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Immediate dentin sealing influences the fracture strength of ultrathin occlusal veneers made of a polymer-infiltrated ceramic network

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A R T I C L E I N F O

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A B S T R A C T

Objective: The objective of this laboratory study was to assess the effect of immediate dentin sealing (IDS) on the fracture strength of teeth restored with ultrathin occlusal veneers made of a polymer-infiltrated ceramic network (PICN – Vita Enamic) with different fissure/cusp thicknesses.
Methods: Forty third molars were identically prepared in the dentin and allocated into four groups ($n = 10$) according to the fissure/cusp thickness of the occlusal veneers (0.3/0.6 mm or 0.6/0.9 mm) and the application or not of the IDS technique. Ten sound third molars were used as the control group. IDS was performed using a universal adhesive system (Single Bond Universal). The prepared teeth were scanned (Cerec software, version 4.1), and the occlusal veneers were shaped following the occlusal anatomy of a right second molar. Blocks of PICN were milled in the unit inLab MC XL. Following luting with Single Bond Universal and RelyX Ultimate, the fracture strength of the specimens was obtained with a universal testing machine. The fractures were classified as reparable or irreparable. Fracture strength values were analyzed with 2-way and 1-way ANOVA ($\alpha = 0.05$) and Tukey's test.
Results: Only the IDS factor was significant ($p = 0.001$). The teeth restored with IDS (2875 $\pm$ 508 N) achieved significantly higher fracture strength than the teeth restored without IDS (2263 $\pm$ 354 N) ($p < 0.05$). The fracture strength of the specimens with IDS did not differ significantly from that of the sound teeth (3230 $\pm$ 620 N). The fractures were predominantly reparable.
Conclusion: IDS improved the fracture strength of ultrathin occlusal veneers made of PICN.

1. Introduction

A decrease in tooth enamel thickness occurs with advancing age. Nonetheless, distinct events can contribute to early loss of the enamel, such as erosion due to gastroesophageal reflux, excessive drinking of acidic beverages and high consumption of acidic foods, medications, and bulimia nervosa (Bartlett et al., 1999). Furthermore, bruxism is a common parafunctional habit that can cause tooth wear (Johansson et al., 2011). Regardless of the origin, severe tooth wear is responsible for aesthetic and functional concerns (Abrahamsen, 2005; Al-Omiri et al., 2006).

Ultrathin occlusal veneers have been used to recover the aesthetic and occlusal vertical dimension with minimally invasive preparations. This restorative technique allows for preservation of the dental structure, maintaining pulp vitality (Vailati and Belser, 2008a, 2008b). Distinct ceramic and composite materials are accessible for computer-aided design/computer-aided manufacturing (CAD/CAM) technology. In the last 10 years, this technology has often been used in the manufacture of ultrathin restorations (Davidowitz and Kotick, 2011).

In relation to ceramic materials, ultrathin occlusal veneers made of lithium disilicate are considered more conservative than inlays, onlays and full crowns, showing promising results (Schlichting et al., 2011; Andrade et al., 2018; Heck et al., 2019). Nanoceramic composites can also be used for manufacturing ultrathin occlusal veneers, demonstrating higher fatigue resistance in comparison to lithium disilicate

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ceramic (Schlichting et al., 2011; Heck et al., 2019). Another material class suitable for ultrathin occlusal veneers, and used in this study, is the polymer-infiltrated-ceramic-network material (PICN). It is an interpenetrating phase composite and comprises a ceramic network infiltrated by a polymer network. The purpose of PICN is to allow quicker milling without cracking in the ceramic blocks and in the restoration borders, reduced thickness of the restorations (0.2–0.5 mm), and satisfactory mechanical behavior after luting (Dirxen et al., 2013).

