Fracture Strength of Fiber-Reinforced Surface-Retained Anterior Cantilever Restorations

Mutlu Özcan, Dr Med Dent, PhD[a]/Ovul Kumbuloglu, PhD[b]/Atilla User, PhD[c]

Purpose: This study compared the fracture strength of direct anterior cantilever fiber-reinforced composite (FRC) fixed partial dentures (FPD) reinforced with 3 types of E-glass fibers preimpregnated with either urethane tetramethacrylate, bisphenol glycidylmethacrylate/polymethyl methacrylate, or bisphenol glycidylmethacrylate monomers and 1 ultrahigh molecular weight polyethylene fiber. Failure types were also evaluated. ***Materials and Methods:*** A total of 40 caries-free, human maxillary central incisors (n = 10 per group) received surface-retained direct cantilever restoration (1 pontic) after etching and application of bonding agent. Four FRC materials were used (FRC1 = EverStick; FRC2 = BR-100; FRC3 = Interling; FRC4 = Ribbond), and pontics were built up using 1 particulate filler composite (Clearfil Photo Posterior). After the fracture test, failure types were analyzed. ***Results:*** No significant difference was found between the 4 FRC types veneered with particulate filler composite (893 ± 459 N to 1326 ± 391 N) (P = .1278). Complete pontic fracture at the connector area was most prominent for FRC4 (90%), followed by FRC3 (70%). Only FRC2 (10%) showed some fiber fractures, with half of the fiber remaining attached on the enamel surface of the abutment. ***Conclusion:*** The fracture strengths of cantilever FPDs made of 4 FRC materials with different monomer matrices and architectures, veneered with particulate filler composite, did not show significant differences. However, failure behavior varied between groups. *Int J Prosthodont 2008;21:228–232.*

A cantilever fixed partial denture (FPD) is a restoration with 1 or more pontics supported by 1 or more abutments at one end and unsupported at the other end. With advances in adhesive technologies, cantilever FPDs became less invasive alternatives to their full-coverage counterparts. This alternative application in restorative and prosthetic dentistry preserves healthy tooth substance and is considered a dynamic treatment approach since it serves as a reversible treatment option.[1–3] In situations where the relationship between the maxilla and mandible is suitable, surface-retained cantilever fiber-reinforced composite (FRC) FPDs may not necessitate any preparation of sound tooth tissues.

[a]Professor, University Medical Center Groningen, University of Groningen, Department of Dentistry and Dental Hygiene, Clinical Dental Biomaterials, Groningen, The Netherlands.
[b]Assistant Professor, Ege University, School of Dentistry, Department of Prosthodontics, Izmir, Turkey.
[c]Professor, Ege University, School of Dentistry, Department of Prosthodontics, Izmir, Turkey.

Correspondence to: *Dr Mutlu Özcan, Department of Dentistry and Dental Hygiene, Clinical Dental Biomaterials, University Medical Center Groningen, University of Groningen, Antonius Deusinglaan 1, 9713 AV Groningen, The Netherlands. E-mail: mutluozcan@hotmail.com*

FRC materials have gained widespread acceptance in a diverse range of structural engineering applications because of the development of materials with widely varying properties. Materials for dental applications including cantilever FPDs must meet expectations regarding the mechanical performance and chemical resistance. FRC materials existing on the dental market vary in resin matrix composition and fiber volume, which may affect their resistance to occlusal forces through their adhesion to the veneering composites.[4] Preimpregnated systems usually involve monomers like urethane dimethacrylate (UDMA), urethane tetramethacrylate (UTMA), bisphenol glycidylmethacrylate (Bis-GMA), or polymethyl methacrylate (PMMA) and are either already impregnated by the manufacturer or can be impregnated by the clinician.[5] Evidence is still lacking regarding whether ultrahigh molecular weight polyethylene (UHMWPE) fibers can be used to fabricate durable FRC restorations.[6–8] Criticism has been focused on the inadequate interfacial adhesion between polyethylene fibers and dental polymers.[8] To date, some studies compared inlay or

Table 1 Brand Name, Abbreviation, Composition, Manufacturer, and Batch No. of the Materials Used in This Study

Brand name	Abbreviation	Composition	Manufacturer	Batch no.
EverStick	FRC1	E-glass/PMMA/Bis-GMA	StickTech	000088
BR-100	FRC2	E-glass/UTMA	Kuraray	00006A
Interling	FRC3	E-glass/Bis-GMA	Angelus	2199
Ribbond	FRC4	UHMWPE	Ribbond	9543
Clearfil Photo Posterior	PFC	Silanated silica Silanated colloidal silica Prepolymerized organic filler containing colloidal silica Urethane tetramethacrylate Bisphenol A Diglycidylmethacrylate Triethyleneglycoldimethacrylate dl-Camphorquinone	Kuraray	00165A

PMMA = polymethyl methacrylate; Bis-GMA = bisphenol glycidylmethacrylate; UTMA = urethane tetramethacrylate; UHMWPE = ultrahigh molecular weight polyethylene.

box-retained cantilever FPDs,[9-11] but no study has compared the mechanical properties of the surface-retained cantilever FRC FPDs.

