Acta Odontologica Scandinavica, 2005; 63: 153–157

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ORIGINAL ARTICLE

Fracture resistance of fiber-reinforced composite restorations with different framework design

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Abstract

Objectives. Veneer fracture and bond deficiency between framework and veneer are typical failures of fiber-reinforced inlay fixed partial dentures (FPD). An eccentric load point on the pontic was used in this study to investigate the fracture resistance of FPDs with different framework designs. As null hypothesis, it was assumed that fracture resistance was not influenced by the fiber framework supporting the veneer. ***Methods.*** Four groups of Vectris/Adoro FPDs ($4 \times n = 10$ each) were manufactured. Beams (25 mm length) of Vectris Pontic (parallel aligned) with (a) rectangular (3×3) sectional view and (b) circular sectional view (⊘ 3 mm) were directly veneered using Adoro. (c) Circular beams like "b" were modified, i.e. those on the upper side were coated with two layers of the cross-sectioned fiber mat Vectris frame. (d) Vectris Pontic fibers were "anatomically" placed in the pontic area and wrapped using Vectris Frame. The frameworks were constructed in a vacuum/pressure process. All FPDs were mounted in a restrained-end apparatus and thermally cycled and mechanically loaded (TCML: $6000 \times 5°\text{C}/55°\text{C}$; $1.2 \times 10^6 \times 50$ N, 1.66 Hz). After TCML, the FPDs were loaded to fracture. ***Results.*** All FPDs surpassed TCML, with no visible damage to the veneer or framework. Without transversal enlargement of the framework, additional cross-sectioned fiber mats alone did not improve resistance to fracture (a: 573 ± 158 N (mean, standard deviation given); b: 737 ± 66 N; c: 694 ± 93 N; d: 902 ± 149 N). Fracture lines occurred only in the veneer; the fiber frameworks were never affected. ***Conclusions.*** Anatomical enlargement of the fiber framework at the pontic area (height, width) to support the veneer material improves the fracture resistance of fiber-reinforced FPDs.

Key Words: *Fiber-reinforced composite, framework design, fracture resistance, inlay fixed partial dentures*

Introduction

Recent investigations of fiber-reinforced composite (FRC) inlay fixed partial dentures (FPD) have revealed promising results [1–6]. Only a few, negligible, failures have been seen after 1 year of observation [1,4,5], and it has been concluded from these clinical data and the results of *in vitro* studies that FRC restorations are potentially reliable alternatives to metal-based FPDs [4,7]. However, with increased observation time, more and more cases of fractured veneers or worn occlusal surfaces occur with FRC-FPDs [2,3,8,9].

The question this poses is: what can be done to improve FRC-FPDs? It has been observed that facings fail in areas where frameworks do not support the facing. The fracture line runs along the border between the framework and facing or in the veneering material itself.

As a first step towards improving FRC-FPDs, framework design and the bond between framework and veneer material can be modified. The aim of this study was to investigate the fracture resistance of different framework designs. Modifications were intended to support the veneer material more effectively during oral service. The null hypothesis was that fracture resistance was not influenced by the veneer being better support by the fiber framework.

Material and methods

Specimen construction was carried out in accordance with the instruction manual of Vectris/Adoro [10] (all materials/devices: Ivoclar-Vivadent, Schaan, FL, Liechtenstein).

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(Received 15 November 2004; accepted 3 January 2005)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2005 Taylor & Francis
DOI: 10.1080/00016350510019793