Regarding fracture, some previous studies assessed, *in vitro*, the fracture strength of molars restored with ultrathin occlusal veneers made of PICN luted to enamel (Ioannidis et al., 2019; Al-Akhali et al., 2019) or luted to dentin (Andrade et al., 2018; Egbert et al., 2015; Maeder et al., 2019). These studies tested different minimal occlusal thicknesses, such as 0.5 mm (Al-Akhali et al., 2017, 2019), 0.5 mm or 1.0 mm (Ioannidis et al., 2019; Maeder et al., 2019), 0.6 mm or 1.5 mm (Andrade et al., 2018), and 0.3 mm or 0.6 mm (Ohse et al., 2021), and the conclusion was that ultrathin occlusal veneers made of PICN are suitable for restoring the posterior region (Andrade et al., 2018; Ioannidis et al., 2019; Maeder et al., 2019; Ohse et al., 2021).

Depending on the severity of tooth erosion, mineral loss can advance and expose the dentin (Al-Omiri et al., 2006). Dentin exposure is an issue to be considered, as it negatively affects the longevity of anterior veneers (Burke, 2012). Several studies have shown that ceramic restorations adhesively luted to dentin have lower fracture strength than those luted to enamel, in addition to presenting a greater risk of failure (Piemjai and Arksornnukit, 2007; Clausen et al., 2010). The weakest bond is usually at the interface between the dentin and the adhesive material (Gresnigt et al., 2016). One of the most effective approaches to increase the bond strength of adhesive to dentin is the immediate dentin sealing (IDS) technique, in which an adhesive system is applied to the dentin immediately after the preparation is completed. The increase in bond strength occurs because the adhesive system is applied to fresh and uncontaminated dentin (Magne, 2005). This technique can be useful to improve the retention of short clinical crowns and excessively expulsive preparations (Magne et al., 2007). Another advantage of this technique is the lower postoperative sensitivity (Magne, 2005).

Studies have shown that IDS improved the fracture strength of inlays (van den Breemer et al., 2017; Hofsteenge et al., 2020), as well as ultrathin occlusal veneers (Yazigi et al., 2017) and laminate veneers (Gresnigt et al., 2016) made of lithium disilicate ceramic. However, IDS was not effective in increasing the fracture strength of inlays made of composite resin (van den Breemer et al., 2017). The literature lacks studies evaluating the effect of IDS on the fracture strength of ultrathin occlusal veneers, and to the author's knowledge, there is no previous study evaluating the influence of IDS on the fracture strength of ultrathin occlusal veneers made of PICN.

Therefore, the objective of this laboratory study was to (a) assess the fracture strength of ultrathin occlusal veneers made of PICN and bonded to prepared teeth, with and without the application of the IDS technique, and (b) evaluate the influence of different occlusal veneer thicknesses on the fracture strength. This study was carried out under the hypotheses that (i) the IDS technique and (ii) the thickness of the restoration influence the fracture strength of ultrathin occlusal veneers.

2. Materials and methods

2.1. Tooth selection

A local ethics committee approved the study's protocol (55675416.7.0000.5336). A total of 50 human third molars, extracted for therapeutic reasons, were used in the study. These teeth were free of restorations, caries, cracks or fractures. To standardize the teeth's size, a digital caliper (Mitutoyo America Corporation, Aurora, IL, USA) was used to measure the mesiodistal and buccal-palatal dimensions, and a maximum variation of 0.5 mm was accepted. The teeth were cleaned and immersed in 0.5% chloramine T solution for 24 h for disinfection and then stored in distilled water at 4 °C. One trained operator was responsible for the experimental steps.

2.2. Periodontal ligament simulation

The roots of each tooth were embedded in liquid wax to obtain a layer of approximately 0.5 mm thickness. After the solidification of the wax, self-cured acrylic resin was placed inside a plastic cylinder, and the roots of each tooth were included in the acrylic resin up to 2 mm from the enamel-cement junction (ECJ). After curing the acrylic resin, the roots were removed from the acrylic resin, and the wax was removed. The periodontal ligament was artificially created with polyether. A portion of Impregum soft-handmix (3M Espe, St Paul, MN, USA) was placed in the artificial alveolar space formed by the acrylic resin, followed by the replacement of the roots. The overflow and excess polyether were removed. The specimens were kept in distilled water at room temperature.

