ORIGINAL ARTICLE

Fracture strengths of chair-side-generated veneers cemented with glass fibers

S Turkaslan, B Bagis[1], E Akan[1], MM Mutluay[2], PK Vallittu[3]

Departments of Prosthodontics, Suleyman Demirel University, Faculty of Dentistry, Isparta, [1]Izmir Katip Celebi University, Faculty of Dentistry, Izmir, Turkey, [2]University of Turku, Faculty of Dentistry, [3]Department of Biomaterials Science and Turku Clinical Biomaterials Centre – TCBC, Institute of Dentistry, University of Turku, Turku, Finland

Abstract

Introduction: CAD/CAM (computer-aided design and computer-aided manufacturing) systems have refreshed the idea of chair-side production of restorations, but the fracture of ceramic veneers remains a problem. Cementation with glass fibers may improve the fracture strengths and affect the failure modes of CAD/CAM-generated ceramic veneers. Therefore, this study compared the fracture strengths of ceramic veneers produced at chair side and cemented with or without glass fibers with those of composite veneers. **Methodology:** Thirty intact mandibular incisors were randomly divided into three groups (n = 10) and treated with CAD/CAM-fabricated veneers cemented with dual-cure composite resin luting cement (CRLC; Group 1), CAD/CAM-fabricated veneers cemented with a glass fiber network (GFN) and dual-cure CRLC (Group 2), and a direct particulate filler composite veneer constructed utilizing fiber and a restorative composite resin (Group 3). The specimens were tested with a universal testing machine after thermal cycling treatment. **Result:** The loads at the start of fracture were the lowest for traditionally fabricated composite veneers and higher for CAD/CAM-generated. Veneers cemented either without or with the GFN. The failure initiation loads (N) for the veneers were 798.92 for Group 1, 836.27 for Group 2, and 585.93 for Group 3. The predominant failure mode is adhesive failure between the laminates and teeth for Group 1, cohesive failure in the luting layer for Group 2, and cohesive laminate failure for Group 3, which showed chipping and small fractures. **Conclusion:** Ceramic material is a reliable alternative for veneer construction at chair side. Fibers at the cementation interface may improve the clinical longevity and provide higher fracture strength values.

Key words: Computer-aided design and computer-aided manufacturing, cementation, fracture strength, glass fiber, laminate veneer

Date of Acceptance: 09-Jun-2014

Introduction

The Cerec CAD/CAM (computer-aided design and computer-aided manufacturing; Siemens/Sirona Dental Systems, Bensheim, Germany) system introduced in 1984 enables the dentist to produce indirect restorations from industrially sintered ceramic blocks directly at the chair side in a single appointment without laboratory assistance.[1,2] This technique eliminates the need for temporary restoration,[3] which can adversely affect the fit and final bonding of the veneer restoration depending on the cementation method used for the temporary restoration.[4] A retrospective study of chair-side CAD/CAM restorations over 10 years has shown that the use of functional dentin adhesives increases the success rates of inlays and partial crowns. In addition, it was found that the size of the restoration does not affect long-term survival.[5] Laboratory tests and clinical trials proved that adhesive placement of all-ceramic partial and full crowns strengthens the remaining natural tooth structure as well as the ceramic restorations themselves,[6,7] which may have positive effects on the longevity of the restoration.

The use of fiber reinforcements with resin materials is gaining popularity as a subject of research. For example,

Address for correspondence:
Assoc. Prof. Bora Bagis,
Department of Prosthodontics, Faculty of Dentistry, Izmir Katip Celebi University, 35640-Çiğli/Izmir, Turkey.
E-mail: bbagis@yahoo.com

Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/1119-3077.151052

Kamble *et al*.[8] studied the effects of different fiber reinforcements on the flexural strength of provisional restorative resins and recommended the use of glass fiber to reinforce provisional restorative resins when esthetics and space are of concern. Sen *et al*.[9] investigated the fracture type and tested the effects of glass and polyethylene fibers on the fracture strength of roots with reattached fragments. They recommend that the separated fragments of vertically fractured teeth be reattached by using a dual-cured resin or by adding polyethylene fibers.

