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In vitro fracture resistance of four-unit fiber-reinforced composite fixed partial dentures

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Summary *Objectives.* The aim of this in vitro study was to investigate the influence of glass fiber-reinforcement on the fracture resistance of four-unit composite fixed partial dentures (FPDs) in the posterior region.
Methods. A total of 70 FPDs were fabricated of the composites Sinfony, Vita Zeta and Targis. With each material, 10 FPDs were made without glass fiber-reinforcement and 10 were reinforced with the new glass fiber system EverStick. In addition, 10 FPDs were fabricated of the material combination Targis/Vectris. After thermocycling, all FPDs were loaded until failure in a universal testing machine. The FPDs were then cut and cross-sectional areas were examined by scanning electron microscopy (SEM).
Results. The load to fracture of the fiber-reinforced FPDs lay between 615 and 1191 N, which was significantly greater than the values found with unreinforced FPDs (between 178 and 307 N). The highest values were found with the combinations Targis/Vectris (1191 N) and Sinfony/EverStick (1137 N). SEM showed that the FPDs with EverStick reinforcement not only exhibited fracture lines in the fiber-composite interface, but also more often in the area of the fiber-reinforcement than was the case with the FPDs with Vectris reinforcement. The load to fracture was not significantly dependent on fiber quantity or course of fracture.
Significance. It may be concluded that the fracture resistance of four-unit composite FPDs can be significantly raised by glass fiber frameworks ($p<0.05$). The reinforcement effect of EverStick depended significantly on the composite used ($p<0.05$).

Introduction

Two different indications must be distinguished in the temporary replacement of missing teeth during prosthetic treatment. Firstly, there are short-term temporary restorations with directly prepared fixed partial dentures (FPD) and secondly, more

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Table 1 Composites and fiber materials used in this study.

Material	Batch number	Manufacturer	Composition (according to manufacturers)
Sinfony	0029	3M Espe, Seefeld, Germany	Aliphatic and cycloaliphatic monomers, 50% inorganic fillers
Vita Zeta	6074U	Vita, Bad Säckingen, Germany	Urethane dimethacrylate, 44% inorganic fillers
Targis 99	D10022	Ivoclar-Vivadent, Schaan, Liechtenstein	Bis-GMA, urethane dimethacrylate, 76% inorganic fillers
EverStick	2011107-ES-036	Stick Tech, Turku, Finland	Unidirectional continuous Bis-GMA and PMMA impregnated glass fiber
EverStickNet	2011107-EN-027		Bidirectional Bis-GMA and PMMA impregnated glass fiber woven (90°)
Vectris Pontic	D9403	Ivoclar-Vivadent, Schaan, Liechtenstein	Unidirectional continuous Bis-GMA impregnated glass fiber
Vectris Frame	D940253		Bidirectional Bis-GMA impregnated glass fiber woven (90°)

long-term restorations during surgical, parodontic or endodontic pre-treatment with composite FPDs prepared indirectly in the laboratory. Although composites of greater material strength have been developed in recent years, temporary FPDs often develop fractures during protracted clinical use [1,2]. Fiber-reinforced composites then offer a promising approach. They have been increasingly studied during recent years and give restorations a considerable increase in strength [3-9]. Such restorations not only resist high levels of mechanical stress, but weigh little, are esthetically satisfactory and can be produced easily and cost effectively [10]. The relationship between fiber content in the polymer matrix and enhancement of the flexural, transverse and impact strength of various fiber-reinforced reconstructions has been controversially discussed in the literature [6,11,12].

The aim of the present study was to examine whether EverStick, a new glass fiber system, can provide adequate and homogenous reinforcement to various composites, making it suitable as a stabilizing insert for long-term provisional four-unit FPDs. For this purpose, fiber-reinforced FPDs were loaded to fracture and examined by scanning electron microscopy (SEM) for quantitative fiber content, bonding between the fiber framework and the composite and fracture morphology.