2.3. Tooth preparation

The preparations were standardized on dentin in 40 teeth. A 4138-diamond bur (KG Sorensen, Cotia, SP, Brazil), operating at high speed under an air-water spray, was used to remove the occlusal enamel and expose the dentin. The buccal and lingual margins were approximately 5 mm from the ECJ and 2.3–2.6 mm above the central groove. The physiologic inclination of the cusps was maintained. Diamond burs 4138F and 4138FF (KG Sorensen, Cotia, SP, Brazil) were used to finish the preparation. The diamond burs were replaced every five preparations.

2.4. Groups

Ten sound teeth comprised Group 1 (control). The prepared teeth were randomly allocated into four different experimental groups according to the occlusal veneer thickness and the application or not of the IDS technique (n = 10): Group 2 – fissure/cusp thicknesses of 0.3/0.6 mm with IDS; Group 3 – fissure/cusp thicknesses of 0.3/0.6 mm without IDS; Group 4 – fissure/cusp thicknesses of 0.6/0.9 mm with IDS; Group 5 – fissure/cusp thicknesses of 0.6/0.9 mm without IDS.

2.5. Immediate dentin sealing technique (IDS)

In the groups that received IDS, this technique was performed immediately after dentin preparation. A layer of the Single Bond Universal adhesive system (3M Espe, St. Paul, MN, USA), in the self-etch mode, was applied to the dentin using a microbrush and it was scrubbed for 20 s. Excess solvent was removed by gentle air drying for 5 s. The application of the adhesive was considered adequate if a uniform and visible layer of adhesive was present over the dentin. The adhesive was then light-cured for 10 s with a LED curing unit (3M, St. Paul, MN, USA). The output of the light unit was 1.000 mW/cm^2, and it was monitored throughout the experiment with a LED radiometer (SDI, Bayswater, Vic, Australia). Polymerization of the adhesive was followed by the application of an air-blocking barrier using a water-soluble gel (KY, Johnson & Johnson, São Paulo, SP, Brazil) and 10 s of additional light-curing to polymerize the oxygen inhibition layer (Magne, 2005). The adhesive that eventually was in contact with the surrounding enamel was removed with a spherical diamond bur. After preparation and IDS, the specimens were stored in distilled water at room temperature.

2.6. Manufacturing the restorations

The preparations were scanned with an optical 3D intraoral camera (Omnicam, Cerec System, software version 4.6 - Dentsply Sirona, Charlotte, NC, USA). A three-dimensional virtual image was created, and the occlusal veneers were shaped according to the occlusal anatomy of a right second lower molar (Fig. 1A). The fissure/cusp thicknesses of 0.3/0.6 mm or 0.6/0.9 mm were defined by the software (Fig. 1B), and the virtual die spacer was set at 80 μm. All occlusal veneers were digitally designated by the same operator. Forty occlusal veneers made of a polymer-infiltrated ceramic network (PICN – Vita Enamic, VITA, Zahnfabrik, Bad Säckingen, Germany) were fabricated in the milling unit inLab MC XL (Dentsply Sirona, Charlotte, NC, USA). The occlusal veneers were checked and fitted to the prepared teeth and then polished with a specific Vita Enamic clinical polishing kit (VITA, Zahnfabrik, Bad Säckingen, Germany).

2.7. Luting procedures

The fit of the occlusal veneers was checked. The intaglio surface of the occlusal veneers was etched with 5% hydrofluoric acid (Condac Porcelain - FGM, Joinville, SC, Brazil) for 60 s and then rinsed off with a forceful water spray for 30 s. The silane (Scotchbond Ceramic Primer, 3M Espe, St. Paul, MN, USA) was applied and dried gently for 5 s. On the tooth preparation, 37% phosphoric acid (Condac - FGM, Joinville, SC, Brazil) was applied only to the enamel for 30 s, rinsed for 30 s and dried with an air jet. The Single Bond Universal adhesive system was applied to the etched enamel and dentin (groups without IDS) or to the etched enamel and adhesive (groups with IDS), followed by gentle air drying for 5 s. The RelyX Ultimate resin cement (3M Espe, St. Paul, MN, USA) was applied to the intaglio surface of the occlusal veneer. Immediately, the occlusal veneer was positioned on the preparation, followed by the application of a 1 kg load. The excess resin cement was removed, and each face of the occlusal veneer was light-cured for 20 s. The specimens were kept in distilled water at 37 °C for 24 h.

