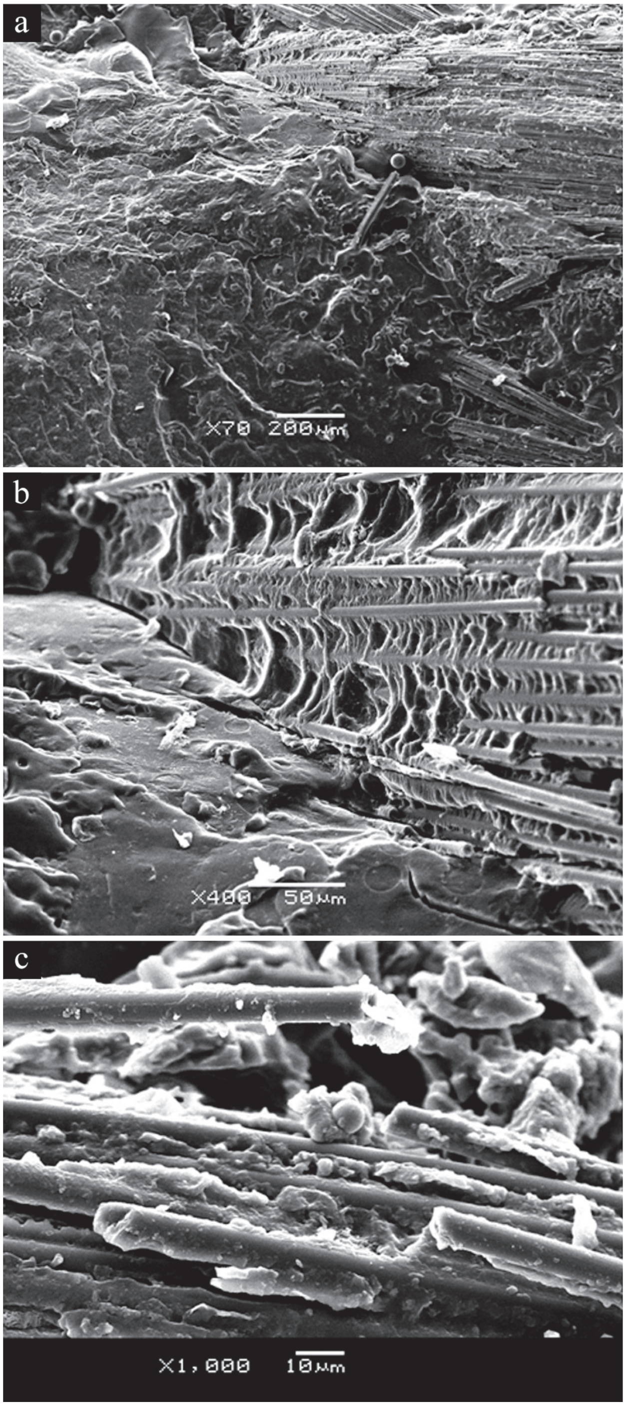

Fig. 6 Scanning electron microscopic images of the fractured segment of a specimen reinforced with carbon fibers.
Continuous contact between the carbon fibers and denture base resin, detected by 70× magnification; a few empty spaces detected by 400× magnification; adhered particles on the surface of the carbon fibers, detected by 1,000× magnification.

