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ORIGINAL ARTICLE

Load-bearing capacity of fiber reinforced fixed composite bridges

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Abstract

Objective. The aim of this study was to evaluate the reinforcing effect of differently oriented fibers on the load-bearing capacity of three-unit fixed dental prostheses (FDPs). ***Materials and methods.*** Forty-eight composite FDPs were fabricated. Specimens were divided into eight groups (n = 6/group; codes 1–8). Groups 1 and 5 were plain restorative composites (Grandio and Z100) without fiber reinforcement, groups 2 and 6 were reinforced with a continuous unidirectional fiber substructure, groups 3 and 7 were reinforced with a continuous bidirectional fiber and groups 4 and 8 were reinforced with a continuous bidirectional fiber substructure and continuous unidirectional fiber. FDPs were polymerized incrementally with a handheld light curing unit for 40 s and statically loaded until final fracture. ***Results.*** Kruskal–Wallis analysis revealed that all groups had significantly different load-bearing capacities. Group 4 showed the highest mean load-bearing capacity and Group 7 the lowest. ***Conclusion.*** The results of this study suggest that continuous unidirectional fiber increased the mechanical properties of composite FDPs and bidirectional reinforcement slowed crack propagation on abutments.

Key Words: *fixed dental prosthesis, load-bearing capacity, fiber-reinforced composite*

Introduction

Partially edentulous dentitions are treated most commonly using crown-retained fixed dental prostheses (FDPs) [1]. Fiber-reinforced composite (FRC) FDPs are an alternative to conventional FDPs when a tissue-saving treatment of relatively low cost is needed [2]. FRC allows the fabrication of adhesive, aesthetic and metal-free tooth replacements [3]. In recent decades, FRC materials have been developed to improve the mechanical properties of denture bases and composite resins [4]. Many studies have focused on the improvement of FRC FDP strength [5–7], because static and repeated masticatory loads introduce the risk of FDP fracture [8]. The reinforcement of resin-based materials with glass fibers has been shown to resolve this problem [4]. Glass fibers are commonly used to reinforce dental polymers due to their efficiency and aesthetic qualities compared with carbon, polyethylene or aramid fibers [9,10]. Fiber-reinforcing efficacy is related to fiber form, orientation and length; the resin used; the quantity of fibers in the resin matrix; and the adhesion of fibers to the polymer matrix [11–15].

In vitro research has shown that fiber reinforcement increases the fracture strength of resin composite to a level that justifies the clinical use of this material in unsupported applications [16–18].

An overview of the literature on FRC FDPs concluded that there is still poor scientific evidence for the advocation of these devices as an alternative to conventional crown-retained FDPs [19]. Previous studies investigated the effect of fiber orientation on the mechanical properties of composite materials [14,20]. The aim of the present study was to investigate the reinforcing effect of differently oriented E-glass fibers on the load-bearing capacity of FDPs made of two particulate filler composites.

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Our hypothesis was that FRC FDPs would demonstrate higher load-bearing capacities than would unreinforced composite FDPs.

Materials and methods

The materials used in this study are listed in Table I. One microfilled (Z100 MP; 3M ESPE AG, Seefelt, Germany) and one nanohybrid (Grandio; Voco GmbH, Cuxhaven, Germany) composite and unidirectional (EverStick; Stick Tech Ltd., Turku, Finland) and bidirectional E-glass fibers (Sticknet; Stick Tech Ltd.) were used.

Forty-eight laboratory-manufactured three-unit FDPs were fabricated and the specimens were divided into eight groups (*n* = 6/group; codes 1–8). FDPs (24 mm total length, 20 mm between abutments) extending from the mandibular first premolar to the first molar and replacing the second premolar and were prepared on a zirconia model (Ice Zirconia; Zirconzahn, Bruneck, Italy; Figure 1A). Crown preparations of the abutments were made with 2 mm of occlusal and axial reduction. An intra-oral camera was used to obtain photographs and the zirconia model was transferred to the Cerec 3 milling unit (Cerec MC L; Sirona Dental Systems, Bensheim, Germany) by optical impression. A three-unit FDP (20-mm span length) was created using a computer. To prepare an ideally contoured FDP, the Cerec 3 unit was used to mill a VITA CAD-Temp block (Vita Zahnfabrik, Sackingen, Germany). A transparent polyvinyl siloxane template matrix (Memosil 2; Heraeus Kulzer GmbH, Herau, Germany) of this FDP was used to standardize the dimensions and occlusal morphology of FDP fabrication.