2.8. Cycling mechanical loading

After storage, the specimens were aged in a mechanical loading machine (ER-11000, Erios, São Paulo, SP, Brazil) using the permanent contact mode of the pistons of the machine on the occlusal surface of the occlusal veneer. The specimens were kept in water at 37 °C, and a load of 200 N and a frequency of 1 Hz were applied for 10^6 cycles. Subsequently, the occlusal veneers were inspected to detect the occurrence of cracks, chips, fractures, or luting failures with a 10X loupe (Olympus, Tokyo, Japan). The following classification was used: a) success (no changes in the occlusal veneer); b) failure (cracks, chips or fractures in the occlusal veneer); or c) survival (a failure that did not compromise the restoration's use) (Shirakura et al., 2009).

2.9. Fracture strength testing

Following the storage period, a universal testing machine (EMIC DL-2000, São José dos Pinhais, PR, Brazil) was used to apply a static load to the specimens until they fractured. A 6-mm-diameter metal sphere connected to a 10 kN load cell was positioned on the occlusal surface of the occlusal veneer to obtain tripodization of the contacts along the cuspal inclines over the central fossa. The compression load was applied at a crosshead speed of 1.0 mm/min. The values of the maximum force were recorded in Newtons (N).

2.10. Fracture mode analysis

The fractures were classified as follows by visual examination: a) reparable (fracture at the occlusal veneer only, or fracture that involved one or more cusps); or b) irreparable (the tooth was divided into two parts at the level of the pulp chamber floor due to fracture).

2.11. Statistical analysis

The statistical analysis was carried out using SPSS 10.0 software (SPSS Inc., Chicago, IL, USA). According to the Kolmogorov–Smirnov test, the data showed normality ($p > 0.05$). The fracture strength data of the experimental groups were evaluated by two-way analysis of variance (ANOVA) (occlusal veneer thickness x IDS) followed by Tukey's test. One-way ANOVA and Tukey's test were used to compare the fracture strengths of sound teeth with those of the experimental groups ($\alpha = 0.05$).

3. Results

Only one specimen from Group 2 was lost due to fracture of the occlusal veneer during the luting procedure. All specimens withstood the aging simulation, and no visible chips, cracks, or fractures were found in the tooth or the occlusal veneers. During the milling step, a small chip was observed at the margin of three occlusal veneers with fissure/cusp thicknesses of 0.3/0.6 mm. However, this failure was considered very small, and the occlusal veneers were luted to their respective teeth.

Two-way ANOVA showed that the IDS factor was significant ($p = 0.001$), the thickness factor was not significant ($p = 0.317$), and the interaction between the factors ($p = 0.563$) was not significant. Specimens with IDS (combination of Group 2 and Group 4) obtained a significantly higher fracture strength than specimens without IDS (combination of Group 3 and Group 5) ($p < 0.001$) (Table 1).

According to one-way ANOVA, the fracture strength of the groups with IDS did not differ significantly from that of the sound teeth. The groups without IDS obtained a lower fracture strength and differed significantly from the sound teeth. However, there was no significant difference in fracture strength among Group 2, Group 3 and Group 5 (Table 2).

There was a predominance of reparable fractures (Table 3).