Therefore, the objectives of this study were to compare the fracture strength of direct anterior cantilever FRC FPDs reinforced with 3 types of E-glass fibers, preimpregnated with either UTMA, Bis-GMA/PMMA, or Bis-GMA monomers, and 1 UHMWPE fiber and to evaluate the failure types.

Materials and Methods

The brand names, codes, compositions, manufacturers, and batch numbers of the materials used in this investigation are presented in Table 1. A total of 40 caries-free, recently extracted human maxillary central incisors were used in this study. The teeth were stored in distilled water with 0.1% thymol solution at room temperature. All teeth were evaluated under blue light transillumination to ensure that the enamel was free of crack lines. The specimens were stored in distilled water up to 3 months before the experiments. The enamel surfaces were cleaned and polished using water and fluoride-free pumice with a prophylaxis brush, rinsed with water, and dried using an air syringe. The teeth were then embedded in autopolymerized PMMA (Vertex, Zeist) resin blocks up to the cementoenamel junction.

Enamel surfaces to be bonded were roughened with a tungsten-carbide bur (Komet, Lemgo) using a high-speed handpiece under water irrigation and then acid etched with 38% phosphoric acid (H_3PO_4) (TopDent) for 60 seconds.[12] After rinsing with water and air drying, an intermediate adhesive resin (Quadrant UniBond, Cavex) was applied to the surfaces using a microbrush, gently air dried, and light polymerized (light intensity: 600 mW/cm^2; Demetron LC, Kerr) for 20 seconds. The concave, soft metal bands (Sectional Matrix System, Danville Engineering) were used as a pontic-forming aid. A thin layer of flowable composite resin (StickFlow) was applied to the tooth surfaces and light polymerized together with the FRC material for 40 seconds while exerting gentle pressure over the fiber using a silicone instrument (Silicone Refix, Stick Tech). To form the pontic, particulate filler composite (PFC) (Clearfil Photo Posterior, Kuraray) was then applied incrementally onto the enamel and light polymerized for 40 seconds.

All restorations were made with 1 bundle of FRC material, except for FRC3 and FRC4, in which 2 bundles were used because of their reduced fiber volume. FRC4, the nonimpregnated fiber, was impregnated using an intermediate adhesive resin (Quadrant UniBond). Fiber surfaces were completely covered with composite resin, and each layer was again light polymerized for 40 seconds from all aspects. Using a transparent silicone mold, standard pontics were created with approximately the same mesiodistal size of a lateral incisor. Subsequently, the dimensions of the pontics were measured with a digital micrometer (accurate to 0.005 µm) (Mitutoyo) and kept at 6 mm in the buccolingual direction, 6.5 mm in the mesiodistal direction, and 9 mm in the cervico-occlusal direction. An interdental wedge (Hawe Sycamore Interdental Wedges, White, KerrHawe) was placed between the retainer and pontic to obtain uniform retainer-pontic contact points, and a connector surface area of 9 mm^2 was achieved after finishing and polishing. Finally, all restorations were finished using fine diamond burs (no. 012, Intensiv) to remove the excess PFC and polished with coarse, medium, fine, and ultrafine finishing disks (Sof-Lex, 3M ESPE).

After water storage in distilled water at 37°C for 3 days, specimens were subjected to fracture strength tests in a universal testing machine (Zwick 1446). Force was applied axially to the center of the pontic with a 6-mm-diameter steel ball at a crosshead speed of 1 mm/min. A sheet of tin foil (0.4 mm) was inserted