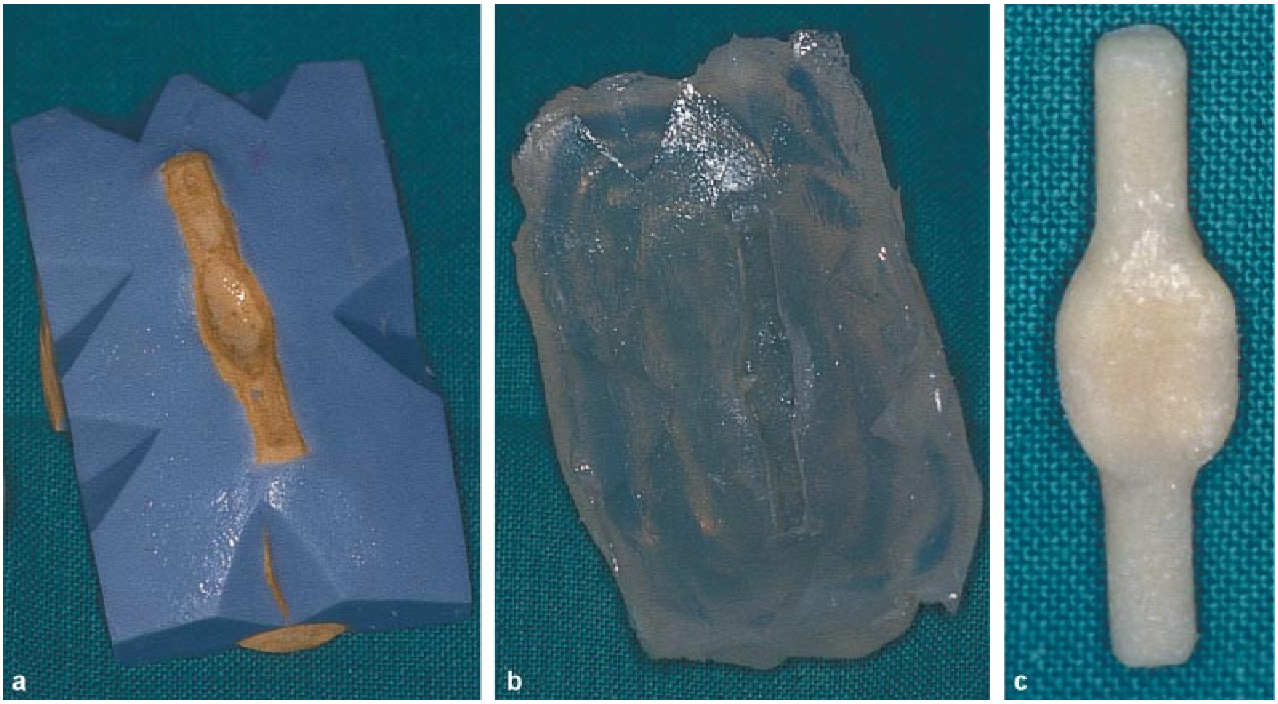

Figure 1. Positive (a) and translucent negative (b) split molds for constructing anatomically-shaped fiber frameworks (c).

FPDs with rectangular framework cross-section (group "a")

Ten rectangular bars of parallel aligned Vectris Pontic® glass fibers were cured under vacuum/pressure in a translucent mold using the Vectris VS-1® device—as shown in Figure 1 for group "d" [10]. Using diamond burs, the bars were prepared to 25 mm length, 3 mm width, and 3 mm height. The tolerance limit was ± 0.2 mm. Immediately after preparation, a silane coupling agent (Wetting agent®) and a flow composite (Vectris Glue®) were applied [10]. Molar tooth-shaped pontics were formed with the veneering material Adoro® in the middle of the bars (Table I). A translucent silicon mold (Transil®) was used to achieve pontics of similar size and shape. The facing material was light-cured in the Quick® device, and the entire specimens were light and heat-cured (104°C) for 25 min in the Targis Power Upgrade® device [10].

FPDs with circular framework cross-section (groups "b" and "c")

Ten frameworks of 3 mm diameter and 25 mm length were cured in the VS-1® device and veneered using the composite Adoro® as described for group "a". Ten bars 3 mm in diameter were constructed and wrapped in the fiber mat Vectris Frame®, which has woven glass fibers that bear load applied from divergent directions. When loaded occlusally, the bars bend and the maximal tensile stress is on the underside of the bars. In this state, parallel aligned Pontic® fibers can better resist the load and therefore the underside of the bars was left without woven Frame® fiber mats. Veneering of the framework was carried out as described for group "a".

Table I. Content of the veneer composite Adoro (dentin, A3)

Veneer composite (dentin A3)	Wt%
Urethandimethacrylate, aliphatic dimethacrylate	16.9
SiO_2	19.8
Prepolymer (Urethandimethacrylate + 72 wt% inorganic filler	62.9
Catalysts, stabilizers	0.4
Pigments	0.1

FPDs with anatomically-shaped frameworks in the pontic area (group "d")

A tooth-shaped framework was waxed up and this model was embedded in silicon to form a split mold (Transil®) (Figure 1a, b). The mold was filled with short strings of Pontic® fibers and centrally with a long Pontic® string (25 mm) (Figure 2). All fiber strings were aligned parallel in the long axis direction of the framework. Voids not filled by the fibers were filled with a flow composite (Vectris Glue®). The mold was closed and the framework was cured under vacuum/pressure by light and heat using the Vectris VS-1® device (10 min). When the mold was opened, the fiber mat Frame® was placed occlusally and pressed over the framework under vacuum pressure. The underside was left blank [10]. Veneering with Adoro® completed construction of the FRC-FPDs.