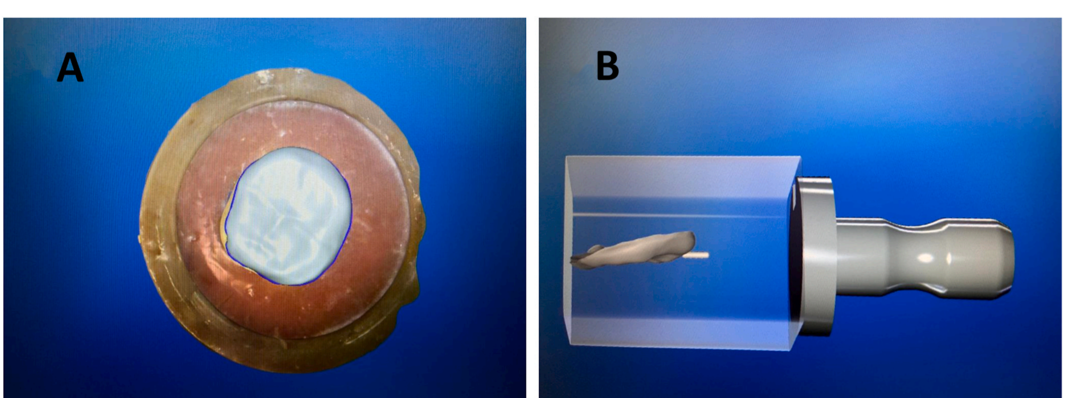

Fig. 1. 1A - occlusal veneers shaped according to the occlusal anatomy of a right second lower molar; 1B - fissure/cusp thicknesses defined by the software.

Table 1
Fracture strength mean (N) between specimens with and without IDS.

IDS	Fracture strength mean (N)	Standard deviation	Sig
With IDS (Group 2 + Group 4)	2875	508	0.001
Without IDS (Group 3 + Group 5)	2263	354	

**P value* < 0.05.

Table 2
Fracture strength mean (N) and standard deviation in the different groups.

Groups	n	Mean (N)	Standard Deviation
Group 1- Control	10	3230[a]	620
Group 2–0.3/0.6 mm with IDS	9	2761[ab]	533
Group 3–0.3/0.6 mm without IDS	10	2231[b]	341
Group 4–0.6/0.9 mm with IDS	10	2989[a]	482
Group 5–0.6/0.9 mm without IDS	10	2292[b]	381

*Different letters represent different means according to Tukey's test (α = 0.05).

Table 3
Failure analyses of the different groups.

Groups	Reparable fracture		Irreparable fracture
	Fracture in the veneer only	Fracture in one or more cusps	
Group 1 – Control - sound teeth	0	6	4
Group 2–0.3/0.6 mm with IDS	1	4	4
Group 3–0.3/0.6 mm without IDS	6	4	0
Group 4–0.6/0.9 mm with IDS	1	4	5
Group 5–0.6/0.9 mm without IDS	4	4	2

Regarding reparable fractures, there were more fractures restricted to the occlusal veneer in the specimens without IDS (Group 3 and Group 5) (Fig. 2A). There was a predominance of fractures in one or more cusps in Group 1 (sound teeth) and in the specimens with IDS (Group 2 and Group 4) (Fig. 2B). Irreparable fractures occurred in all groups, with the exception of Group 3 (Fig. 2C) (Table 3).

4. Discussion

This study evaluated whether the application of IDS could influence the fracture strength of molars restored with ultrathin occlusal veneers made of PICN. To our knowledge, this issue has not been previously investigated.

Based on the results, a higher fracture strength was achieved for the specimens with IDS. Therefore, the first hypothesis was accepted. This finding is in agreement with other studies (Gresnigt et al., 2016; Yazigi et al., 2017; van den Breemer et al., 2017; Hofsteenge et al., 2020). An explanation for the higher fracture strength of restorations bonded with IDS is the application and precuring of the adhesive system on the cut dentin, leading to a higher bond strength to this substrate (Magne, 2005; Magne et al., 2007). Previous studies have shown that the bonding of adhesive systems to freshly cut dentin is better immediately after preparation in comparison with dentin contaminated with temporary materials or saliva (Terata, 1993; Watanabe et al., 1997). Freshly exposed dentin provides the most favorable substrate for bonding and a higher bond strength (Magne, 2005; Magne et al., 2007). However, the justification based on the contamination of dentin with impression materials or temporary cements does not apply to the present study. As the occlusal veneers were obtained using CAD/CAM technology, the preparations were scanned by an oral camera, avoiding the use of impression material. In addition, as CAD/CAM technology allows for the fabrication and luting of the restorations in the same clinical session, provisional restorations and provisional cements were not used. Nonetheless, the specimens with and without IDS were stored in water during the fabrication of the occlusal veneers until the luting procedures. Thus, the specimens without IDS received an application of the Single Bond Universal adhesive system on nonfresh dentin, which may have produced a lower bond strength.