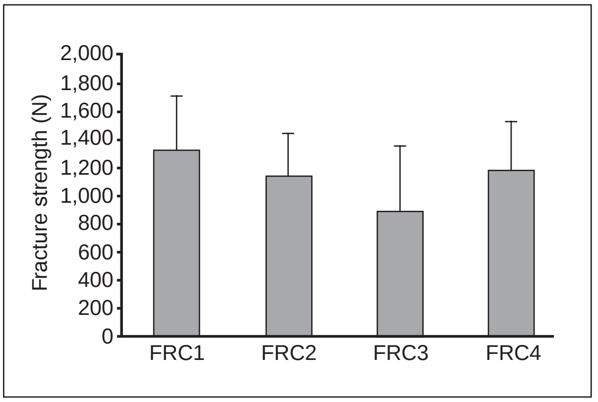
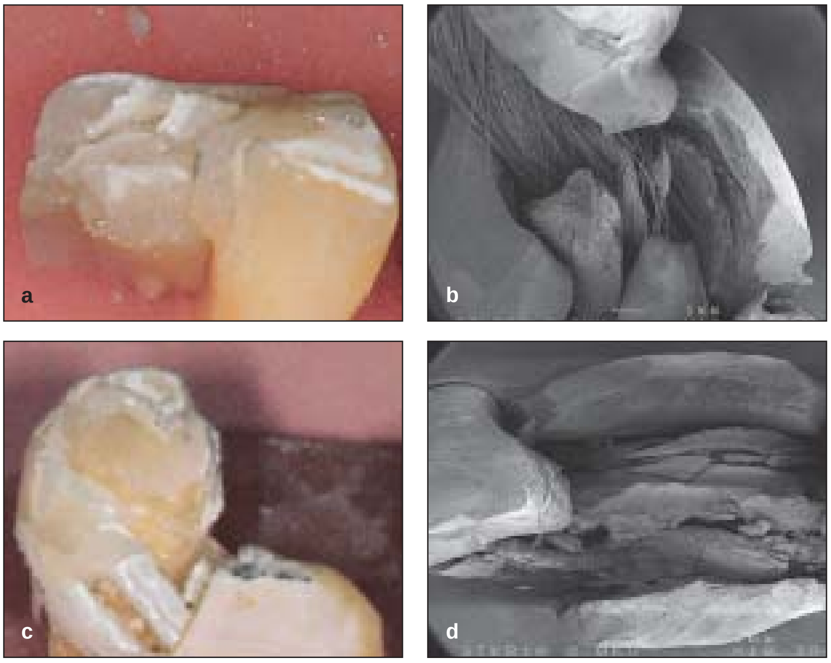


Fig 1 Mean (± SD) fracture strength (N) values for the experimental groups.

Table 2 Distribution (%) of Failure Types for Each Study Group

	Type A	Type B	Type C	Type D
FRC1	10	60	30	–
FRC2	20	60	10	10
FRC3	–	70	30	–
FRC4	–	90	10	–



Figs 2a to 2d Representative specimen photographs **(a and c)** and SEM images after the fracture strength test **(b and d)**. Note the delamination of the veneering resin into 2 primary pieces in FRC1 **(c)** and the catastrophic delamination of the veneering resin in FRC4 **(d)**. (Original magnification ×10.)

between the steel ball and pontic to avoid local force peaks and sliding of the load cell. Because specimens did not abruptly fail following delamination of the fibers and showed decreasing load-bearing capacities and increasing deformation caused by delamination of the veneering composite or fiber, failure strength was set at 10% below the maximum loading force registered.[13]

Following fracture strength tests, failure types were analyzed by two operators (MÖ and OK), and scanning electron microscopy (SEM) (JSM-5500, Jeol) images were taken of the representative specimens. Failure types were classified as follows:

- Type A: Detachment of the veneering composite from the fiber, with the fiber attached on the enamel
- Type B: Complete pontic fracture with the fiber debonded from the abutment surface
- Type C: Chipping of the veneering composite
- Type D: Fiber fracture

Statistical analysis was performed using SPSS 12.00 (SPSS). The means of each group were analyzed using 1-way analysis of variance. Statistical significance was set at $P < .05$.

Results

No significant difference was found between the 4 FRC types veneered with PFC (893 ± 459 N to 1,326 ± 391 N) ($P = .1278$) (Fig 1). Complete pontic fracture at the connector area (type B) was most prominent for FRC4 (90%), followed by FRC3 (70%) (Table 2). Only FRC2 (10%) showed some fiber fractures with half of the fiber remaining attached on the enamel surface of the abutment. Further, type A failures in the FRC1 and FRC2 were primarily in the mesiodistal direction, indicating that unidirectional fibers change the path of the crack. SEM images revealed that delamination of the veneering resin was more catastrophic for FRC4 than FRC1 (Figs 2a to 2d).

Discussion

Current philosophy in dentistry is based on conservation of the intact tooth tissues by employing the least invasive approach. Such restorations could be accomplished with the use of FRC materials with different architectures and preimpregnation. Favorable results in terms of mechanical properties were reported with the use of resin-preimpregnated, silanized glass fibers compared to nonimpregnated UHMWPE fibers.[14] In this study, however, no statistically significant differences were found between the fracture strengths of E-glass and UHMWPE fibers. Considering the geometry of the FPDs prepared in this study and the insignificant differences between the FRC materials, it can be anticipated that the PFC type is one of the predominant factors in the fracture strength. The PFC used in this study with UTMA monomer matrix and prepolymerized organic fillers must have contributed to the fracture strength of the FPDs, thus offsetting the variations in the fiber materials.

