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## Fracture strength of direct versus indirect laminates with and without fiber application at the cementation interface

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### ABSTRACT

**Objectives.** This study compared the fracture strength of direct and indirect resin composite laminate veneers and evaluated the effect of a bidirectional E-glass woven fiber application at different locations at the cementation interface.

**Methods.** Standard preparations on canines ( $N=50$ , 10 per group) were made using a depth cutting bur (0.7 mm depth) designed for laminate veneer restorations. Forty indirect laminates using a highly filled polymeric material (Estenia) and 10 direct laminates (Quadrant Anterior Shine) were prepared according to the manufacturer's instructions. Bidirectional E-glass woven-fiber sheet (0.06 mm) (Everstick) was applied at different locations at the cementation interface. The control group received no fibers. The specimens were stored in water at 37 °C for 1 month prior to fracture testing performed in a universal testing machine where the load was applied from the incisal direction at 137° (1 mm/min).

**Results.** No significant differences were found between the five groups ( $P>0.01$ ) (one-way ANOVA). While indirect laminate veneers showed mean fracture strength of  $247 \pm 47$  N, direct laminate veneers revealed  $239 \pm 104$  N. The use of E-glass fibers at the cementation interface at different locations did not increase the fracture strength significantly (286–313 N) ( $P>0.01$ ). Failure analysis showed mainly cohesive fracture of the veneer restoration (20/50) and adhesive failure between the cementation interface and the laminate with fiber exposure (19/50) covering more than half of the restorations.

**Significance.** Direct and indirect resin composite laminate veneers showed comparable mean fracture strengths. The use of E-glass woven-fiber sheet at the cementation interface did not increase the fracture strength of the polymeric laminate veneers.

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### 1. Introduction

With the introduction of total-etch, multi-step, adhesive systems, progress in bonding to enamel and dentin, and further development of resin composites has led to a more conservative restorative treatment of discolored or damaged anterior teeth. One such minimal invasive treatment modality is the application of laminate veneers made of either ceramics or particulate filler composites (PFC). Lami-

nate veneers require minimal preparation of only 0.3–0.9 mm which is highly conservative when compared to their full-coverage counterparts. Basically, three types of preparation design have been described for laminate preparations: namely, window or intra-enamel preparation, overlapped incisal edge or knife-edge incisal preparation [1–3]. Several studies suggested the window type as the most conservative preparation when strength is an important factor [3–5].

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To date, little information is available in the literature on the survival rates of different laminate materials [6]. The Cochrane Collaboration concluded that there was no evidence as to whether indirect laminates are better than direct ones [7]. Direct composite laminate veneers are less expensive than the indirect options and they can be accomplished in one session. However they still suffer from a limited longevity since they are susceptible to discoloration, wear and marginal fractures, thereby reducing the esthetic result in the long-term [6,8].

Indirect laminates can either be made of ceramics or PFCs where the latter is considered less expensive with improved wear resistance, physical properties and color stability [8,9]. The new PFCs are characterized by a filler/matrix ratio that is significantly greater (up to 92%) than that of the preceding generation of resin composite materials. Indirect laminate veneer restorations should firmly adhere to the underlying tooth substrate with adhesive cement in order to improve the fracture resistance [10]. Micro-tensile bond strength of MDP monomer-based resin cement bonded to an indirect resin composite was found to be superior when compared to other cements [11].

Delamination is one of the predominant forms of failure in laminated composites, due to the lack of reinforcement in the thickness [12-15]. Particularly, delamination as a result of impact forces can cause significant reduction in the compressive load-carrying capacity of a structure. In order to strengthen laminated composite materials, fibers can be placed at the interface [16,17]. Several types of fiber have been

used to reinforce dental polymers [14]. E-glass fibers demonstrate an ability to withstand tensile stresses and stop crack propagation in composite materials [18,19]. There exist potential applications for fiber-reinforced composites in different disciplines of dentistry, but no study was based on their use for the purpose of reinforcing the cementation interface in laminate veneers.

The objectives of this study were to compare the fracture strength of direct and indirect resin composite laminate veneers and to evaluate the effect of bidirectional E-glass woven fiber application, at different locations at the cement interface, on fracture strength and failure modes.