Materials and methods

Manufacture of the master casts

Teeth 24 and 27 were prepared for the uptake of four-unit FPDs, using a 0.8 mm wide circular chamfer type preparation in a plastic model of an upper jaw (Frasaco OK 119, A-3 T, Franz Sachs and Co., Tettnang, Germany). After impressions were taken of this situation, plaster casts were prepared for manufacturing the FPDs and duplicate models for the load tests were produced, made of polyurethane-based resin (Alpha Die Top, Schütz Labortechnik, Rosbach, Germany). The roots of the polyurethane teeth were covered by a latex layer (Erkoskin, Erkodent, Pfalzgrafenweiler, Germany), to simulate the natural mobility of the teeth.

Manufacture of the FPDs

In all, 70 FPDs were prepared from the composites Sinfony, Vita Zeta and Targis (Tables 1 and 2). The FPDs of all composites were prepared both with and without EverStick reinforcement. To be able to compare the glass fiber system EverStick with a conventional fiber system, Targis FPDs were additionally reinforced with the fiber material Vectris, as recommended by the manufacturer.

Table 2 Combinations of composites and fiber materials used.

Veneering material	Fiber	Number
Sinfony	None	10
	EverStick	10
Vita Zeta	None	10
	EverStick	10
Targis	None	10
	EverStick	10
	Vectris	10

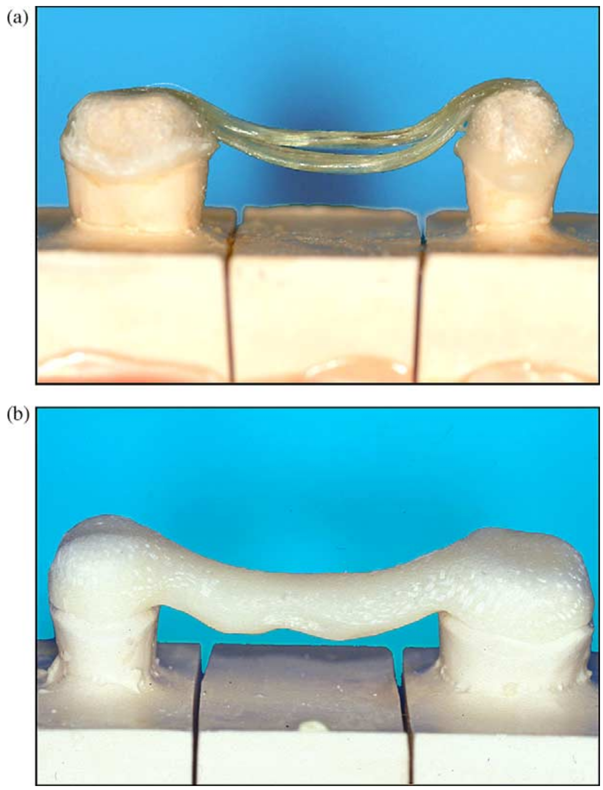

Figure 1 (a) Fiber framework of EverStick. (b) Fiber framework of Vectris.

Ten FPDs in each group were examined. The cross-sectional area of connectors was measured as 16 mm^2 and the FPD span was 15 mm.

The composite materials were processed in accordance with the instructions of the manufacturer. For the preparation of the EverStick fiber frameworks, three layers of EverStickNet fiber mat for each prepared stump were wetted with a drop each of StickResin (StickTech, Turku, Finland) and laid on top of each other, rotated at an angle of 45°. Two pieces of EverStick fiber bundle were cut to size for the whole length of the restoration and adapted to the fiber mats (Fig. 1(a)). Light hardening was performed with the Targis Quick light instrument (Ivoclar-Vivadent, Schaan, Liechtenstein).

For the Vectris frameworks, two sections of Vectris Pontic fiber bundle were measured out. The first of these filled the space between the abutment teeth and the second was adequate for the whole length of the restoration. Light hardening was then performed in the framework former Vectris VS1 (Ivoclar-Vivadent, Schaan, Liechtenstein). The fiber mat Vectris Frame was then adapted and also hardened. Finally, the framework was sandblasted, wetted using the recommended silane coupling agent and veneered using the composite Targis (Fig. 1(b)).

