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Comparison of conventional ceramic laminate veneers, partial laminate veneers and direct composite resin restorations in fracture strength after aging

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ABSTRACT

Objectives: The objectives of this study were to test the fracture strength *in vitro* of laminate veneers, partial laminate veneers and composite restorations after aging and analyze the failure mode.
Methods: Forty extracted, sound human teeth were selected and divided into four groups: 1) Control group (CG); 2) Conventional Laminate Veneer (CLV); 3) Partial Laminate Veneer (PLV); 4) Direct Composite Resin (DCR). Laminate veneer preparations with incisal overlap were made in group CLV whereas only incisal preparations were made with a 1 mm bevel in group PLV and DCR. The indirect restorations were luted with a resin composite and the DCR group was restored with a direct resin composite restoration. The restored teeth were subsequently aged by thermocycling (20.000 cycles, 5–55 degrees C). Subsequently, the fracture strength was tested by a load to failure test at 135° on the incisal edge. A failure analysis was performed using light microscopy. The results were analyzed using Shapiro-Wilk and Kruska-Wallis test.
Results: After thermocycling, one sample from group CLV presented a premature adhesive failure and was excluded. Three restorations from groups PLV and DCR presented small cracks but were taken to the fracture test. After aging mean fracture load + SD (N) were: Group DCR ($n = 10$): 385 ± 225; Group CG ($n = 10$): 271 ± 100; Group PLV ($n = 10$): 266 ± 69; Group CLV ($n = 9$): 264 ± 66. Fracture strength means from groups CLV and PLV did not differ statistically from each other nor from control ($p = 0.05$). In the group CLV the root fracture was the most occurring fracture. In groups PLV and DCR, material cohesive failures and a mix (adhesive, tooth and material cohesive) failures were most observed.
Significance: This *in vitro* study showed for the first time that partial laminate veneers can exhibit fracture strength values similar to direct composite restorations or conventional ceramic laminate veneers. All three restorative procedures presented clinically acceptable values of fracture strength. Even though three samples from groups PLV and three from DCR presented small cracks after thermocycling, these cracks do not appear to have a negative effect on the fracture strength.

1. Introduction

A common clinical situation in dentistry is trauma with fracture of an upper incisor (Wiegand et al., 2005). Due to the developments in adhesive dentistry, the variety of treatments have accordingly expanded (Peumans et al., 1997). In some cases, the fractured fragment of the tooth may be reinstated. This can lead to an esthetically pleasing result at relatively low costs. This conservative treatment is generally accepted and it is a good alternative for artificial restorations (Wiegand et al., 2005). In the event of fragment loss, two other options are available: direct composite restoration and a ceramic laminate veneer (Christensen, 2004).

A direct composite resin restoration can be performed with less tissue removal when compared to ceramic conventional laminate veneers.

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Also, direct treatment can be performed in one single session and is relatively cheap. The direct composite resin restorations have their disadvantages though: need of replacement due to wear and loss of anatomical shape (van Dijken and Pallesen, 2010) and lack of color stability in the long term (Peumans et al., 1997). In addition to the color changes and wear of the composite, there is another factor that can lead to failure of a composite restoration. In a study of class IV direct composite resin restorations, 36.5% of the restorations were fractured after an average of 8.8 years (van Dijken and Pallesen, 2010).

Ceramic laminate veneers are manufactured in a dental laboratory being placed in a second session with the patient. A notorious advantage of ceramic laminate veneers for anterior teeth is its long-term rates of survival (D'Arcangelo et al., 2012). The ceramic undergoes less wear when compared to composite resin (Vanoorbeek et al., 2010) and its color stability can endure up to ten years of clinical use (Gresnigt et al., 2019). This long-term success rate relies on factors such as inherent material properties, preparation form and the functional and morphological condition of the tooth, being this last one not controlled by the dentist (D'Arcangelo et al., 2012). One clinical study found that success rates of ceramic laminate veneers can reach 98.8% after 6 years (Della Bona and Kelly, 2008). Major marginal defects and ceramic fractures are the main causes of failure (Gresnigt et al., 2019) but less than 5% of the ceramic veneers fail after five years due to loss of retention and fractures (Della Bona and Kelly, 2008).