The higher bond strength of the adhesive to dentin with IDS is also related to the luting procedure, in which the adhesive layer is already cured and has penetrated the collagen network to form a hybrid layer (Dietschi and Herzfeld, 1998; Magne and Douglas, 1999). Thus, the pressure related to the placement of the resin cement and the seating of the occlusal veneer avoid the collapse of the collagen network or the hybrid layer. This collapse might occur in the specimens without IDS, since the dentin adhesive is not polymerized until the application of the resin cement and seating of the restoration (Magne, 2005; Gresnigt et al., 2016). Furthermore, sealing of the dentin at the time of preparation allows the dentin bonds to freely develop without restriction. The habitual stresses and strains are decreased when the placement of restoration is delayed and, consequently, the exposure to occlusal forces is postponed (Park and Ferracane, 2005). This, in addition to the findings that adhesive luting strengthens ceramic restorations (Spazzin et al., 2016; Barbon et al., 2018), would contribute to improving the fracture strength of adhesively luted occlusal veneers following the IDS technique.

It is known that adhesive luting favors the formation of a single unit between the occlusal veneer and the prepared tooth. This single unit allows the forces applied on the restoration to be dissipated through the tooth structure, periodontal ligament and alveolar bone (Magne and Douglas, 1999). Therefore, it is thought that a stronger bond of adhesive to fresh dentin also favors a stronger bond of the occlusal veneer to the prepared tooth, allowing for better dissipation of the forces during the application of the static load, resulting in a higher fracture strength. This dissipation of forces may have prevented the concentration of the forces

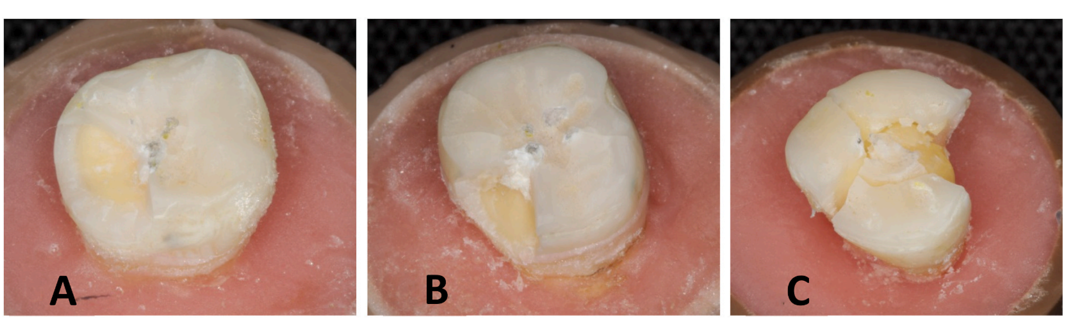

Fig. 2. Types of failures: A - Occlusal veneer fracture (classified as reparable); B - Cusp fracture (classified as reparable); C - Longitudinal fracture of the tooth into two parts at the pulpal chamber floor (classified as irreparable).

in the intaglio portion of the occlusal veneer, which would lead to fracture (Attia et al., 2006). This finding can explain the greater number of fractures involving one or two cusps in specimens with IDS compared to specimens without IDS, which had fractures restricted to the occlusal veneer. Possibly, there was lower dissipation of forces through the tooth structure and a greater concentration of these forces at the occlusal veneers without IDS, favoring fracture of the restoration.

A further possible explanation for the higher fracture strength of the specimens with IDS is the thicker film of adhesive, as it is applied at two different times, immediately after preparation and again during the luting procedure. This thicker film tends to support the brittle occlusal veneers, resulting in a higher fracture strength (Hofsteenge et al., 2020). However, some studies evaluated the influence of IDS application in combination with flowable composite resin on the fracture strength of ceramic restorations (van den Breemer et al., 2017; Hofsteenge et al., 2020). The application of flowable composite resin may be achievable clinically for inlays and onlays that present deep preparations. The reduced interocclusal space in other preparations, such as ultrathin occlusal veneers and full crowns, may make the application of flowable composite resins clinically unfeasible (Elbishari et al., 2021). Because the occlusal veneers tested were ultrathin, which corresponds to a small interocclusal space, the application of a low viscosity composite resin was not considered in the present study, since this material increases the thickness of the adhesive materials and could reduce the space available for the occlusal veneers.