One newly suggested idea for increasing the survival rates of restorations is placing fibers at the interface.[10,11] E-glass fibers have a demonstrated ability to withstand tensile stresses and stop crack propagation in composite materials.[12,13] In dental practice, fiber-reinforced composites are gradually gaining preference, but there have been only a few suggestions to use these materials to reinforce the cementation interface in veneer restorations[14] or veneer repairs.[11] The two previous studies demonstrated that fiber-reinforced composites at the cementation interface do not increase the fracture strength, but do affect the failure modes of the restorations and help maintain the integrity of the abutment teeth. A more recent study found that with good bonding, preimpregnated bidirectional fiber-reinforced composites can reinforce the tooth interface in two directions, distributing the stresses more evenly and increasing the toughness of the restoration by preventing crack propagation.[15]

The purpose of the current *in vitro* study is to determine the fracture strengths of CAD/CAM-generated Cerec veneers cemented either with or without glass fiber networks (GFNs) and compare the results with those for indirect composite veneers strengthened with glass fiber. The hypotheses of the present study were that the fracture mode and fracture strength of laminate veneers would be affected by cementing with glass fibers.

Material and Methods

Thirty caries-free human mandibular central incisors with similar dimensions, which were extracted for periodontal reasons, were randomly selected for this study. For standardization, the incisal, mid-coronal, and cervical areas of the teeth were measured in the mesial–distal and buccal–palatal directions. The cervical–incisal dimensions were also recorded, and only samples with values no more than 10% different from the mean value were accepted for the experiment.

The teeth were stored for a maximum of three months in 0.5% chloramine solution, prior to use. Adhering soft tissues and calculus deposits were removed with a hand scaler, and the buccopalatal, mesiodistal, and cervico-incisal dimensions of each tooth were measured with a digital micrometer (Mitutoyo Corp., Tokyo, Japan; accuracy of ± 0.002 mm). The teeth were mounted in a cylindrical block (2.5 cm diameter), 2 mm below the cementoenamel junction, using a self-curing acrylic resin (Palapress, Heraeus Kulzer, Germany). The teeth were then divided into three groups ($n=10$), and each group was assigned to a different fabrication procedure. Group 1 (C) was used for the application of Cerec CAD/CAM-generated (Siemens/Sirona Dental Systems, Bensheim, Germany) veneers, cemented with dual-cure composite resin luting cement (CRLC). Group 2 (CF) was used for the application of Cerec CAD/CAM-generated (Siemens/Sirona Dental Systems, Bensheim, Germany) veneers, cemented with dual-cure CRLC, with a glass fiber network (GFN) (StickNey, Stick Tech, Turku, Finland) at the cementation interface. Group 3 Particulate filler composite (PFC) was subjected to the direct composite veneering technique (Filtek Z250, 3M ESPE, USA) [Figure 1]. All teeth were stored in Grade 3 deionized water, except when the experimental procedure required moisture isolation.

Tooth preparation

Prior to tooth preparation, a sectional index that could be reconstructed over the original tooth was produced using a polyvinyl siloxane impression material (Elite H-D, Zhermack, Germany). The teeth were prepared using a freehand technique by a single clinician. Furthermore, to avoid biases caused by large amounts of repetition, the teeth were prepared on three different days, at different intervals.

During preparation, the depth of the removed tooth structure was controlled using the polyvinyl-siloxane index. The facial, mesial and distal surfaces were reduced to 0.5 mm, and the preparation ended at the mid-incisal line. All the incisors were prepared with a chamfered finishing line, with rounded internal line angles. The cervical preparation ended at the cementoenamel junction. Smooth margins were created to prevent stress concentration zones.