FDPs in the eight specimen groups were fabricated using the following materials: group 1, plain nanohybrid composite (NC); group 2, NC reinforced with a continuous unidirectional fiber (CUF) sub-structure (NCUF); group 3, NC reinforced with a continuous bidirectional fiber (CBF) sub-structure (NCBF; thickness = 0.12 mm); group 4, NC reinforced with CBF and a CUF sub-structure (NCBUF); group 5, plain microfilled composite (MC); group 6, MC reinforced with a CUF sub-structure (MCUF); group 7, MC reinforced with a CBF sub-structure (MCBF); and group 8, MC reinforced with CBF and a CUF sub-structure (MCBUF). In groups 2 and 6, the NCUF was placed over the occlusal surfaces of the mandibular first premolar to first molar, and a short piece of CUF was placed on the occlusal surface of the main framework perpendicular to the main framework fibers (Figure 1B). In groups 3 and 7, the NCBF was placed over the axial and occlusal surfaces of the mandibular first premolar and first molar abutments without exceeding the finishing lines (Figures 1C and D).

The FDPs of each group were polymerized with a handheld light curing unit (Optilux 501; Kerr Dental Corporation, Danbury, CT) for 40 s (380 and 520 nm wavelengths, 470 nm maximum intensity, 800 mW/cm^2 light irradiance). Each FDP was cemented to the zirconia model with a dual-curing luting cement (Rely X Unicem App.; 3M ESPE AG) according to the manufacturer's instructions and excess luting cement was removed. The luting cement was light cured from three directions (occlusal, buccal and lingual). After cementation, the model with FDP was fixed to the metal base of the testing device (Figure 1E), a static compressive fracture test was performed using a universal testing machine (Model LRX; Lloyd Instruments Ltd., Fareham, UK) at a speed of 1 mm/min and data were recorded using PC software (Nexygen; Lloyd Instruments Ltd.). The load was applied to the central fossa of the pontic using a steel ball (3-mm diameter) and each specimen was loaded until final fracture occurred. The fracture patterns of the FDPs were analyzed visually and determined to be brittle fractures, partial fractures or delaminating and veneering cracks.

Means and standard deviations were calculated and reported. Kruskal–Wallis and Mann–Whitney U-tests

Table I. Materials used in the study.

Brand	Manufacturer	Lot no.	Composition
Grandio	VOCO (Cuxhaven, Germany)	321467	Bis-GMA, UDMA, TEGDMA
Z100	3M ESPE (St Paul, MN)	20040420	Bis-GMA,TEGDMA
EverStick	StickTeck Ltd. (Turku, Finland)	2050426-ES-125	PMMA, BisGMA, E-glass fibers
Sticknet	StickTeck Ltd. (Turku, Finland)	2040315-w-0050	Porous PMMA pre-impregnated bidirectional E-glass fibers
Stick Resin	StickTeck Ltd. (Turku, Finland)	540 1042	60% BisGMA–40% TEGDMA
RelyX Unicem	3M ESPE (Seefeld, Germany)	3415	methacrylated phosphoric acid ester, DMA, GL, silica, initiator, stabilizer, acetate, calcium hydroxide, polymer

Bis-GMA, Bisphenol-A-glycidyl dimethacrylate; UDMA, Urethane climethacrylate; TEGDMA, Trietyleneglycol climethacrylate; PMMA, Polymethylmethacrylate.