## 2. Material and methods

Fifty sound human canines of similar size, free of restorations and root canal treatment were selected from a pool of recently extracted teeth. Before preparation, an impression was taken from each tooth using a high precision condensation silicone (Zhermack, Marl, Germany) in order to obtain molds for creating laminate veneers of the original form and shape of the teeth. Window type tooth preparations ( $N = 50$ , 10 per group), without incisal overlap, were made with a depth cutting bur especially designed for laminate preparations (Swiss Dental Products, Intensiv SA, Lot M-9306, Grancia, Switzerland). After the depth cuts of 0.7 mm were made, preparation was

**Table 1 - The materials used for the experiments, their compositions, manufacturing company names and batch numbers**

Product name	Type	Manufacturer	Composition	Batch number
Quadrant Anterior shine	Hybrid resin composite	Cavex, Haarlem, The Netherlands	Methacrylate monomer, silica, silicate glass and fluoride containing fillers, polymerization catalysts, inorganic pigments	010026C
Quadrant Unibond Primer	Primer	Cavex, Haarlem, The Netherlands	2-Hydroxyethyl methacrylate, maleic acid-mono-2-methacryloyl-oxyethyl ester, maleic acid, ethanol	030033
Quadrant Unibond Sealer	Bonding agent	Cavex, Haarlem, The Netherlands	Maleic acid, methacrylate monomers	060043
Panavia F2.0	Dual-cure resin cement	Kuraray Co., Tokyo, Japan	Silanated barium glass, silanated silica, surface treated sodium fluoride, bis-phenol A polyethoxy dimethacrylate, MDP, hydrophobic dimethacrylate, hydrophilic dimethacrylate, benzoyl peroxide, sodium aromatic sulfinate, <i>N,N</i> -diethanol <i>p</i> -toluidine, photo-initiator	41114
Clearfil SE Bond Primer	Primer	Kuraray Co., Tokyo, Japan	MDP, HEMA, hydrophilic dimethacrylate, <i>N,N</i> -diethanol, <i>p</i> -toluidine, water	00262A
Clearfil Porcelain Bond	Activator	Kuraray Co., Tokyo, Japan	Bisphenol a polyethoxy demethacrylate	001248
Estenia	Hybrid composite	Kuraray Co., Tokyo, Japan	3-methacryloyloxypropyl trimethoxy silane	D3-E1-3
EverStick Net	Woven bidirectional E-glass fiber	Stick Tech Ltd., Finland	Urethane tetramethacrylate (UTMA), Lanthanum oxide (filler)	CE0510
Ultra-etch 35%	Etching agent	Ultradent Products Inc., USA	Siliciumoxide, calcium oxide, aluminium oxide, natrium oxide, magnesium oxide, kalium oxide, barium oxide = E-glass (electric glass, silanated); bis-GMA and PMMA	L117
ESPE-Sil	Silane	3M, St. Paul, USA	35% phosphoric acid	152745
			Ethyl alcohol, methacryloxypropyl trimethoxysilane	

finalized using a round-ended tapered diamond chamfer bur (Swiss Dental Products, Lot S-4180, FG-2309). The preparations ended 1 mm above the cemento-enamel junction. Smooth margins were created to prevent stress concentration zones. All prepared teeth were randomly assigned to five experimental groups. Forty indirect laminate veneers using a highly filled polymeric material (Estenia) (Shade E1) (groups 1-4) and 10 direct laminate veneers (Quadrant Anterior Shine) (Shade A1) (group 5) were prepared using a micro-hybrid composite according to the manufacturers' instructions. The materials used for the experiments, their compositions and manufacturers are listed in Table 1.

Standard thickness of the laminates in the original form of the teeth was achieved using the impression molds made before tooth preparation. For each tooth, an individual laminate was produced. While the direct laminates were only light-polymerized (Demetron LC, SDS Kerr, Germany, light intensity: 500 mW/cm<sup>2</sup>) following etching, priming and bonding (group 5), the indirect ones were both light and heat-polymerized using the polymerization unit advocated by the manufacturer (Tecnomedica, Bareggio, Italy). Excess composite around the margins was removed and the laminates were finished using finishing burs (Swiss Dental Products, FG-2309) and polished (Sof-Lex discs, 3M ESPE, St. Paul, MN, USA).

### 3. Cementation of the laminate veneers

Dual-cure resin composite cement (Panavia F2.0) was used for the cementation of the indirect laminate veneers. A three-step bonding procedure was employed to ensure good adhesion of the resin cement in case dentin was exposed.

