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Original Article

Thickness of immediate dentin sealing materials and its effect on the fracture load of a reinforced all-ceramic crown

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ABSTRACT

Objectives: The objective of this study is to evaluate, *in vitro*, the thickness of immediate dentin sealing (IDS) materials on full crown preparations and its effect on the fracture load of a reinforced all-ceramic crown. **Materials and Methods:** Sixty premolars received full crown preparation and were divided into the following groups according to the IDS technique: G1-control; G2-Clearfil SE Bond; and G3-Clearfil SE Bond and Protect Liner F. After the impressions were taken, the preparations were temporized with acrylic resin crowns. IPS empress 2 restorations were fabricated and later cemented on the preparations with Panavia F. 10 specimens from each group were submitted to fracture load testing. The other 10 specimens were sectioned buccolingually before the thicknesses of Panavia F, Clearfil SE Bond and Protect Liner F were measured in 10 different positions using a microscope. **Results:** According to analysis of variance and Tukey's test, the fracture load of Group 3 (1300 N) was significantly higher than that of Group 1 (1001 N) ($P < 0.01$). Group 2 (1189 N) was not significantly different from Groups 1 and 3. The higher thickness of Clearfil SE Bond was obtained in the concave part of the preparation. Protect Liner F presented a more uniform range of values at different positions. The thickness of Panavia F was higher in the occlusal portion of the preparation. **Conclusions:** The film thickness formed by the IDS materials is influenced by the position under the crown, suggesting its potential to increase the fracture load of the IPS empress 2 ceramic crowns.

Key words: Ceramic, film thickness, fracture load, immediate dentin sealing

INTRODUCTION

The traditional technique for indirect esthetic restorations consists of taking an impression of the tooth immediately after preparation, followed by the luting of a provisional restoration. After the indirect restoration fabrication, the provisional material is removed and an adhesive system is applied to the tooth after which a resin luting agent is used for the adhesive luting procedure.[1]

Some studies have shown that adhesive systems bond better to freshly prepared dentin than to dentin contaminated by provisionalization,[2,3] which may lead to microleakage,[4] hybridization failure, and sensitivity.[5] To avoid these problems, the immediate dentin sealing (IDS) technique was suggested in the early 1990s.[6] This technique consists of the application of an adhesive system immediately after tooth preparation and before taking the impression. Another technique was developed in which a sealing film is produced on the dentinal surface using an adhesive system and a low-viscosity composite resin immediately after tooth preparation.[7,8] This layer of low-viscosity composite resin is thought to isolate the underlying hybrid layer, consequently aiding in the preservation of the dentinal seal.[9]

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IDS techniques have the clinical advantages of covering the prepared dentin with a resinous agent immediately after cavity preparation, thereby sealing and protecting the dentin – pulp complex as well as preventing or decreasing sensitivity and bacterial leakage during the provisional stage.[10] Thus, IDS has been suggested when a significant area of dentin has been exposed during tooth preparation for indirect restorations, such as inlays, onlays, veneers, and crowns.[6]

Most studies on IDS techniques have evaluated the efficacy of the bond strength between the resin cement and dentin, showing good bonding of the resin used in IDS[11] as well as an increased resin bond strength in IDS with an adhesive system and an additional low-viscosity microfilled resin.[12,13] Fewer gaps were observed at the internal dentin – restoration interface in the specimens coated with an adhesive system and a low-viscosity microfilled resin compared with non-coated specimens.[14]

Due to the demand for tooth-colored restorations, ceramic or composite resin materials have been widely used. Ceramic biocompatibility and mechanical properties (e.g., high-elastic modulus and hardness) make them attractive for use as biomechanical prostheses. Thus, ceramics are used widely for cusp replacement restorations as well as for esthetics. Despite their many advantages, ceramics are fragile under tensile strain. This weakness can be attributed to the presence and propagation of microflaws present on the surface of the material, making the ceramic susceptible to fracture during the luting procedure and under occlusal force.[15,16] To increase retention,[17] and fracture strength of the restored tooth,[18] resin luting materials are commonly used to join ceramic crowns to the prepared hard tissue foundation.