In IDS techniques, bonding of the adhesive luting agent to the preexisting resin layer must be applied to a contaminant-free substrate (Watanabe et al., 1997). When provisional restorations are made, it is important to remove any remnants of temporary cements that may cause a significant decrease in the bond strength of the luting agents (Paul and Schärer, 1997; Millstein and Nathanson, 1992). Therefore, different surface conditioning strategies have been suggested, such as airborne-particle abrasion with aluminum oxide (Magne, 2005) and cleaning with pumice and pumice with an additional tribochemical silica coating (van den Breemer et al., 2019). However, as only an adhesive system was applied to obtain the IDS, without flowable composite resin, these procedures of cleaning and conditioning could remove part of the adhesive, decrease the film thickness and expose the dentin substrate (Stavridakis et al., 2005). Therefore, as temporary material was not used in the present study, the preexisting resin layer was only etched with 37% phosphoric acid (Dillenburg et al., 2009).

In the present study, there was no significant difference in fracture strength between the two different thicknesses. This finding suggests that even under a constant compressive load, an ultrathin occlusal veneer, such as one with fissure/cusp thicknesses of 0.3/0.6 mm, obtained high strength. Therefore, the second hypothesis was rejected. Studies have shown higher fracture strength for 1.0-mm-thick occlusal veneers than 0.5-mm-thick occlusal veneers (Maeder et al., 2019) and a higher fracture strength for 1.5-mm-thick occlusal veneers than for 0.6-mm-thick occlusal veneers made of PICN (Andrade et al., 2018). However, in the present study, thicker occlusal veneers made of PICN did not improve the values of fracture strength when comparing 0.3/0.6- and 0.6/0.9-mm-thick occlusal veneers at the fissure/cusp. This finding may be due to the possibility of milling PICN to thin restorations that are still strong enough to avoid cracks, which are stopped by the interpenetrating polymer within the ceramic network (Dirxen et al., 2013). PICN is a hybrid material with two interpenetrating networks of ceramic (86 wt%) and polymer (14 wt%) (Dirxen et al., 2013). The association of ceramic with polymer has the objective of increasing the mechanical properties of the material, such as strain at failure and flexural strength (Coldea et al., 2013). In addition, the bonding protocol used to lute the occlusal veneers can be another reason for the high fracture strength values obtained in the study.

The luting protocol of the occlusal veneers made of PICN was standardized. Selective etching of the enamel with 37% phosphoric acid was carried out, aiming to enhance the bonding of the adhesive to this tissue (Frankenberger et al., 2008). Then, the Single Bond Universal adhesive system was applied to the enamel and adhesive for the specimens with IDS and to the enamel and dentin for the specimens without IDS. Hydrofluoric acid at 5% was applied to the intaglio surface of the occlusal veneers for 60 s. In sequence, silane was applied, which establishes chemical bonding between the silicon present in the ceramic and the resinous material used for luting (Spohr et al., 2003). A dual-cure resin cement was then used to bond the occlusal veneer to the tooth preparation. Therefore, a single unit between the tooth and occlusal veneer was obtained, favoring dissipation of the forces (Magne and Douglas, 1999) and higher values of fracture strength even with ultrathin occlusal veneers. This finding corroborates the fracture types observed in this study, since fractures in the tooth structure occurred in all groups, being predominant in the groups with IDS.

The fracture strength of the sound teeth (Group 1 - Control) did not differ significantly from the specimens with IDS. These data are relevant, showing that even with 0.3/0.6-mm-thick occlusal veneers at the fissure/cusp region, the restored teeth with IDS had a fracture strength similar to that of sound teeth. However, regardless of the IDS technique or the occlusal veneer thickness, the fracture strength values were greater than the bite forces registered clinically, which have reached 1120 N in patients with bruxism (Sakaguchi et al., 1986). It is important to emphasize that there was a relatively high standard deviation even with the standardization of specimen's sizes, which may be related to the extracted human teeth. Teeth are a biological material, being difficult to obtain similarities among all teeth, since even slight differences in microstructure or composition can affect the results (Nawrocka and Lukomska-Szymanska, 2019). However, despite the standard deviation, it was possible to obtain a statistical difference between samples with and without IDS.