Preparation of the laminate veneer restorations

Table 1 lists the manufacturers' information and lot numbers of the etching agent, bonding agent, luting cement, PFC, GFN, and ceramic materials used in this study. Laminate veneers were fabricated with a standardized thickness during the CAD procedure using the impression molds made before tooth preparation.

Group 1 (C), Cerec CAD/CAM

Optical impressions of the prepared abutment teeth were taken using a Cerec intraoral 3D measuring camera. The prepared teeth were uniformly covered with anti-reflecting powder (Vita Cerec Powder) with the help of a propellant (Vita Cerec Propellant) for the scanning process. The data were stored utilizing Cerec 3D software. The same software was used for designing the veneers. The setting for the machining of all veneers was 0.5 mm, and after the design procedure was finished, the data were sent to the milling unit via wireless connection. Identical

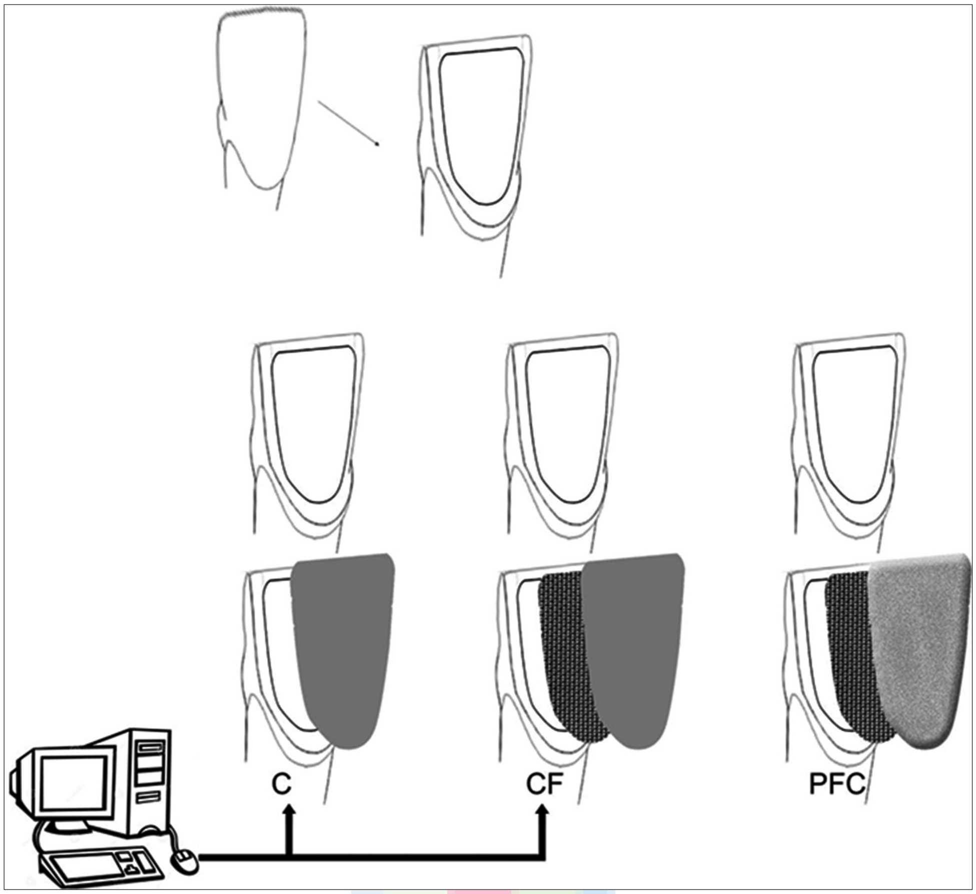

Figure 1: Schematic drawing of the veneer applications in the different test groups