Clinically, type B and type D failures usually require total replacement of the restorations, whereas repairs to prolong the service life of restorations are still possible following type A and type C failures.[15] The presence of only chipping failures also indicates that the adhesion of the PFC to the etched enamel was extremely strong. Complete fracture of the pontics with the fiber debonded from the abutment surface reveals that the weakest part of the FPD was the connector area, where the fracture started and propagated to the bonded area on the palatal surface of the abutment.

In FRC4 groups, delamination of the veneering composite was more catastrophic compared to that seen in FRC1 and FRC2, in which the failure type was predominantly separation of the veneering composite into 2 laminates. Unfortunately, laminated composites have a relatively poor mechanism for absorbing energy because of local impact damage where loading is normal to the laminate planes. For this reason, application of more fibers for a given PFC volume may change the load-bearing capacity of the whole structure. However, this approach could lead to exposure of fibers that may impair esthetics, especially in the anterior region. Future studies should concentrate not only on the fracture strength, but also the failure types and fracture behavior of FRC FPDs.

Different testing methods and the difficulty of measuring masticatory forces result in a wide range of occlusal force values. Stress applied during mastication may range between 441 and 981 N, 245 and 491 N, 147 and 368 N, and 98 and 270 N in the molar, premolar, canine, and incisor regions, respectively.[16] The materials examined in the present study exhibited means that exceeded these values. Direct comparison with previous studies is difficult because of design differences, but the fracture strength values obtained in this study were higher than those reported by Behr et al,[17] who found final fracture strength values of 696 and 722 N for 3-unit indirect FRC FPDs in which glass fibers were used (Vectris) as the fiber framework in box-shaped and tube-shaped preparations. Although no preparations were made on the abutment teeth, the fracture strength values obtained in this study with all FRC materials were higher than the values reported by Behr et al.[17]

The initial failure point could show the onset of failure. Some studies have established the fracture forces of FPDs by determining the initial failure from the force-deflection curve.[5,11] Previous loading events at lower stress levels could cause internal failures to the material that can progress only with subsequent higher stress levels, leading to final fractures. Unfortunately, initial failures, including chipping, are not easy to detect clinically, and until catastrophic failure occurs, the need for intervention is often missed. In this study, strength at final failure was used to compare the materials. However, FRCs and PFCs may show variations in their initial fracture strength.

Static compression tests demonstrated the relationship between the quantity of the fibers in a polymer matrix and the enhancement of the flexural strength. It has been reported that with increasing fiber content, flexural strength increases linearly.[9] This information is often derived from bar-shaped specimens prepared according to the ISO norms where only 2 mm of veneering composite was placed on the FRC material. Considering the geometry of the specimens prepared in this study, representing the actual clinical situation as much as possible, and the insignificant differences between the 4 FRC materials, it can be stated that the thickness of the veneering composite is one of the predominant factors in the fracture strength data in static tests. The nature of loading in static tests surely has limitations compared to cyclic mechanical fatigue forces where load-bearing capacity may decrease dramatically under fatigue; however, for screening purposes, static tests had been used more frequently in the dental literature than the latter. The clinical implication of static tests in which PFC materials are thinner than the actual pontic height warrants further translational research.

Under the influence of compressive cyclic stresses, the damage associated with delamination may reduce the overall stiffness and residual strength, thus leading to structural failure. Therefore, the behavior of FRCs requires further investigation under fatigue conditions in such an experimental setup. Further, water sorption of FRC matrix may also influence the flexural strength of the FRCs. FRC FPDs are completely covered with a layer of unfilled polymer or a layer of PFC to obtain polishable and wear-resistant surfaces. This study did not look at the aging effect of water storage or thermocycling. The results are in accordance with clinical studies showing that not only fatigue but also static stress can cause failures.[10,15]

Conclusions

1. Fracture strength of direct cantilever fixed partial dentures made of 4 fiber-reinforced composite materials with different monomer matrices and architectures, veneered with particulate filler composite, did not show significant differences, although the failure behavior varied among the fiber-reinforced composites.
2. Failure types with all fiber-reinforced composite materials were mainly in the form of complete pontic fracture, with the fiber debonded from the abutment surface. The failure type differed between fiber types, with the polyethylene fiber presenting the most catastrophic failures.

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