Measurement of load to fracture

All FPDs were submitted to 10 000 thermocycles of 30 s each in water at 5 and 55 °C, respectively, dried for 24 h in air and then luted onto the polyurethane models with temporary zinc oxide eugenol cement (Temp Bond, Kerr, Romulus, MI, USA). The FPDs were loaded in a universal testing instrument (Type 20K, UTS) at a cross-head speed of 1 mm/min, until failure (Fig. 2). The load was applied axially, via a stainless steel ball (∅ 6 mm) to the area of the mesial ridge of the pontic 26. A 0.2 mm thick zinc foil was interposed to prevent local stress peaks. The machine was programmed such that a drop of 10 N in force was rated as fracture or failure of the FPD [13]. Both, deflection at a load of 300 N and load to fracture, were recorded. All FPDs then underwent a visual examination, and fracture behavior was described for each group.

SEM analyses

Five FPDs were randomly selected from each of the groups with fiber-reinforcement (Sinfony/EverStick, Vita Zeta/EverStick, Targis/EverStick, Targis/Vectris). They were analyzed by scanning electron microscopy with respect to fiber quantity, bonding between fiber and composite and fracture morphology. The FPDs were cut with an annular saw in the middle of the connector between the two pontics. The areas cut open by the saw were smoothed consecutively using abrasive paper (500, 800, and 1200 grit, respectively) and diamond paste (DP-Paste, 6 μm, Struers, Copenhagen, Denmark) on polishing cloth (DUR, Struers) in a polishing

Figure 2 Test set-up in the universal testing instrument.

machine (DAP-7, Struers). Finally, the samples were cleaned for 20 min in an ultrasonic bath.

For SEM inspection, the fixed partial dentures were sputter-coated with a gold-palladium alloy. Total overviews of the cross-sectional areas at 30- or 40-fold magnification were first prepared, to evaluate the fracture behavior. Contours of the fiber-reinforcement were marked using Adobe Photoshop (Version 7.0, Adobe Systems Inc., San Jose, CA, USA). The size of the area was then calculated by means of the program Scion Image (Scion Corporation, Frederick, MD, USA), giving an estimate of fiber quantity. The fibers, the fiber-composite interfaces, and the fracture regions were examined in detailed images at 500- and 1500-fold magnification.

Statistics

Univariate analysis of variance (ANOVA) was performed to evaluate statistically significant differences of load to fracture between groups. The post hoc Scheffé or Tamhane test was used depending on the variances being homogenous or not.

The cross-sectional areas found in scanning electron microscopy were tested for significant differences using the non-parametric Kruskal–Wallis test. The Mann–Whitney *U*-test was used for subsequent paired comparisons between groups. The influence of fiber quantity and fracture course on load to fracture was tested by ANOVA, with the two parameters regarded as covariates and the different fiber composite combinations as fixed effects. A *p*-value less than 0.05 was considered to be statistically significant.

Results

The results of load to fracture are shown in Fig. 3. FPDs reinforced with EverStick gave mean values of 615–1137 N, which were significantly higher than the values of 178–307 N obtained by unreinforced FPDs. The enhancement by EverStick in combination with Sinfony (1137 N) was significantly greater than with Vita Zeta (878 N) or Targis (615 N). The fracture strength in the unreinforced composite FPDs was also greatest with Sinfony, with an average of 307 N, followed by Targis FPDs with 276 N. The mean value with Vita Zeta (178 N) was significantly lower. The load to fracture of Vectris-reinforced Targis FPDs (1191 N) was markedly greater than that of EverStick-reinforced Targis FPDs (615 N). The highest values were found with the combinations Targis/Vectris (1191 N) and Sinfony/EverStick (1137 N).