Table 1: Materials used in the study

Material	Lot No.	Manufacturer
VITABLOCS mark II for cerec	6590	Vita Zahnfabrik, Bad Sackingen, Germany
Cerec powder	7779	Vita Zahnfabrik, Bad Sackingen, Germany
Cerec propellant	24290	Vita Zahnfabrik, Bad Sackingen, Germany
Vococid	59022	Voco, Germany
Solobond plus adhesive	591583	Voco, Germany
Filtek Z 250	6021A3,5	3M ESPE
Stick resin light cure adhesive	5509986	Stick Tech Ltd, Turku, Finland
Stick net		Stick Tech Ltd, Turku, Finland
Bifix QM	530324	Voco, Germany
Ceramic bond	580382	Voco, Germany
Vita ceramic etch	20891	Vita Zahnfabrik, Bad Sackingen, Germany

veneers were fabricated by machining Vita Mark II ceramic blocks (Vita Zahnfabrik, Bad Sackingen, Germany).

Group 2 (CF), Cerec CAD/CAM

The ceramic veneers for this group were fabricated using the same technique as for Group 1, but before cementation, Group 2 (CF) received a layer of porous, polymer-pre-impregnated, bidirectional GFN at the cementation interface (thickness per layer: 0.06 mm).

Group 3 (PFC), Direct particulate filler composite

The direct PFC veneers (Filtek Z250, 3M ESPE) were fabricated on the abutment teeth. Each tooth was etched for 15 seconds using a 35% phosphoric acid etching gel (Vococid, Voco). Subsequently, the tooth surface was rinsed thoroughly and air-dried gently. Dentin primer and adhesive were applied according to the manufacturer's instructions (Solobond plus, Voco). Following the bonding agent application, a layer of GFN (0.06 mm) was applied to the surface and light-polymerized for 40 seconds (Elipar Free Light, 3M ESPE) at a light intensity of 740 mW/cm^2. The PFC laminate was built up in two increments, and 40 seconds of light irradiation was used for every increment. To duplicate the original configuration, the polyvinyl-siloxane index was sectioned axially along the midline in order to enable build-up of the restoration in layers, and PFC was injected.

Cementation

Table 2 lists the tooth and restoration surface treatment protocol for the samples. Dual-cure resin luting agent (Bifix, Voco, Germany) was used for the cementation of the CAD/CAM-fabricated laminate veneers. The etching, priming, and bonding steps followed the same procedure as used for the direct restoration group. After etching, the

Table 2: Surface treatment protocol among groups

	Surface treatment protocol for the samples used in this study		
	Group		
	CAD/CAM-generated cerec veneers	CAD/CAM-generated cerec veneers	Direct composite veneer (bidirectional GFN)
Tooth surface	Diamond bur preparation, aluminum oxide embedded polishing discs, 37% phosphoric acid, primer, adhesive	Diamond bur preparation, aluminum oxide embedded polishing discs, 37% phosphoric acid, primer, adhesive	Diamond bur preparation, aluminum oxide embedded polishing discs, 37% phosphoric acid, primer, adhesive
Restoration surface	5% hydrofluoric acid, silane, adhesive	5% hydrofluoric acid, silane, adhesive	Light curing adhesive on GFN
Interphase layer	Dual-cure composite resin luting cement	Dual-cure composite resin luting cement, gfn	Dual-cure composite resin luting cement
Storage condition	Water storage/thermocycled	Water storage/thermocycled	Water storage/thermocycled

CAD=Computer-aided design, CAM=Computer-aided manufacturing, GFN=Glass fiber network

dentin surfaces were dried gently to maintain the shiny and visibly hydrated surface.

The inner surfaces of indirect veneers were treated by air particle abrasion using 30 μm Al_2O (Korox, Bego, Germany). For this purpose, a chair-side air abrasion device (CoJet, 3M ESPE, Germany) was used from a distance of 15 mm at a pressure of 250 kPa bar for 5 seconds. In addition to air particle abrasion treatment, the veneers were acid-etched with 9% hydrofluoric acid prior to silanization. Then, at each surface, a silane coupling agent (Ceramic Bond, Voco) was applied to the internal veneer surface for 60 seconds and air-dried.