The cementation surfaces of the veneers were silica coated (CoJet<sup>®</sup>-Sand, 30 μm SiO<sub>x</sub>, 3M ESPE, Seefeld, Germany) using a chairside air-abrasion device (Dento-Prep<sup>™</sup>, RØNVIG A/S, Daugaard, Denmark) from an approximate distance of 10 mm until the surface became matt and then silanized.

Bidirectional E-glass woven fibers (Everstick, Sticktech, Finland) (0.06 mm) of 42-48 mm<sup>2</sup> were cut using straight scissors depending on the surface area of the preparation. Labial surfaces of the canines that would receive the laminate veneers were measured using a micrometer (Mitutoyo Ltd., Hampshire, UK). Care was taken not to extend the measurements further than the mesial and distal margins of the preparation in order to avoid fiber exposure.

The fiber sheet was placed at the cementation interface at three locations namely: (a) tooth surface-fiber-cement-laminate (group 1), (b) tooth surface-cement-fiber-cement-laminate (group 2) and (c) tooth surface-cement-fiber-laminate (group 3). During the cementation procedure, the cement thickness was controlled using an ultrasonic tip, working it based on oscillation principles (Amdent, Nynäshamn, Sweden). The tip of the cementation device was held perpendicular to the surface after seating the laminate veneer on the prepared tooth surface. Excess cement was removed from the margins using an explorer. The restoration was then light polymerized (Demetron LC) for 40 s from each direction. Oxygen inhibition gel (Oxyguard, Kuraray) was applied around the margins of the laminate to ensure complete polymeriza-

tion and then rinsed thoroughly. The control group (group 4) received no fibers and cementation in this group was performed as described above.

### 4. Fracture strength test

The teeth with the cemented laminate veneers were embedded perpendicularly in polymethylmethacrylate (Autoplast, Condular, Wager, Switzerland) up to the cemento-enamel junction in the middle of the plastic rings (PVC, diameter: 2 cm, height: 1 cm). The specimens were stored in water at 37°C for one month prior to the fracture test, which was performed in a universal testing machine (Zwick ROELL Z2.5MA, 18-1-3/7, Zwick, Ulm, Germany). In order to simulate the clinical situation as closely as possible, the specimens were mounted onto a metal base and load was applied at 137° at a crosshead speed of 1.0 mm/min from the incisal direction to the laminate-tooth interface (Fig. 1) [20]. The maximum force to produce fracture was recorded. Digital photos were taken from the specimens and failure type, location and size were determined.

Statistical analysis was performed using the SAS System for Windows, release 8.02/2001 (Cary, NC, USA). The means of each group were analysed by one-way analysis of variance (ANOVA). *P* values less than 0.01 were considered to be statistically significant in all tests.



Fig. 1 - Application of the load cell to the laminate-tooth interface in a universal testing machine until fracture.

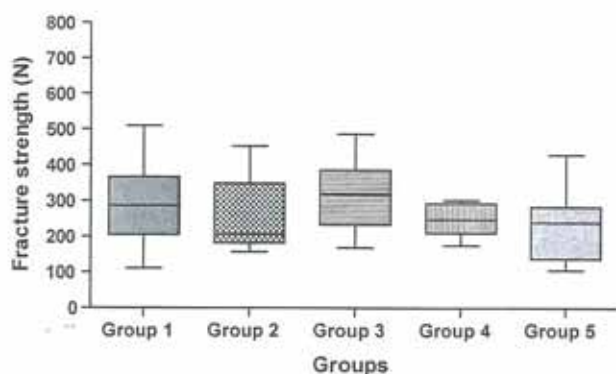


Fig. 2 - The mean fracture strength values (N) for direct (group 5) indirect (group 1) resin composite laminates with (groups 2-4) and without fiber reinforcement (group 1) at the cementation interface. Vertical lines represent the standard deviations.

## 5. Results

One-way analysis of variance showed no significant difference between the five experimental groups ( $P > 0.01$ ) (Fig. 2). The use of woven E-glass-fibers at the cementation interface at different locations (groups 1-3) ( $251 \pm 110$  to  $313 \pm 100$  N) did not increase the fracture strength significantly ( $P > 0.01$ ) when compared with the control group without glass-fiber at the interface (group 4) ( $247 \pm 47$  N).

There were no significant differences between the mean fracture strength of direct (group 5) ( $239 \pm 104$  N) and indirect laminate veneers (group 1) ( $247 \pm 47$  N) ( $P = 0.43$ ).