The strength of ceramics is amongst others related to the structural defects in the material and its absence of plastic deformation (Craig and Powers, 2004). Restorations made of PICN, such as Vita Enamic, are manufactured by subtractive CAD/CAM technology. Due to the presence of two networks (ceramic/polymer) within PICN, crack propagation is generally limited by interfacial crack deflection and crack bridging mechanisms (Coldea et al., 2013), improving the strength against breakdown phenomena (Mainjot et al., 2016). This characteristic must have made an important contribution to the high fracture strength values of the ultrathin occlusal veneers. It is also important to consider the tooth preparation form performed in the present study. The preparations respected the anatomy of the natural tooth, allowing a more favorable stress distribution (Xia et al., 2018) at the time of the fracture strength test.

In the present study, all specimens were aged for 10^6 cycles of mechanical loading under a 200 N loading force, simulating approximately four years of natural function (Sakaguchi et al., 1986; Delong and Douglas, 1991). There were no failures, such as cracks or fractures, in any restoration after this aging methodology, providing positive results. This finding is in accordance with other studies that submitted specimens restored with ultrathin occlusal veneers made of PICN to thermocycling (Hampe et al., 2021) or thermocycling and chewing simulation (Ioannidis et al., 2019; Maeder et al., 2019; Al-Akhali et al., 2017), and all aged specimens survived without fracture, ceramic chipping, or cracks.

Bulk fracture of ceramic restorations is a major reason for failure due to the brittleness of ceramics (Morimoto et al., 2016). Thus, improvement of the ceramic fracture strength is an important issue, especially in posterior teeth, and the IDS technique proved to be effective in increasing the fracture strength of ultrathin occlusal veneers made of PICN. However, the extrapolation of the results must include the limitations of a laboratory study that does not reproduce the clinical scenario, such as the oral environment or masticatory biomechanics (Shirakura et al., 2009). The following limitations of the present study can be cited: a) a constant axial load, which does not occur clinically, was applied to the specimen until fracture; b) the cyclic mechanical loading corresponded to an axial load applied by a pneumatic piston in the occlusal central area of the restoration, not simulating the clinical reality in which forces are applied in different directions; c) the small sample size of the study; however, the statistical analysis could demonstrate significant differences in fracture strength for specimens with and without IDS.

The clinical indication of ultrathin occlusal veneers is for cases with limited interocclusal space due to wear of the teeth or for cases in which the remaining tooth structure must be preserved. A study conducted on high-risk patients for two years demonstrated high survival and success rates for PICN restorations applied using a minimally invasive technique. The most frequent failure was related to minor chipping of very thin occlusal borders (Oudkerk et al., 2020). Therefore, upon analysis of the laboratory and clinical studies, PICN ultrathin occlusal veneers may be a promising restorative choice.

5. Conclusions

Within the limitations of this laboratory study, it can be concluded that the immediate dentin sealing technique can have a beneficial influence on the fracture strength of ultrathin occlusal veneers made of a polymer-infiltrated ceramic network. Moreover, it can be concluded that ultrathin occlusal veneers made of a polymer-infiltrated ceramic network showed a fracture strength higher than the values recommended for restoring posterior teeth.

CRediT authorship contribution statement

Francesca Pigatto Teche: Writing – original draft, Methodology, Conceptualization. **Eneida Beatriz Sanfelice Valenzuela:** Methodology, Investigation, Conceptualization. **Julieta Gomes Tavares:** Conceptualization, Methodology, Writing – original draft. **Eduarda Waiss Castellan de Oliveira:** Methodology, Investigation. **Hélio Radke Bittencourt:** Writing – original draft, Formal analysis, Data curation. **Luiz Henrique Burnett Júnior:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Ana Maria Spohr:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

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.

Data availability

Data will be made available on request.

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