In Group 2 (CF), before application the GFN layer was cut to 0.5 mm short of the finish line of the preparation procedures. Then, the GFN layer was further impregnated with a light-curing adhesive resin (Stick Resin, Stick Tech.) for one hour in a dark container. The further impregnation of the polymer-pre-impregnated fibers with a light-curing resin matrix formed a semi-interpenetrating polymer network with a relatively coarse structure. This structure was previously shown to boost the bonding strength.[11,16-18] After further impregnation, the GFN layer was applied to the prepared tooth surface. Then, the veneers were gently seated on the abutment teeth and excess cement was removed with microbrushes and light-cured from the lingual, facial, and incisal sides for 40 seconds. The margins were finished with polishing disks (Sof-Lex, 3M ESPE). Cementation of the Group 1 samples without GFN followed the same procedure.

The specimens were first stored in water at 37°C for 24 hours and then subjected to thermocycling in Grade 3 deionized water for 6000 cycles between 5°C and 55°C, with a dwell time of 30 seconds and a transfer time of five seconds.[15,22] Then, 24 hours after thermocycling, a load test was performed using a universal testing machine (Lloyd LRX, Lloyd Instruments Ltd., Fareham, UK) at a crosshead speed of 1.0 mm/minute, as illustrated schematically in Figure 2.[15,22] To simulate the clinical situation as closely as possible, the teeth were loaded from the incisal direction. The load-deflection curve was recorded with a Nexygen 4.0

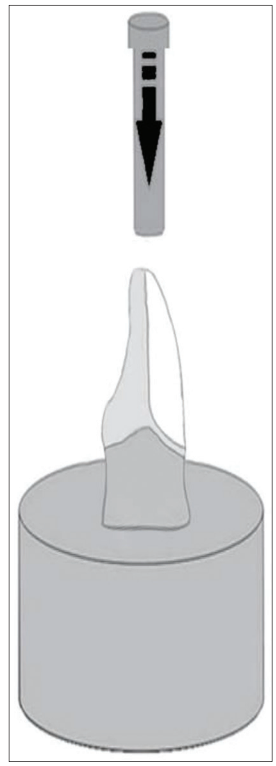

Figure 2: Schematic drawing of the test setup in the universal testing machine

software (Lloyd Instruments Ltd.). The teeth were stored in water at all times except for the testing period.

The fracture pattern of each loaded specimen was observed visually and with a stereomicroscope (Wild M3B, Heerbrugg, Switzerland). The failure modes were classified as follows: Adhesive failure between the laminate and tooth, mixed failure consisting of partly adhesive and partly cohesive failure between the tooth and laminate veneer, in which the fractures extend to less than one-third of the tooth structure, or cohesive laminate failure, in which chipping and small fractures were limited to the laminate only.

Data from all the groups were analyzed statistically by factorial analysis of variance (ANOVA). This was followed by Tukey's *post hoc* test at a significance level of $P < 0.05$

using SPSS 14.0 software (Statistical Package for the Social Science, SPSS Inc., Chicago, Illinois, USA) to establish the effects of laminate veneer material and fiber layer. The deflection data obtained using the universal testing machine was also analyzed statistically using the one-way ANOVA test.

Results

Figure 3 shows the mean fracture loads and standard deviations. Although some groups had higher fracture loads, ANOVA showed no significant differences among the ceramic laminate veneer materials ($P > 0.05$). Among the test groups, the lowest mean fracture load was obtained for Group 3 veneers, which were directly fabricated utilizing PFC (585.9 N). The highest was obtained for the CAD/CAM-generated ceramic laminate veneer with GFN at the interface (836.3 N).

The failure initiation loads (N) for the veneers were 798.92 for Group 1, 836.27 for Group 2, and 585.93 for Group 3, as shown in Figure 3. The fracture values were lowest for the traditionally fabricated composite veneer group. CAD/CAM-generated Cerec veneers cemented without or with fiber both had higher strengths but were not statistically significantly different from each other. Figure 4 shows the differences among the deflections obtained for the different restoration designs. Statistical analysis of the data showed that the Cerec group deflected significantly less than the other groups (one-way ANOVA, $P = 0.04$ for Cerec-fiber and $P = 0.02$ for fiber-reinforced composite).