Analysis of the fractured laminate veneers showed mainly three types of failures: cohesive fracture of the veneer restoration (CF), adhesive failure between the cementation interface and the laminate either with fiber exposure (FE) or tooth exposure (TE). Failure types were further classified as irreparable (type 1 = greater than half of the restoration) and repairable (type 2 = lesser than half of the restoration) types of failure. The observed failure types per group are demonstrated in Table 2. The most frequently experienced failure types were CF (20/50)

and FE (19/50). While 33 restorations out of 50 were considered as type 1, 17 out of 50 were classified as type 2 failures.

## 6. Discussion

Although direct or indirect laminate veneers offer restoration of missing dental tissues in a minimal invasive approach, the most frequent failures associated with indirect laminate veneers are debonding or fracture, and marginal degradation at the margins [21]. This is an important clinical problem as it relates to the longevity of such restorations.

In an attempt to increase the interfacial strength and change the crack propagation, in this study, bidirectional E-glass woven fibers were employed at the cementation interface of indirect composite laminate veneers. Laminated composite plates are extensively used in the construction of high performance structures, etc., in the aerospace, civil, marine, automotive industry, due to their high stiffness and strength, excellent fatigue resistance and long durability. Due to the anisotropy of composite laminates and non-uniform distribution of stresses in the laminae under either static or dynamic loading, the failure process of laminates is very complex. When such laminates are adhered to dentin, then the orientation of the tubuli could also contribute to the complexity. Unfortunately, laminated composites have relatively poor mechanisms for absorbing energy due to local impact damage where loading is normal to the laminae planes [17]. For this reason, application of fibers at the interface between two or three laminates may change the load bearing capacity of the whole structure. However in this study, the application of a 0.06 mm E-glass woven fiber layer at the cementation interface did not contribute to an improvement in the fracture strength of the laminate material tested. It is well known that the quantity and location of the fibers in a composite construction could affect the delamination mode of fiber-reinforced composite laminates [13]. Based on this information, fiber sheet was placed at three locations but the results were not statistically significant. Increasing the quantity of fibers could affect the results. However, the thickness of the fiber would

Table 2 - Tabulation and frequency of the failure modes experienced after the fracture test per group with representative images

Groups	CF	FE	TE	Type 1	Type 2
1	4	6	0	7	3
2	5	5	0	8	2
3	2	8	0	8	2
4	6	0	4	4	6
5	3	0	7	6	4
Example					

CF: cohesive fracture of the veneer restoration; FE: adhesive failure between the cementation interface and the laminate with fiber exposure; TE: adhesive failure between the cementation interface and the laminate with tooth exposure. Type 1 = greater than half of the restoration failure = greater than half of the restoration, type 2 failure = lesser than half of the restoration.

then impair the marginal adaptation, which would lead to marginal discoloration or degradation of the luting cement at the interface. Although small in thickness, the interphases have significant effect on the micromechanical behavior of fiber-reinforced composites [22]. The addition of two layers of the same fiber tested, has led to a dramatic improvement in fracture strength values in metal-ceramic repairs [20]. The current results are in compliance with a recent study where it was also reported that the incorporation of single woven E-glass fiber did not increase the load-bearing capacity for cuspl-replacing direct restorations with a beneficial effect: however on the failure mode, increasing the re-restorability of the fracture [17].

Failure analysis of the fractured laminates in this study showed mainly cohesive fracture of the veneer restoration followed by adhesive failure between the cementation interface and the laminate with fiber exposure. The cohesive failure of the laminate within the resin composite indicates good adhesion of the laminate to either the fiber or the cement layer. The strengths of indirect composite restorations were found to be significantly lower than those of direct composite restorations, even when a resin coating system was employed [23]. These favorable results could be attributed to the effect of surface conditioning and silanization of the PFC prior to cementation as described elsewhere [24]. The adhesive failure on the other hand, shows the weak link between the fiber and the laminate veneer. Problems associated with adhesion of composite to fibers have previously been reported [25]. The results may also be influenced by the cement type. In this study, MDP-based cement (Panavia F) was used since it has been previously reported to deliver the best microtensile bond strength results for the resin composite used (Estenia) [10].