A more recent restorative technique is the partial ceramic laminate veneer. The partial ceramic laminate veneer differs from the conventional ceramic laminate veneer in the sense that there is almost no or no removal of sound tissue during preparation of the tooth (Edelhoff and Sorensen, 2002). The fractured portion of the tooth is reestablished only by additive approach.

Although direct composite restorations are a cheaper treatment alternative they lack color stability and undergo high wear rates (Peumans et al., 1997). Ceramic laminate veneers are not subjected to these factors but these are more invasive options. Both kinds of restorations are susceptible to fracture. There is lack of studies that have compared the fracture strength of direct composite restorations, ceramic laminate veneers and partial laminate veneers. Ceramic partial laminate veneers were recently included as a treatment alternative, no research has been published about their fracture strength to date. Thus this *in vitro* study aims to fulfill this void comparing the fracture strength of a conventional ceramic laminate veneer, a partial ceramic laminate veneer and a direct composite restoration on upper central incisors.

2. Materials and methods

This is a laboratory study. The brands, types, manufacturers, chemical compositions and batch numbers of the materials used in this study are listed in Table 1.

Healthy central upper incisors were collected and selected for this study from a bank of fresh extracted central incisors. Teeth with 8.7 ± 0.2 cm crown width and 11.2 ± 0.5 cm crown length, without restorations, caries, fractures and endodontic treatments were included and randomly divided into four groups (n = 10): Control group (CG) consisting of healthy teeth that will not be prepared nor restored, conventional laminate veneer (CLV), partial laminate veneer (PLV) and direct composite resin restoration (DCR). All the teeth were stored in water at room temperature until use and the water was refreshed every week.

2.1. Preparation

Preparations were performed with a diamond bur ISO 856018 (Diatech, Switzerland). Fig. 1 is a schematic representation of the shape of preparation per group. CG did not receive any preparation. For group CLV, orientation grooves of 0.3 mm depth were made from cervical to incisal. Subsequently, the grooves were merged leading to a whole buccal surface preparation. The cervical outline was a shallow chamfer of 0.1 mm thickness. The incisal edge was lowered 1.5 mm thus dentine was exposed. Groups PLV and DCR did not have the full extent of buccal surface prepared. In these groups only the 1.5 mm incisal lowering and a bevel of 1 mm width on the buccal side were placed.

2.2. Restoration

Preparations of CLV and PLV were duplicated into gypsum casts. Conventional and partial laminate veneers and were made of glass ceramic IPS e.max Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) by one dental technician. The restorations were fired at 770 °C for 8 min and afterwards finished an polished following the manufacturer's instructions. During the fabrication of the laminate veneers, the prepared teeth of CLV and PLV groups received a temporary restoration made with Protemp 4 (3 M ESPE, St. Paul, MN, USA) until luting of the laminate veneers.

In group DCR, teeth were restored immediately after preparation. Enamel was etched for 30 s and dentin for 10 s with phosphoric acid 37% (Total-Etch, Ivoclar Vivadent). After rinsing and gently air-drying,

Table 1
The brands, types, chemical compositions, manufacturers and batch numbers of the main materials used in this study.

Product name	Type	Manufacturer	Chemical composition	LOT number
Ceramic etching gel <5%	Hydrofluoric acid	Ivoclar Vivadent	Hydrofluoric acid	N21838
Total-Etch	37% phosporic acid	Ivoclar Vivadent	37% phosporic acid	P14739
Monobond Plus	prime	Ivoclar Vivadent	Ethanol, 3-trimetho-xysilsylpropylmetha-crylate, methacrylated phosphoric acid ester	N37750
Syntac Primer 1	Light-curing total-etch adhesive	Ivoclar Vivadent	Water, acetone, maleïcacid,/dimethacrylate	P17329
Syntac Adhesive 2	Light-curing total-etch adhesive	Ivoclar Vivadent	Water, glutaaraldehyde, maleic acid, poly-ethyleenglycodi-methacrylate	P15364
Syntac Heliobond 3	Light-curing total-etch adhesive	Ivoclar Vivadent	Bis-GMA, dimethacrylaat, initiators and stabilzers	P06157
Variolink Veneer	Light-curing resin cement	Ivoclar Vivadent	Urethane dimethacrylate, inorganic fillers, ytterbium trifluoride, initiators, stabilizers, pigments	N64556
Liquid Strip	Glycerin Gel	Ivoclar Vivadent	Glycerin gel	P28325
Optibond FL	Filled light-cure bonding agent/total-etch two-component adhesive	Kerr	HEMA, disodium hexa-fluorosylicate	3661962
Composite IPS Empress Direct	Light-curing nano-hybrid composiet	Ivoclar Vivadent	Urethane dimetha-crylate, tricyclodocan-dimethanoldimetha-crylat, bis-GMA	N32527 N30972
Ceramic	IPS e.max Ceram	Ivoclar Vivadent	SiO2, CaO, Al2O3, CeO2, Na2O, K2O, B2O3, ZnO, F, Li2O, ZrO2, P2O5, SrO, TiO2, pigments	N48547