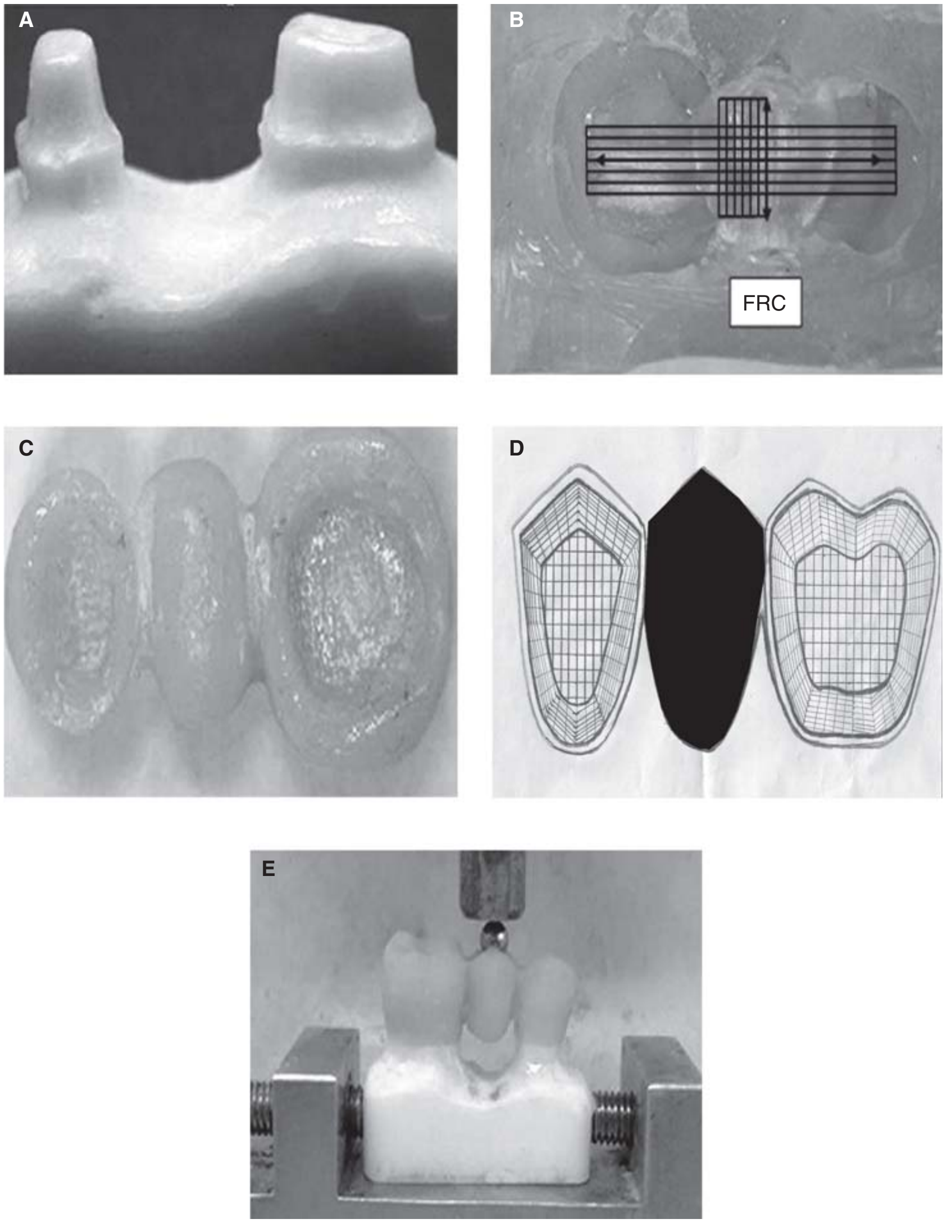

Figure 1. (A) Photograph of the zirconium model. (B) Placement and directions of continuous unidirectional fiber framework. (C) Insight of FDP with continuous bidirectional fiber framework. (D) Illustration of continuous bidirectional fiber framework. (E) Test set-up and position of loading tip.

were used to determine significant differences among groups.

Results

The load-bearing capacities of tested FDPs with standard deviations, standard errors and maximum and minimum values are given in Table II. Kruskal–Wallis analysis revealed that all groups had significantly different load-bearing capacities ($p < 0.01$); these differences were further evaluated with the Mann–Whitney U-test (Table III).

The NCBUF exhibited the highest mean load-bearing capacity. However, no significant difference was observed between the NCBUF and the NCUF or NCBUF and the MCBUF ($p > 0.05$). Although the MCBF showed the lowest load-bearing capacity, it did not differ significantly from that of the MC ($p > 0.05$). No significant differences were observed between the NC and NCBF, NCUF and MCUF or MCUF and MCBUF ($p > 0.05$), but load-bearing capacity differed significantly between all other pairs of groups ($p < 0.05$).

Fracture pattern analysis showed four types of fractures (Figure 2). Brittle fractures occurred in the NC and MC and delamination was present in the NCUF, NCBUF, MCUF and MCBUF. Veneering cracks at abutments occurred in some NCUF and MCUF samples. Partial fractures were seen in the NCBUF and MCBUF.

Table II. Descriptive statistics for groups.