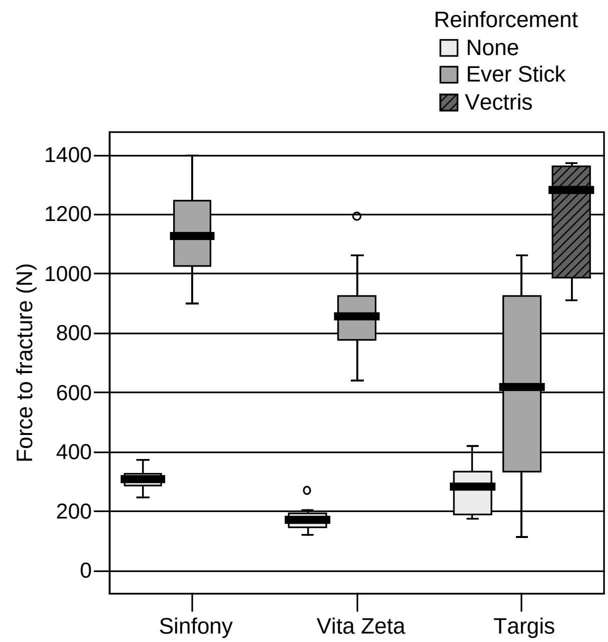

Figure 3 Force to fracture of four-unit composite FPDs.

At a load of 300 N, the mean deflection of the fiber-reinforced FPDs was 0.31–0.40 mm (Fig. 4). The deflection with the Vita Zeta/EverStick combination was 0.40 mm, which was significantly higher than with the combination Sinfony/EverStick (0.36 mm). On the other hand, the deflections with the Targis/Vectris FPDs (0.30 mm) and the Targis/EverStick FPDs (0.31 mm) were significantly lower than with Sinfony/EverStick.

Visual examination of the fractured FPDs showed that the fracture lines in the unreinforced composite FPDs were between the two pontics and ran from the side of tensile stresses to the mesial ridge

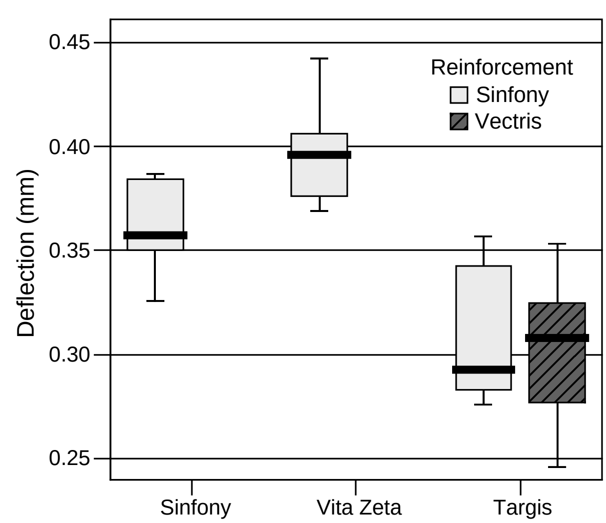

Figure 4 Deflection of four-unit fiber-reinforced composite FPDs (measured at a load of 300 N).