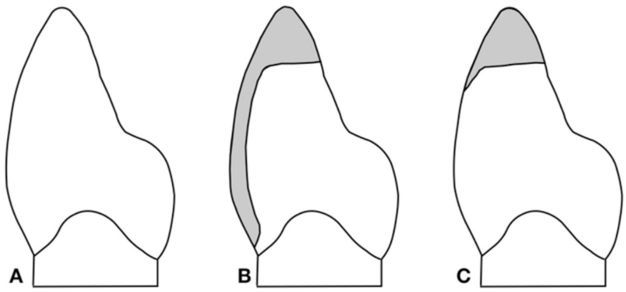

Fig. 1. Schematic representation of preparations for CG, CLV, PLV and DCR. A: intact tooth, B: tooth with full laminate veneer of 0.3 mm buccal and 1.5 mm overlap, C: tooth with 1.5 mm overlap and 1 mm bevel (partial ceramic and direct composite).

primer and adhesive Optibond FL (Kerr Dental, Orange, California) were applied to the entire preparation following manufacturer's instructions. The restoration was performed by layering technique with nanohybrid composite resin IPS Empress Direct Enamel and Dentine (Ivoclar Vivadent). Each layer was light-cured for 20 s with 1220 mW/cm^2 (Bluephase 20i, Ivoclar Vivadent). The composite restorations were then finished with Soflex (3 M ESPE, St. Paul, MN, USA) discs and polished with Small Flame cups.

2.3. Luting

Laminate veneers from CLV and PLV were internally etched with hydrofluoric acid (4.9% IPS Ceramic Etching gel, Ivoclar Vivadent) for 60 s, thoroughly rinsed with water and ultrasonic cleaned in distilled water for 5 min. After air-drying and the silane coupling agent Monobond Plus (Ivoclar Vivadent) was applied. After 1 min of gentle air-drying, the adhesive Heliobond (Ivoclar Vivadent) was applied.

Teeth from groups CLV and PLV were etched like described for DCR. After rinsing and drying, the primer Syntac Primer (Ivoclar Vivadent) and the adhesive Heliobond were applied according to manufacturer's instructions. The light-curing luting composite (Variolink Veneer, Ivoclar Vivadent) was then dispensed on the preparation, the laminate veneer was put in place and light curing was performed for 5 s (1220 mW/cm^2). After removing the excess of luting composite with a scaler, glycerin gel (Liquid Strip, Ivoclar Vivadent) was applied around the outline and another 40 s of light curing were performed. The outline was polished with Small Flame cups (Ivoclar Vivadent).

2.4. Thermocycling

All groups were thermocycled to age the restorations in a similar way to a clinical situation. The restorations underwent 20,000 cycles between 5 °C and 55 °C with a dwell time of 30 s and a transferring time of 10 s in a thermocycling machine (Willytec, Munich, Germany).

2.5. Fracture test

The root of the restored teeth were embedded in polymethyl methacrylate (PMMA) resin in order to perform the fracture test. The PMMA was applied up to 1 mm below the enamel cement junction. After the complete chemical cure the upper incisors were placed in the universal testing machine (Zwick Roel Z2.5ma18-1-3/7) at an angle of 137° with the load cell (Fig. 2) to simulate the incisal force pattern in the mouth.[17] The test was performed at a speed of 1 mm/min until fracture. The maximum loading force registered in Newtons (N) to break the sample was registered and the fracture pattern analyzed using a light microscope (40x Wild, Heerbrugg, Switzerland).