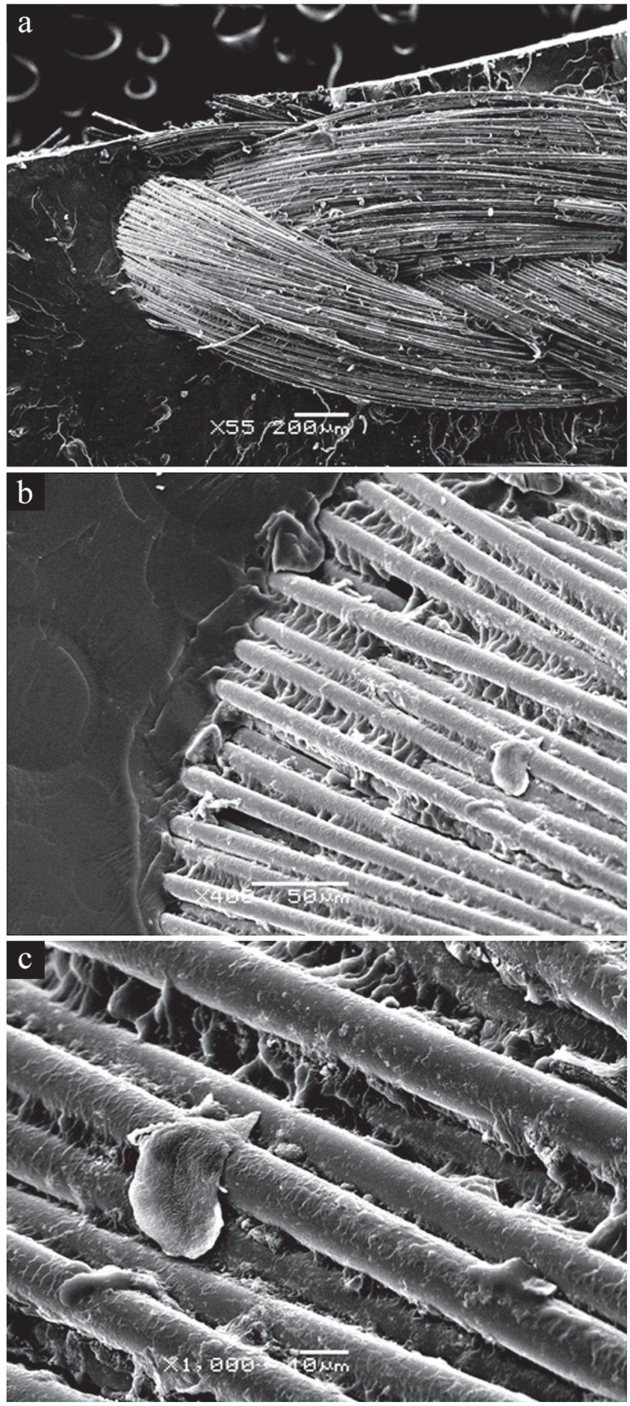

Fig. 7 Scanning electron microscopic images of the fractured segment of a specimen reinforced by glass fibers.
Continuous contact between the glass fibers and denture base resin, detected by 55× magnification; small empty spaces detected by 400× magnification; adhered particles on the surface of the glass fibers, detected by 1,000× magnification.

DISCUSSION

Denture base materials bear different forces during the mastication process, including compressive stress, tensile stress, and shear stress, together known as complex stress[9]. The flexural strength can describe the performance of denture base materials under such complex stress[14]. The flexural modulus is associated with elastic deformation; a larger flexural modulus indicates greater difficulty to induce elastic deformation, increased stiffness and decreased toughness of the denture base material[15].

In this study, the placement of two abutments in specimens without fiber reinforcement decreased the flexural strength of the resin base, but the flexural modulus remained unaffected. On the other hand, carbon or glass fiber reinforcement enhanced the flexural strength as well as flexural modulus compared with no reinforcement. However, the flexural modulus was lower for the glass fiber-reinforced specimens than for the carbon fiber-reinforced specimens, which means that glass fiber-reinforced denture base resin can maintain a certain level of toughness while enhancing the flexural strength. There is a limitation that the force placed on the specimen was only uni-directional in the three-point loading test, while multi-directional stresses were applied on the denture base within the mouth. However, occlusal adjustment is an important step in clinical practice, and therefore any undesirable lateral stress should be avoided and patients were instructed to eat with their posterior teeth. The maximum occlusal contact was in the implant-supported area in a centric relationship, and there was no occlusal contact towards the distal cantilever in any position. Furthermore, the tissue surface of the prosthesis did not always show a "face to face" type of close contact to the alveolar crest, and to some degree, the implants corresponded to the supports of the three-point loading test.

In addition to the fiber type, other factors affecting the strength of fiber-reinforced composites include the fiber orientation[8], resin impregnation of fibers[16], fiber-resin adhesion[11], and volume concentration[17].