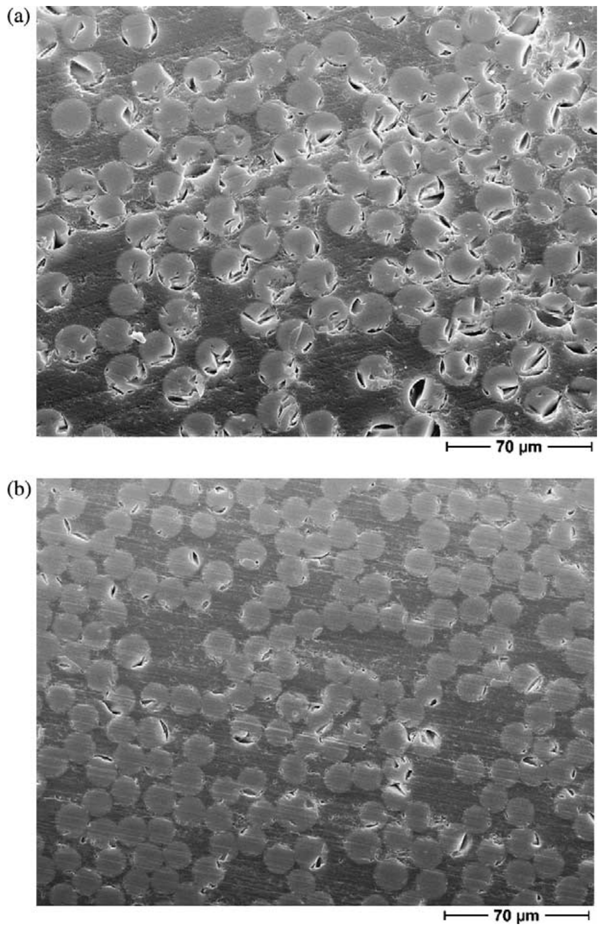

Figure 5 (a) Cross-section of EverStick fiber-reinforcement (500-fold magnification). (b) Cross-section of Vectris fiber-reinforcement (500-fold magnification).

of pontic 26, in a vestibulo-palatal plane. With the fiber-reinforced FPDs, fractures on the tension side were in both mesio-distal and vestibulo-palatal planes. In addition, fractures were evident in the occlusal areas of the pontics in all FPDs.

The SEM analyses of the fracture areas revealed a high density of transversely cut unidirectional fibers and effective embedding of the fibers in the surrounding pre-impregnation polymer, both with EverStick and with Vectris fiber-reinforcement. The diameters of EverStick (Fig. 5(a)) and Vectris fiber bundles (Fig. 5(b)) were 19 and 16 μm, respectively. The interfaces between fiber bundles and surrounding composite indicated good bonding. Separation occurred only when the fracture surface partially ran along the interface (Fig. 6).

The overall views of the cross-sectional areas of EverStick fiber-reinforced FPDs showed obvious fractures in the area of veneering composite and fiber-reinforcement. Eight samples (53.3%) exhibited vertical fracture lines which continued through the fiber insert (Fig. 7(a)). In these cases, the

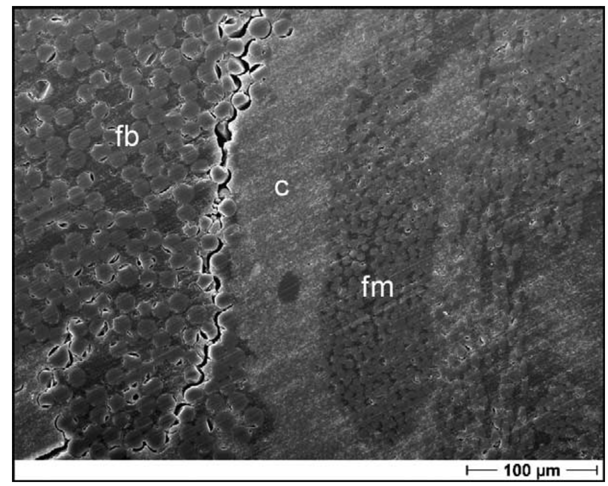

Figure 6 Cross-section of Targis/Vectris FPD with fracture along the interface between fiber bundle and composite (fb, fiber bundle; c, composite; fm, fiber mat; 300-fold magnification).

unidirectional fibers had come free from the surrounding pre-impregnation polymer and were separated from each other. In five samples (33.3%), the fractures ran along the fiber composite interface, from the tension to the compression side. In two samples (13.3%), the fractures were within the veneering composite. Additionally, in all FPDs fracture lines were found which ran around the lower fiber bundle and along the fiber composite interface on the tensile side.

In FPDs with Vectris reinforcement, there was a smooth transition between fiber bundles, fiber mat, and intermediate polymer (Fig. 7(b)). The fracture lines were clearly finer than with the EverStick-reinforced FPDs. The fracture in one sample was exclusively in the area of the composite, although most samples (60%) exhibited fractures in the interface between fiber mat and composite.