The fracture modes of the groups are shown in Figure 5. The predominant failure mode is adhesive failure between the laminates and teeth for Group 1, cohesive failure in the luting layer for Group 2, and cohesive laminate failure for Group 3, which showed chipping and small fractures.

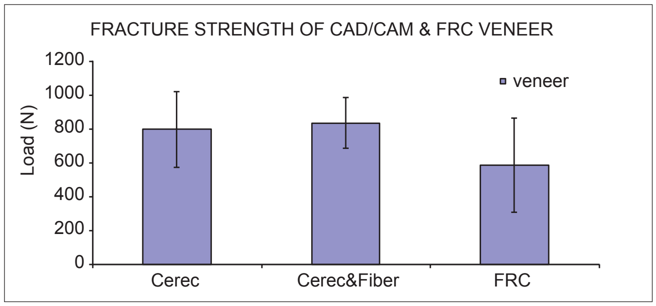

Figure 3: Means (N) and standard deviations of measured loads ($n = 10$) at the start of fracture for CAD/CAM-generated ceramic veneers and traditionally fabricated FR veneers

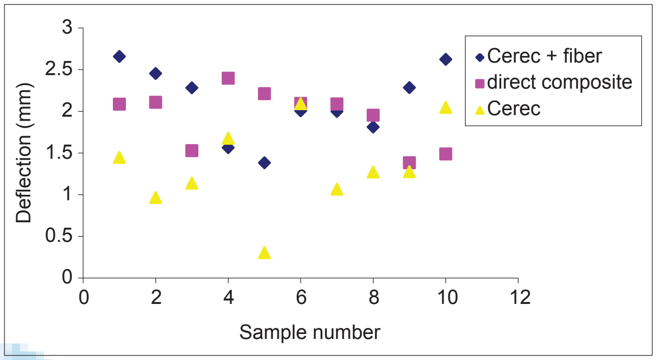

Figure 4: Deflection values of tested groups

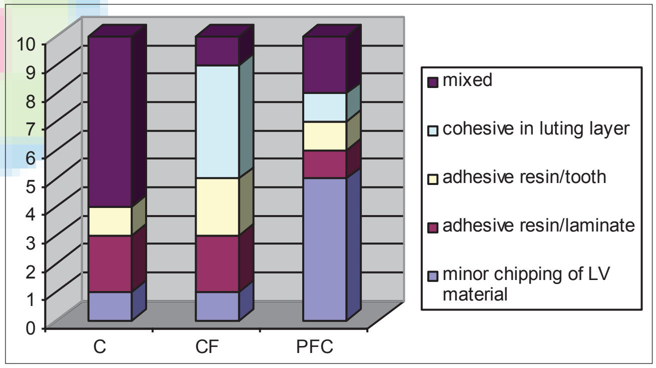

Figure 5: Failure modes of tested groups. "Mixed" means the fractured surface of the tooth has ceramic and resin remnants. "Cohesive in luting layer" means the fractured surface and the restoration surface have resin cement. "Adhesive resin/tooth" means the tooth surface is clean. "Adhesive resin/laminate" means the restoration surface is clean. "Minor chipping of LV material" means only small separated fragments from the restoration were observed

Discussion

Nowadays, chair-side restorations are becoming popular, as patients wish to receive their restorations as quickly as possible. Not only CAD/CAM manufacturing, but also freehand composite resin laminate restorations are becoming popular treatment choices, since they require only a single appointment in most cases. Although direct or indirect laminate veneers offer restorations with minimally invasive techniques, the most frequent failures associated with indirect veneers are debonding or fracture.[19] To increase the interfacial strength and change the crack propagation, this study evaluated the effect of bidirectional E-glass fiber at the cementation interface of CAD/CAM-generated Cerec veneers. It is well known that the quality and location of the fibers in a composite construction could affect the delamination mode of composite laminates,[20] which is very important because it is directly related to longevity of such restorations. This study compared the fracture strengths of CAD/CAM-generated Cerec veneers cemented either with or without GFNs with those of direct composite veneers also strengthened with glass fiber.