Fig. 2. Representation of the restored tooth place at 137° to the load cell.

The normality of the results from the fracture test were analyzed by Shapiro-wilk test. Differences were then analyzed by Kruskal-Wallis in BioEstat (Instituto Desenvolvimento Susentavel Mamiraua, Para, Brazil). Significance level was set to $p < 0.05$.

3. Results

After thermocycling, one sample from group CLV presented a premature adhesive failure and was excluded from further testing. Three restorations from groups PLV and DCR presented small cracks but were taken to the fracture test. Values of fracture strength measured in the universal testing machine were displayed in Fig. 4a and b Means and standard deviation (SD) of these values are shown in Table 2.

Fracture strength means from all groups did not differ statistically from each other ($p > 0.05$) (Fig. 4b and Table 1). Group DCR though presented a wider data set with higher values and variances. Besides that, the data set for group PLV and CLV presented a small dispersion,

Table 2
Fracture strength mean and standard deviation expressed in Newtons.

Group	Mean (±SD) N	Min	Max
CG	271 (±100)[a]	125	476
CLV	264 (±66)[a]	115	358
PLV	266 (±69)[a]	141	359
DCR	385 (±225)[a]	86	768

Same letters represent no statistical difference between the mean values.

which is a trend also observed for group the control group (Fig. 4a).

Samples from each group were classified according to the fracture pattern presented after fracture test (Table 3). Group CG did not present restorations thus the fractures presented were only related to tooth structure, being most of it in the root. In the group CLV the root fracture was also the most occurring fracture. In group PLV, material cohesive failures and a mix between adhesive and material cohesive failures (C and A + C) were the most occurring ones. In group DCR the most occurring patterns were involving material cohesive failure and a mix between tooth fracture and material cohesive failure (C and T + C).

4. Discussion

It is already known that ceramics are brittle materials. Also, it is of great risk that catastrophic failure of this material initiates at defects such as cracks (Sato and Takahashi, 2018). In this study the partial laminate veneers even containing cracks after thermocycling were able to perform similarly to the control group and to the conventional laminate veneers group. Ceramic indirect restorations, such as conventional or partial laminate veneers, are bonded to tooth structure by a layer of a resinous material (luting composite resins or conventional composite resins) therefore this layer is of utter influence on the fracture behavior of the indirect restoration (Magne and Douglas, 1999; Suzuki et al., 2008). Previously it was already stated that a poor fit between tooth and restoration causes an uneven cementation area that can lead to concentrated tensions in the bulk of the restorative material and in the adhesive interface (Magne et al., 1999). In this sense adaptation and an optimal luting protocol might play a more relevant role than the restorative material properties per se as we can observe in group PLV, that even with some of the samples presenting small cracks did not present lower values than CG or CLV which might be quite interesting for clinicians.

It is already well described in the literature that ceramics present higher elastic modulus (65–90 GPa) (Guazzato et al., 2004; Li et al., 2014; Niem et al., 2019; Rodrigues Junior et al., 2007) than composite resins (1.6–12.4 GPa) (Ilie and Hickel, 2011), meaning that the first is stiffer and less resilient than the second. Less resilient materials, also referred as brittle materials, do not undergo significant elastic deformations (Niem et al., 2019) which means that when subjected to stresses they absorb little energy and break shortly after (Anusavice, 2013). Composite resins, as more resilient materials, can better dissipate the stresses which could explain the higher values of fracture strength for group DCR. Samples in this group that presented cracks after thermocycling might have caused the lowest values observed thus future studies should be performed with more samples aiming also for lower variances.

Table 3
Fracture pattern per group after fracture test.

		Tooth			Material		Mix	
Group	Total samples	D	E	R	C	A	T + C	A + C
CG	10	1	8	1	N.A.	N.A.	N.A.	N.A.
CLV	9	0	0	4	1	1	1	2
PLV	10	0	0	0	4	1	1	4
DCR	10	1	0	1	4	0	4	0

D: Dentine fracture; E: Enamel fracture; R: Root fracture; C: material cohesive failure; A: Adhesive failure; T + C: Mix of tooth fracture and material cohesive failure and A + C: Mix of adhesive and material cohesive failures. N.A.: Not applicable.