Aging procedures

Twenty-four hours after fabrication, the specimens were fixed in a restrained-end test apparatus (Figure 2a,

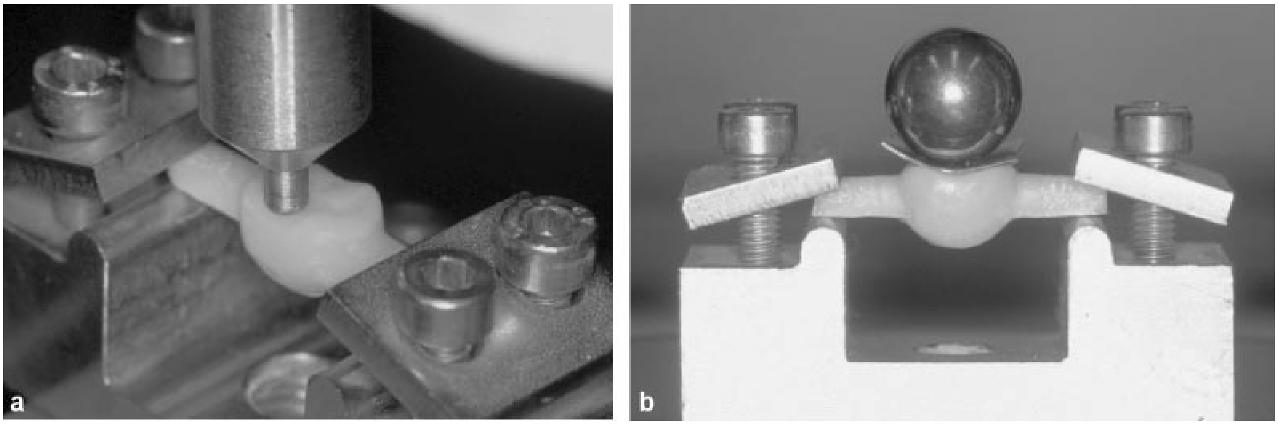

Figure 2. (a) Restrained-end apparatus with specimen inserted. Eccentric load application during thermal cycling and mechanical loading. (b) Scheme of load application for the final fracture test after thermal cycling and mechanical loading.

b) [11]. The fixation screws were tightened with a torque of 20 N cm^{-1}. Span length between the supports was 20 mm. The supports were round in shape, with a radius of 2 mm. All specimens were loaded 1,200,000 times with 50 N at a frequency of 1.66 Hz on the pontic area and 6000 times thermally cycled (TCML) [11]. The specimens were suspended in distilled water which alternated between 5°C and 55°C every 2 min in the test chambers. Thirty seconds was needed for each change. During thermal cycling a steel loading die with a hemispherical shape (2 mm of diameter) loaded the specimens eccentrically on the pontic area. The loading die hit the pontic veneer laterally in an area not supported by the fiber framework of groups "a–c" (see hypothesis) (Figure 2a). The entire TCML process lasted 8.3 days.

Fracture test

After thermally cycling and mechanically loading (TCML), all specimens were loaded to fracture using a universal testing machine Zwick 1446 (Zwick; Ulm, Germany). The cross-head speed was 1 mm min^{-1}. The load was applied as a 3-point occlusal contact on the pontic using a steel ball of 12 mm diameter (Figure 2b) [12]. During the load to fracture, the specimens were fixed in the restrained-end apparatus. Due to fiber-reinforced reconstructions showing abrupt failures as well as decreasing load-bearing capacities and increasing deformation, the failure strength was set at 10% below the maximum loading force registered [5].

Statistics

Mean and standard deviation were calculated and one-way ANOVA and Tukey tests were used ($\alpha = 0.05$).

Results

All specimens surpassed TCML with no visible signs of damage and no veneer fracture occurred. The null hypothesis was that the fracture resistance was not influenced by the veneer being better supported by the fiber framework.

FRC-FPDs with anatomically-shaped framework design ("d") reached significantly higher fracture resistance (902 ± 149 N) in the final fracture test than did the other designs ($p < 0.001$). Both framework types with circular sectional view had higher fracture resistance than specimens with rectangular sectional view ("a": 573 ± 158), but only specimens of type "b" showed statistically significantly higher fracture resistance ($p = 0.026$). There was no statistical difference between circular-shaped frameworks with and without a coating of cross-linked fiber mats ("b": 737 ± 66 N vs. "c" 694 ± 93 N).

Fractures occurred only in the veneer or at the border between framework and veneer. The fiber frameworks were not affected.