The null hypothesis was partially rejected. Although the mean failure load values were not statistically different among the ceramic and composite materials with or without fibers, the failure modes were different. Despite the known differences among the mechanical properties of the materials, they all produced a strong structure when they were bonded to the tooth structure.

In particular, the mean failure loads of the groups in this *in vitro* study ranged from 585 to 836 N, reaching levels higher than the physiological biting force of the anterior teeth, which varies between 108 and 176 N.[21] The measured standard deviations given in Figure 3 are high, but are similar to those in the previously published articles.[15,22] The large deviations may be explained by differences in the physical composition of the surfaces of the natural teeth.

Gresnigt and Ozcan[14] also studied the fracture strength of direct versus indirect laminates with and without fiber applied at the cementation interface. They obtained similar results to those in the current study. In their study, the direct and indirect resin composite laminate veneers showed comparable mean fracture strengths, and the use of E-glass woven-fiber sheet at the cementation interface did not increase the fracture strength of the polymeric laminate veneers. However, unlike in the current study, their laminate veneers were prepared with a highly filled polymeric material (Estenia) and direct laminates (Quadrant Anterior Shine). Turkaslan *et al*.,[22] who also obtained similar results, used fibers to cement laminate restorations made of composite restorative materials including heat-pressed technique lithium disilicate ceramic (IPS Empress 2) and copy-milled zirconium oxide blocks (ICE Zirkon, ZirkonZahn, Italy). The similarity of these fracture strength results may be explained by the homogenous structure of the laminate veneer restorations in both cases. In the current study, the use of CAD/CAM-generated feldspathic ceramic did not produce any difference in the fracture strengths of the restorations, probably because the resin cement is the primary factor affecting the adhesion of the teeth and the laminate veneer materials. Furthermore, the use of fibers does not increase the bonding strengths of the restorations with the teeth. However, the strength and integrity of the resin cement may be slightly improved when fibers are used, and the amount of cohesive failures in the resin cement may be decreased.

As mentioned above, the Cerec group deflects significantly less than the other groups [Figure 4]. This shows that adding a fiber-reinforced interface also increases the flexibility of the restored tooth, which may improve the service life of the restoration.

A deflection of up to 2 mm seems to be high, considering the nature of restorative composite and ceramic structures. However, the testing fixture, loading pin, restored teeth, and acrylic potting resin all contribute to this flexibility, which helps to explain the deflection values. Moreover, except for the restoration design, all other factors are standard in every individual test step, and thus the differences in the results can be attributed to differences in the restoration design.

The results obtained from the present study show that the restoration type significantly influences the deflection of the restored tooth. The laminate restoration and cementation material attached to the tooth using an adhesive technique allow the tooth to deflect differently, depending on the restoration.

Consequently, the fracture modes might be influenced by this strong cohesive structure of the resin cement with fibers. In particular, instead of big fractures, smaller and more repairable failures of the laminate restorations occur.

One limitation of this study is its usage of only glass fibers with the same thickness. Different fiber types, thicknesses, surface pretreatments, and cementation techniques should be evaluated in further investigations.

Conclusion

Within the limitations of this study, it is concluded that the various materials used for laminate veneers showed comparable fracture strengths. The addition of a GFN at the interface had no effect on the fracture strength but did change the failure modes. Further investigation is thus needed to elucidate the precise fracture mechanics at the interface.

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How to cite this article: Turkaslan S, Bagis B, Akan E, Mutluay MM, Vallittu PK. Fracture strengths of chair-side-generated veneers cemented with glass fibers. Niger J Clin Pract 2015;18:240-6.

Source of Support: Nil, **Conflict of Interest:** Author PV consults Stick Tech - Member of GC Group in their RD.