The fact that DCR presented such elevated values of fracture strength might also explain the incidence of mixed fractures (T + C). This group presented values of fracture strength way above the maximum value registered for the CG, composed solely by non-restored teeth (Fig. 3a and Table 1), thus it is coherent that in DCR fracture of tooth structure would also occur.

Considering that mean forces acting in the maxillary front teeth are below 150 N (Ferrario et al., 2004) and that fracture strength means of all tested groups were above 200 N (Table 1), it could be inferred that conventional and partial laminate veneers could safely withstand these forces acting on the upper anterior region.

Sufficient thickness of the conventional laminate veneer, an even luting composite resin layer (Magne and Douglas, 1999) and a conservative preparation fully in enamel (Blunck et al., 2020) can prevent future restoration cracks and ultimately restoration fracture. Magne & Douglas proved that conventional laminate veneers when optimally cemented are able to reestablish the mechanical behavior of natural teeth (enamel-dentin complex). This fact can explain why group CLV presented higher incidence of root fractures like the CG.

Partial laminate veneers, among the ceramic indirect restorations, are less invasive and as chemically stable. These indirect restorations do not need tooth preparation and can correct small diastemas and re-anatomizations (Farias-Neto et al., 2015) or small fractures (Sinhori et al., 2018) but little is known of its resistance though. This was the first study to display fracture strength facing static load and compare it to conventional laminate veneers and direct composite resin restorations. Even undergoing themocycling, the partial laminate veneers performed similarly to the control and CLV in the fracture strength values (Fig. 3 and Table 2).

5. Conclusion

This *in vitro* study has shown for the first time that partial laminate veneers can exhibit fracture strength values similar to conventional laminate veneers. The adoption of an optimal protocol of luting and a good internal adaptation of the partial laminate veneers prevented the cracked ones of performing poorly in the fracture test. In all, the 3 restorative possibilities presented higher mean values of fracture strength than the forces acting in the maxillary anterior region.

CRediT authorship contribution statement

Marco M.M. Gresnigt: Conceptualization, Funding acquisition, Methodology, Investigation, Writing - review & editing, Visualization, Supervision, Resources. **Mari M. Sugii:** Writing - original draft, Visualization. **Karin B.F.W. Johanns:** Conceptualization, Investigation, Methodology, Writing - original draft, Visualization. **Stephan A.M. van der Made:** Conceptualization, Methodology.

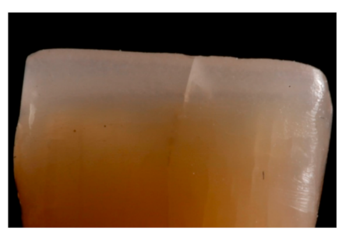

Fig. 3. Representative example of group PLV, crack after thermocycling.

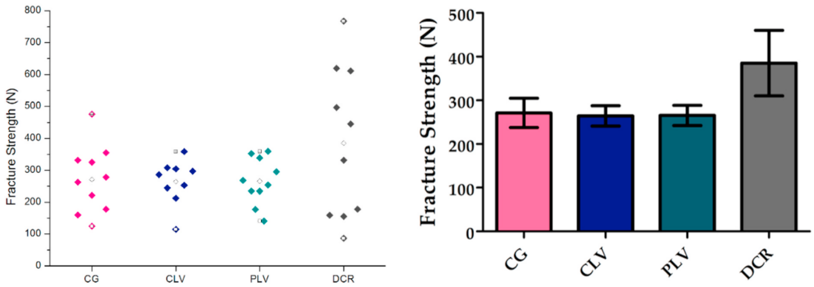

Fig. 4. a) Distribution of the fracture strength values in Newtons for: CG (n = 10), CLV (n = 9), PLV (n = 10) and DCR (n = 10). Symbol ◇ represents mean, minimum and maximum values, b) Mean and standard deviation (SD) of the fracture strength in Newtons per group obtained in the universal testing machine.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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