Groups	*n*	Mean	SD	SE	Maximum	Minimum	*p*-Value
NC	6	1720.5	206.5	84.3	2077.00	1440.00	< 0.01
NCUF	6	1962.6	346.2	141.3	2367.00	1650.00	< 0.01
NCBF	6	1613.3	198.6	81.1	1804.00	1259.00	< 0.01
NCBUF	6	1990.2	212.3	101.7	2391.00	1700.00	< 0.01
MC	6	1296.0	265.2	108.2	1717.00	976.00	< 0.01
MCUF	6	1772.5	394.6	161.1	2101.00	1308.00	< 0.01
MCBF	6	1226.0	214.8	87.6	1622.00	1021.00	< 0.01
MCBUF	6	1817.0	312.7	107.9	2153.00	1340.00	< 0.01

NC, Nanohybrid composite; NCUF, Nanohybrid composite reinforced with a continuous unidirectional fiber sub-structure; NCBF, Nanohybrid composite reinforced with a continuous bidirectional fiber substructure; NCBUF, Nanohybrid composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure; MC, Microfilled composite; MCUF, Microfilled composite reinforced with a continuous unidirectional fiber sub-structure; MCBF, Microfilled composite reinforced with a continuous bidirectional fiber sub-structure; MCBUF, Microfilled composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure.

Discussion

Fractures are the most common type of restoration failure [21]. Crowns and FDPs may become damaged by fracture or delamination during service [22,23]. Several studies have focused on overcoming these problems and improvements in the FRC framework have been proposed to provide more support to the veneering composite [24–26].

The load-bearing capacity of composite-resin three-unit FDPs after the addition of a fiber sub-structure was of interest in this study. Previous studies have investigated the reinforcing efficiency of fiber [3,14,20,24] using unreinforced composites as controls and have found that fiber reinforcement increased load-bearing capacity. In addition, instantaneous fractures occurred in the unreinforced composite groups. Fibers used in the construction of FRC FDPs effectively stop crack formation and transfer stress from the polymer matrix to the fibers [27,28].

Previous studies have investigated the relationship between the mechanical properties of composite resins and different filler volume fractions. Materials with higher filler volume fractions demonstrated superior mechanical properties [29,30]. Curtis et al. [31] concluded that, despite the high filler loading of the NC and MC (71.4 and 66.0 vol%, respectively), the NC failed to survive pre-loading regimes of 50 and 100 N, whereas approximately half of the MC specimens survived pre-loading regimes of 100 N. The high flexural modulus combined with low fracture strain of the NC and MC may inhibit the ability of resin-bonded composites to resist deformation loading, stress relief and the accumulation of surface and bulk defects, resulting in premature failure [32,33]. These factors may also have contributed to the lower load-bearing capacity values found in the present study.

In the plain composite and CBF-reinforced groups, fractures occurred between the abutment and the pontic. Similarly, the results of finite element analyses reported by Fisher et al. [34] showed that the connector between the bridge abutment and pontic is the critical area of bridges. Tinschert et al. [35] also claimed that dental bridge fractures develop preferentially between the abutment and the pontic. Garoushi et al. [36] reported that composite-only specimens showed a brittle fatal fracture pattern. Keulemans et al. [37] showed that composite FDPs suffered from catastrophic pontic failure. In the present study, fatal fractures developed in FDPs in the plain composite groups due to the brittleness of commercial composites. In the CBF-reinforced groups, CBF provided a stiffer sub-structure and showed an ability to slow or arrest crack propagation on abutments.

A previous study showed that the additional fibers in the pontic were able to arrest crack development and propagation within the composite resin under loading [25]. In the present study, most FRC FDPs failed without main fiber framework fracture, as reported by Xie et al. [25] and Ozcan et al. [38]. Keulemans et al. [37] claimed that FRC FDPs suffered from delamination and veneer cracks and that fiber reinforcement minimized instantaneous and catastrophic failures. The failures in the CUF- and CBUF-reinforced groups, such as veneering cracks or delamination, were related to the veneering material. CUF, which also increased load-bearing capacity, arrested cracks and led to delamination of the composite from the underlying fiber, thereby preventing fractures between the abutment and pontic. The load-bearing capacity was increased by placing one additional piece of unidirectional fiber on the occlusal surface, perpendicular to the main framework [25]. Besides delamination, some veneering cracks occurred at abutments in the CUF-reinforced

Table III. Multiple comparision testing for groups with Mann-Whitney U-test.