Clinically, the most favorable failure type to be experienced would be cohesive fracture in the composite or bulk fracture covering less than half of the restoration, which allows for intraoral repair options. The majority of the failure types in size covered more than half of the whole restoration. Fracture below the cement-enamel junction was not observed in any of the groups that were considered more difficult to repair [19]. Future studies should not only report the fracture strength but also the failure types of such restorations.

The average masticatory forces in the anterior region vary between 155 and 200 N [26]. The results of the current study exhibited mean values ranging between 239 and 313 N, indicating that composite laminate veneers could be considered strong enough to withstand masticatory forces. No perfect tooth model presently exists for conducting fracture strength studies. Natural teeth show a large variation depending on age, anatomy, size, shape and storage time after extraction, and therefore can cause difficulties in standardization. Several studies used steel or resin dies for the fracture testing of laminates or crowns [18,27,28]. However tooth preparation made on steel or resins does not simulate the actual force distribution that occurs on laminate veneers cemented on natural teeth. Therefore the results of this study could not be directly compared with those of others.

The ratio between the thickness of the restoration and the luting cement appears to have a relevant influence on the stress distribution in laminate veneers [29,30]. Magne et al. stated that thin restorations with poor internal fit result in

higher stresses at both the surface and interface of the restorations [31]. In order to obtain optimal physical properties, a minimal thickness of 0.6 mm is required for indirect laminate veneers [32]. Insufficient tooth reduction could lead to an overcontoured final restoration, whilst excessive reduction results in an increased reliance upon dentin bonding systems to effectively retain and seal the restoration [26]. In this study, preparations were made using standard depth cutting burs since freehand preparation has the distinct drawback of reducing too much or too little enamel. After preparation, a thin layer of enamel with partially exposed islands of dentin was sometimes visible at the labial surface. For this reason, a total etch, multiple-step dentin bonding procedure was employed during the cementation procedures. Furthermore, cement thickness was maintained at the minimum by using the ultrasonic tips working them based on oscillation principles. In this cementation technique, the vibration alters the viscosity of the cement, eliminates possible air bubbles in the cement and also allows the restoration to seat itself easily.

In laminated fiber reinforced composites, crack growth under tensile stresses is generally arrested by the fibers [33]. By using fibers between the laminae, resistance to fatigue crack propagation could be increased and failure then happens only at high stress levels. Under the influence of compressive cycle stresses, the damage associated with delamination and separation of the fiber reinforced layers, which are stacked together to form laminates, must be taken into account. The presence of delamination may reduce the overall stiffness as well as the residual strength leading to structural failure. Low delamination resistance causes delamination cracks [33]. Future studies should therefore involve fatigue forces and evaluate the effect of fibers in such an experimental set-up.

In a 2-year clinical study, resin materials processed under heat and pressure did not provide a veneering system that was more compatible with intra-oral stresses than comparatively rigid porcelain [34]. Although recently PFC materials improved dramatically, microfilled direct composite resins are still not resistant to chipping when used at the incisal edge [6]. The indirect PFCs have higher flexural fatigue strength than the microfilled direct composites [8]. In a study by Yamaga et al., it became evident that resin composites containing four-functional urethane methacrylate (UTMA) had both hardness and fracture toughness greater than those of two-functional urethane methacrylate (UDMA) [35]. The filler content in the composite tended to be linearly proportional to both hardness and fracture toughness. The reason for high fracture strength of laminate veneers without fiber reinforcement could therefore be attributed to the PFC system used in this study.

Non-significant fracture strength values obtained from direct laminate veneers versus indirect ones could be related to the polymerization method, where the latter was processed in a xenoscopic light polymerization device under heat and light. A high degree of conversion results from the use of heat and light used for processing laboratory type resin composites. This causes improvement in mechanical strength and hardness but on the other hand makes the attachment of the new composite to the polymerized composite more difficult [24]. In laboratory polymerization devices, often thermal, chemical and visible light activation are involved. This procedure increases the crosslinking of the resin to a high extent and

consequently leads to a more brittle material. This could be one of the explanations why the indirect and direct composite laminate veneers delivered similar fracture strength results.

## 7. Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Direct and indirect resin composite laminate veneers tested in this study showed comparable mean fracture strength values.
2. The use of bidirectional E-glass woven fiber sheet at the cementation interface did not increase the fracture strength of the polymeric indirect laminate veneers significantly.
3. The most frequently experienced failure types were cohesive fracture of the veneer restoration and adhesive failure between the cementation and the laminate interface with fiber exposure. The majority of the fractures covered more than half of the restorations.

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