The results for the fiber bundle cross-sectional areas are summarized in Table 3. There were statistically significant differences between the fiber cross-sectional areas of EverStick and Vectris ($p<0.05$). There was, however, no significant effect of fiber quantity or of course of fracture on load to fracture within the material groups ($p>0.05$).

Discussion

The present study has examined the fracture resistance of four-unit glass fiber-reinforced composite FPDs under in vitro conditions. All FPDs were temporarily cemented, as the materials in the study are only suitable for temporary FPDs, due to the risk

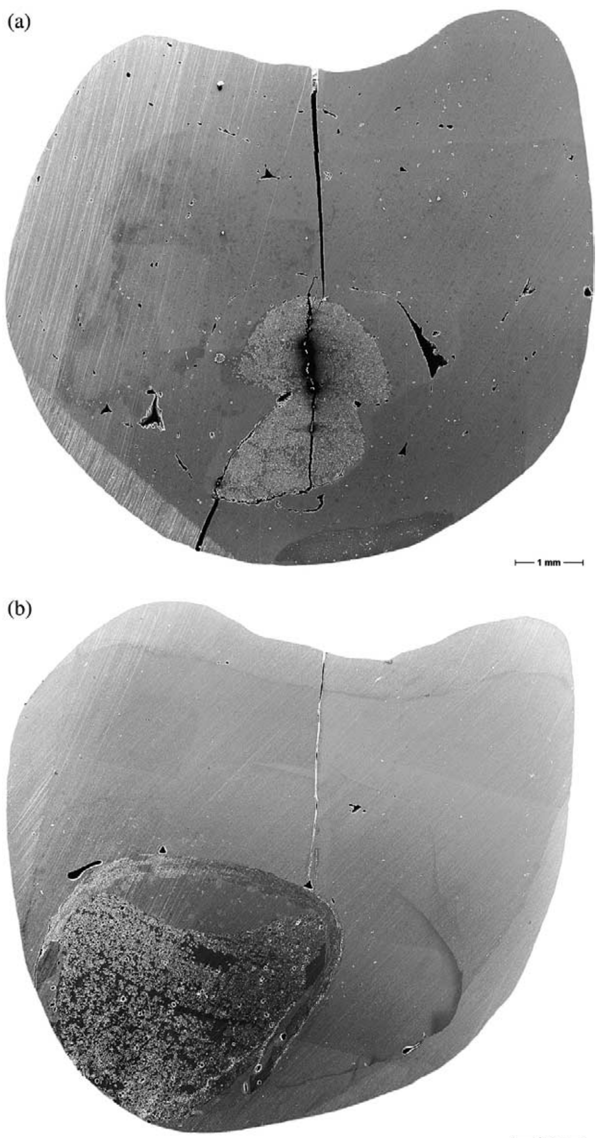

Figure 7 (a) Vita Zeta FPD with EverStick reinforcement (fracture passes through the fiber bundle). (b) Targis FPD with Vectris reinforcement (fracture runs along the fiber-composite interface).

of discoloration, loss of superficial gloss and increased wear [14–16]. The abutment teeth were kept mobile, in an attempt to imitate the clinical situation. Mobility of the abutments during loading corresponded to mobility of natural teeth [17]. Preliminary experiments showed an axial mobility of 30–95 μm at a load of 50–100 N [18].

This study found differences in load to fracture between different unreinforced composite FPDs which might be explained by the different mechanical properties of the composites used. For example, FPDs of Vita Zeta showed the lowest loads at fracture corresponding to the flexural strength of Vita Zeta (85 N/mm^2) being considerably smaller than that of Sinfony (105 N/mm^2) and Targis (105 N/mm^2).

In all of the three light hardened composites tested, fiber deposition caused significant increases in load to fracture. The values obtained were in all cases greater than the required minimum static load to fracture of 600 N [19,20]. The reinforcement effect found in this study has also been reported by other authors who studied Vectris or Stick, a predecessor of the EverStick system [3,13,21,22].