Groups	*n*	Mean	SD	Mann-Whiney U	*p*
NC	6	5.53	32	7.00	*
NCUF	6	7.67	46		(0.025)
NC	6	8.83	53	14.00	n.s.
NBUF	6	7.14	25		(0.525)
NC	6	4.74	38	4.00	*
NCBUF	6	8.60	52		(0.028)
NC	6	9.17	55	2.00	*
MC	6	3.83	23		(0.010)
NCUF	6	3.83	23	2.00	*
NBUF	6	9.17	55		(0.010)
NCUF	6	7.46	23	14.00	n.s.
NCBUF	6	6.67	44		(0.459)
NCUF	6	6.67	46	13.00	n.s.
MCUF	6	8.67	52		(0.261)
NBUF	6	4.26	56	3.00	*
NCBUF	6	8.01	27		(0.039)
NBUF	6	8.83	53	4.00	*
MBUF	6	4.17	25		(0.025)
NCBUF	6	6.14	35	13.00	n.s.
MCBUF	6	8.29	41		(0.451)
MC	6	4.33	26	5.00	*
MCUF	6	8.67	52		(0.041)
MC	6	7.17	43	14.00	n.s.
MBUF	6	5.83	35		(0.522)
MC	6	9.47	31	5.00	*
MCBUF	6	7.74	46		(0.035)
MCUF	6	8.96	49	6.00	*
MBUF	6	4.83	32		(0.037)
MCUF	6	9.17	28	16.00	n.s.
MCBUF	6	8.03	51		(0.680)
MBUF	6	8.72	45	3.00	*
MCBUF	6	4.01	22		(0.022)

n.s., non-significant; $^*p < 0.05$.
NC, Nanohybrid composite; NCUF, Nanohybrid composite reinforced with a continuous unidirectional fiber sub-structure; NCBF, Nanohybrid composite reinforced with a continuous bidirectional fiber sub-structure; NCBUF, Nanohybrid composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure; MC, Microfilled composite; MCUF, Microfilled composite reinforced with a continuous unidirectional fiber sub-structure; MCBF, Microfilled composite reinforced with a continuous bidirectional fiber sub-structure; MCBUF, Microfilled composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure.

groups. CBF also prevented crack propagation on abutments in the CBF-reinforced groups. CBF alone did not improve load-bearing capacity, but contributed to load-bearing capacity when used with CUF.

The results of this study showed that unidirectional fibers improved the strength of FDPs, whereas bidirectional fiber reinforcement did not. In addition, FPDs made from NC had higher strength values than did those made from MC.

In the posterior mandible, the average maximum masticatory force is 500–600 N [39]. All groups of FDPs showed high fracture strength, from 1700–2391 N to 1021–1622 N, according to the loading condition. Load-bearing capacities may have been negatively affected by the rigidity of the test set-up [36]. Scherrer and de Rijk [40] claimed that increasing the elastic modulus of the supporting material resulted in increased fracture strength.

Fracture type	NC	MC	NCUF	MCUF	NCBF	MCBF	NCBUF	MCBUF
A 	6	6	0	0	0	0	0	0
B 	0	0	0	0	6	6	0	0
C 	0	0	6	6	0	0	6	6
D 	0	0	4	5	0	0	0	0

Figure 2. Fracture types in fixed dental prostheses. (A) Brittle fracture; (B) Partial fracture; (C) Delamination; and (D) Veneering cracks. NC, Nanohybrid composite; MC, Microfilled composite; NCUF, Nanohybrid composite reinforced with a continuous unidirectional fiber sub-structure; MCUF, Microfilled composite reinforced with a continuous unidirectional fiber sub-structure; NCBF, Nanohybrid composite reinforced with a continuous bidirectional fiber sub-structure; MCBF, Microfilled composite reinforced with a continuous bidirectional fiber sub-structure; NCBUF, Nanohybrid composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure; MCBUF, Microfilled composite reinforced with a continuous unidirectional and bidirectional fiber sub-structure.

Conclusion

Load-bearing capacity was increased by the addition of a CUF sub-structure. Although CUF arrested cracks, CBF arrested or slowed down crack propagation on abutments, provided a stiffer sub-structure and contributed to load-bearing capacity in conjunction with CUF. The results of this study did not exactly support our hypothesis; CBF alone did not improve load-bearing capacity. In addition, FPDs composed of NC materials had higher strength values than did those made with MC material.

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