Discussion

Eckrote et al. [11] has stated that rigidity or stiffness of the prosthesis is important for the adhesive interfaces between FRC lamina, between the substructure and the veneer, and between the prosthesis and tooth structure. Instead of the entire restoration, only bars of the framework were investigated. In similar studies, attempts have been made to predict stiffness by measuring the Young's modulus using a 3-point bending test with freely supported specimens [11,14,15]. However, the result of this simple test is limited because the framework of an *in vivo* restoration is restrained on the abutment teeth [11]. Furthermore, it has been documented that classic small deflection theory is not accurate when the length/depth (L/d) ratio of the beam is below 20, which is the case for 3-unit FPDs [15]. A test design was therefore chosen which fitted the clinical situation better. Bars, veneered like a pontic, were clamped at both ends and a restrained-end model which better simulates the real situation was achieved. In the model, the ends of the

FPD are adhesively luted into the abutment teeth. In contrast to classical 3-point bending tests, a load (50 N) was applied 1,200,000 times in the simulator and, additionally, thermal-cycling (5°C/55°C) was carried out. These parameters are similar to a 5-year period in the oral cavity [13]. After aging, the specimens were loaded continuously until they fractured.

Eckrote [11] and Jauß [15] emphasize that shear forces influence the properties of anisotropic specimens with low L/d ratio (<20). High shear forces load the bond between the fiber framework and veneer composite. This corresponds to the high rate of facing failures observed clinically by inlay FRC-FPDs [8]. However, this is in contrast to *in vitro* studies and short-term clinical reports [1–6]. The reason for the discrepancy between *in vitro* and *in vivo* results lies in the fact that the load was *in vitro* applied in the pontic center so that the facing was supported by the fiber framework [5,6]. By loading the pontic in non-fiber supported areas, comparable failures (number and type) could be produced *in vitro*. A test design using lateral load application was therefore used in this study.

It has been stated that a well cross-linked polymer matrix with a high degree of carbon double bond conversion does not bond readily to dimethacrylate monomer resins or composites [16]. There are different approaches for solving this problem. The Stick system, for example, uses the interdiffusion of monomers within the polymer network [16,17]. Low molecular weight monomers dissolve the linear PMMA phase on the Stick FRC polymer matrix of the framework and offer bonds between framework and veneer composite. In contrast, Vectris needs a silane coupling agent to improve adhesion to the glass fiber framework [18,19]. The oxygen inhibition layer of the matrix can contribute to the bond, but this is almost completely removed during construction and fitting of the Vectris framework. Application of the silane coupling agent to bond di-methacrylate-based composite should ensure a reliable bond. However, this bond can fail [6]. Laterally loaded FPDs of the former veneer material Targis showed fractures. *In vivo*, many failures of the pontic veneers have been reported [6,9]. The modified veneer composite Adoro, based on a UDMA matrix and another filler technology, seems more compatible with the silianted Vectris frameworks than the veneer material Targis. No fractures of the Adoro veneers were found during TCML. A recently published *in vivo* study seems to support this observation [19].

It is shown in this study that circular-shaped frameworks are superior to rectangular-shaped frameworks. This is indicated not just by the higher mean values of the fracture resistance, but also by the closer standard deviation for circular-shaped frameworks. However, additionally applied cross-linked fiber mats (Frame) did not improve the fracture resistance.

The highest fracture values after TCML were noted with the anatomically-shaped framework. This supports the veneer as much as possible. Using a wax up, the shape of an enlarged framework can be constructed in consideration of the clinical situation. However, this method requires much effort and is time-consuming. Compared with the simpler construction of FRC-FPDs with circular cross-section, the fracture resistance is significantly higher. Körber & Ludwig [20] postulated that a reconstruction in the posterior area should resist a load of 500 N after aging. With mean values of more than 600 N in this study, it can be expected that the simpler constructed (circular) FPDs will be successful during oral service too. Some specimens with rectangular-shaped fiber frameworks fell short, with mean lower to the value of 500 N, and clinical failure could be expected. The anatomically-shaped fiber framework offers more fibers than the simpler frameworks to support the restoration. But the difference between the fracture resistance values of the above-mentioned and those of frameworks with less fiber content is not as high as expected. The reason is the influence of the shear forces, which play an important role with anisotropic materials like FRC [15]. High shear forces stress the bond between fiber and matrix and framework and veneer composite. Further improvements of the fracture resistance of FRC-FPDs can therefore be expected by enhancing the bond strength between fibers and matrix and framework and veneer material as well as the framework design.

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