In the present study, a combination of the fiber material EverStick with Sinfony gave a significantly higher load to fracture result than the combination with Vita Zeta or Targis. This difference can be attributed to the different mechanical properties of the composites, such as flexural strength and modulus of elasticity. The optimal veneering composite should not only possess high flexural strength, but also a modulus of elasticity as low as possible to show sufficient compliance under stress. The requirement of high flexural strength is fulfilled by both Sinfony and Targis (see above), whereas the elastic modulus of Sinfony (3100 N/mm^2) is somewhat lower than that of Targis (4900 N/mm^2). This difference in modulus of elasticity partially explains why in the present study FPDs made of Targis and EverStick showed a deflection under load, which was almost 50% lower than that of FPDs made of Sinfony and EverStick. Studies by other authors have shown that the flexural strength of Sinfony—also when combined with other fiber materials such as FiberKor and Vectris—can be markedly increased by using glass fiber reinforcement [23]. The high load to fracture of the combination Targis/Vectris has also been described by authors of other in vitro

Table 3 Cross-sectional area of fiber bundles for different fiber materials.

Material	Fiber cross-sectional area in mm^2			
	Mean value	Standard deviation	Minimum	Maximum
Sinfony/EverStick	5.32	0.90	4.31	6.02
Vita Zeta/EverStick	4.93	0.32	4.69	5.16
Targis/EverStick	5.02	0.46	4.38	5.40
Targis/Vectris	9.67	1.17	8.15	10.76

studies [3,13,21,24] and might be due to the physical properties of the components having been specifically attuned to each other by the manufacturer.

The SEM investigation provided valuable information on the cross-sectional area, the form of the fiber bundles and on the course of the fracture. The geometry of the fiber bundles in EverStick and in Vectris proved to be roundish and compact. The additional Vectris fiber mat covered the top of both fiber bundles like a coat and had quite a different appearance.

There was no evidently consistent morphology in the fractures in the samples examined. However, in contrast to visual microscopy, electron microscopy revealed that the fracture lines were not restricted to the composites, but also sometimes passed through the fiber frameworks. This was particularly evident with the EverStick fiber frameworks. In most of these FPDs, the vertical fracture lines extended from the occlusal surface across the fiber insert to the lower side. Although the unidirectional fibers were not fractured, they were separated from each other.

In contrast, fibers in the FPDs with Vectris reinforcement were rarely separated from each other which is probably due to the additional bidirectional fiber mat, in which the fibers are kept at 90° to each other. This seemed also to be the reason for the fracture to spread along the border between fiber and veneering material and for the selected FPDs to show fewer and finer fracture lines than the FPDs with the EverStick fiber framework. The weak point in Vectris restorations was always in the bonding between silanized fiber framework and veneering composite.

As the fiber mat only covered the unidirectional fibers on the occlusal side, the shielding effect could not act on the underside (tension side) of the restoration. This was underlined by one case of a Vectris FPD in which the fracture started at the lower side and continued in the region of the unidirectional fibers which were separated along the course of fracture.

As both course of fracture and fiber cross-sectional area were not found in this study to have a significant effect on the load to fracture, this seems to be more dependent on the fiber geometry, on the mechanical properties of the veneering and fiber materials and on their mutual adhesion. This is corroborated by the results of Behr et al. [11], who found that not so much the fiber content, but the matrix composition and the bond between fibers and matrix determine flexural strength of fiber-reinforced composite beams.

Conclusion

In summary, it can be concluded that the load to fracture of composites used in the present study was significantly increased by adding glass fiber frameworks. After failure of the reinforced restorations, no fractures of glass fibers as such could be detected, but separation of the fibers, and fractures within the composite as well as at the interfaces between composite and fiber were apparent. Since the reinforcing effect of the glass fiber system EverStick depended significantly on the composite to be reinforced, only specific combinations can be recommended for clinical use. Clinical studies are now required to test the behavior of these combinations in long-term provisional restoration work.

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