A previous study showed that strands of fibers are more effective in reinforcing the denture base resin compared with woven fiber mats[8]. Continuous unidirectional strands of fibers placed perpendicular to the direction of the applied force can result in the most favorable flexural strength[12]; a decreased flexural strength can be the result of woven fiber mats reinforcing the denture base resin in two directions. However, the fibers tend to spread out laterally, and their placement in the ideal position can be difficult and requires complicated technical procedures[18]. The difficulty of this technique may outweigh the potential advantages[12]. Furthermore, multidirectional forces are placed on the dentures within the oral cavity, and it is often difficult to predict the direction of the highest force. Continuous unidirectional strands of fibers were selected for this study, although they were woven together in three strands for better handling and to facilitate close packing without lateral spreading.

Studies have shown void formation in the interface between the acrylic resin and fibers, probably because of poor resin impregnation of the fibers and polymerization shrinkage of the acrylic resin[16]. Favorable impregnation is a prerequisite for the bonding of fibers to acrylic resin. Inadequate impregnation can occur because of a relatively high viscosity and poor wetting properties in the dough stage of heat-cure PMMA, when the continuous fibers are placed in the denture base resin[17,19]. This problem can be solved by fixing the fibers in an "8" pattern between two abutments before the injection of acrylic resin, which is applied over the woven fibers at a low viscosity to result in better impregnation. Furthermore, tightening of the woven fibers between two abutments may decrease polymerization shrinkage through decreased fiber distortion in the denture base resin[20]. The injection molding technique was selected for this study because it results in less polymerization shrinkage compared with the compression molding technique[21]; moreover, the mechanical properties of injection-molded denture base polymer are significantly better than those of compression-molded polymer[22].

The silane coupling agent A174 (γ-Methylacryloylox ypropyltrimethoxysilane) has been used to improve the adhesive properties of glass fibers, although it does not increase the adhesion between resin and carbon fibers[11]. However, SEM showed that the amount of adhered particles on the surface of the carbon fibers was higher than that on the surface of the glass fibers in this study (Figs. 4c and 5c). The reason for this conflicting result should be investigated in further studies. To the best of our knowledge, evidence on the adhesive properties of different silane coupling agents with regard to different fibers is scarce. However, 85% fracture points occurred at the interface between resin and abutments in the fiber reinforcement specimens, which was probably because the bond between abutment and resin or fibers is still a weak area.

PFR involves reinforcement with a relatively small amount of fibers that are accurately placed in the weak area of the denture[13]. Twisting and tightening of the woven fibers between two abutments provides effects similar to those of PRF, ensuring adequate reinforcement and simplifying the procedure. Special care should be taken to ensure that the fibers are totally covered with the denture base resin without exposure to the oral environment in order to avoid mucosal irritation, which was detected in a study by Yazdanie *et al.*[8]. However, there is no evidence of long term toxicity from carbon fibers[23]. According to the previous literature, the fibers should be wrapped in the resin matrix of the composite to avoid discoloration due to a possible increase in the adhesion of *Streptococcus mutans*[24]. Furthermore, fibers exposed to the oral environment result in increased water resorption and decreased mechanical properties due to potentially poor impregnation and void formation in the fiber-reinforced composite[19,24].

The brittleness[25] of glass fibers may be a drawback when they are used alone for reinforcement of the denture base resin. Therefore, a hybrid fiber-reinforced composite containing both carbon and glass fibers should be investigated in further studies. Although carbon fibers may present esthetic problems, the four abutments emerge on the lingual or palatal side of All-on-Four provisional fixed dentures and the position of the fibers in the provisional prosthesis is usually located at the top of the patient's smile line; therefore, the black color is not very conspicuous from the frontal view.

CONCLUSIONS

Within the limitations of this study, the following conclusions were derived.

The placement of abutments in denture base resin significantly decreases the flexural strength.

The addition of carbon or glass fibers between two abutments in the All-on-Four provisional fixed denture base resin may clinically increase the fracture resistance.

PFR allows total fiber coverage by the denture base resin, without any exposure to the oral environment, and provides several advantages for clinical use.

ACKNOWLEDGMENTS

The authors would like to thank Qiang Hao for his help in specimen preparation. This study was supported by the Capital Medical Research and Development Fund.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest related to this study.

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