The cement layer may act as a cushion between the crown and dentin substrate,[19] although the effect of this on the fracture strength of all-ceramic restorations is not well-established. Molin *et al*.,[20] verified the influence of the film thickness of resin luting agents on the joint bond strength of the ceramic – dentin interface and showed that the bond strength values were significantly lower with 20-µm film than with 50-, 100- or 200-µm films. Scherrer *et al*.,[21] reported the effect of cement film thickness on the fracture resistance of glass ceramic plates loaded under compression using a spherical indenter. They found that the fracture resistance of glass ceramic cemented with zinc phosphate cement was not dependent on film thickness. When resin cement was used, a gradual decrease in the fracture strength was observed with increasing cement thickness. Prakki *et al*.,[22] evaluated the fracture resistance of ceramic plates (1- and 2-mm thick) cemented to dentin as a function of the resin cement film thickness. These authors concluded that a higher cement film thickness resulted in increased fracture resistance only for 1-mm ceramic plates.

The materials used in the IDS can create a film thickness covering a vast range of values, depending on the type of resin material and the topography of the tooth preparation.[23] However, no information exists regarding such film thickness in a full crown preparation and its influence on the fracture load of all-ceramic crowns.

Therefore, the aim of this *in vitro* study was to evaluate the thickness of an adhesive, a low-viscosity microfilled resin and a resin cement under full crown preparations as well as the influence on the compressive fracture load of a reinforced all-ceramic crown luted to human teeth. This study investigated the following hypotheses: (a) There are differences in the thickness of the resin materials at different positions under crowns and (b) the thickness of the resin materials does not influence the compressive fracture load of the all-ceramic crown.

MATERIALS AND METHODS

Sixty sound maxillary premolars extracted for therapeutic indications were cleaned and disinfected by immersion in 10% thymol for 24 h. The premolars were then stored in distilled water at 4°C for a maximum period of 6 months. These teeth had the following coronal dimensions: Buccal-lingual distance of 9.0-9.6 mm; mesiodistal distance of 7.0-7.4 mm; and cervical-occlusal distance of 7.7-8.8 mm. A variation of 0.5 mm was associated with each measurement.

The roots were mounted in acrylic resin approximately 2 mm below the cementoenamel junction of the tooth. Tooth preparation was performed using a standardized preparation machine consisting of a high-speed hand piece (Kavo, Joinville, SC, Brazil) coupled to a mobile base. The mobile base moved vertically and horizontally, in increments of 3 µm, with the aid of a micrometer (Mitutoyo, Tokyo, Japan). Cusps were removed and the long axes of teeth were positioned vertically on the preparation machine. Subsequently, a no. 3139 diamond wheel

bur (Sorensen, Cotia, SP, Brazil) was attached to a high-speed hand piece and all lateral convex surfaces were leveled. Each tooth was prepared for a full crown using a no. 2135 diamond wheel bur (KG Sorensen, Cotia, SP, Brazil). The cervical margin was situated below the cementoenamel junction. A water spray was used throughout the preparation procedures. The dimensions of the preparations were as follows: 6° taper on each side, 1.2 ± 0.2 mm shoulder margin and a 5 mm core height with rounded line angles. The prepared teeth were then randomly divided into the following 3 groups ($n = 20$) according to the materials used [Table 1]:

- Group 1: Control, without the IDS technique
- Group 2: IDS with Clearfil SE Bond. SE Primer was first applied to the cavity for 20 s and gently air dried. SE Bond was then applied; mildly air-dried and light cured for 10 s using a conventional halogen light curing unit. Polymerization of the adhesive was followed by the application of an air-blocking barrier (glycerine jelly) and light cured for a further 10 s to polymerize the oxygen inhibition layer. The glycerine jelly was rinsed under running tap water
- Group 3: IDS with Clearfil SE Bond and Protect Liner F. Clearfil SE Bond was applied as described in Group 2 but without the air-blocking barrier. After application of the adhesive, Protect Liner F was placed on the adhesive surface using a brush-on technique and light cured for 20 s. The surface of the cured low-viscosity microfilled resin was wiped with a cotton pellet soaked in alcohol for 10 s to remove the unpolymerized layer on the surface.

An impression of each prepared tooth was taken using a polyvinyl siloxane impression material (Express, 3M/ESPE, St. Paul, MN, USA) and a custom-made impression tray fabricated with acrylic resin. The impressions were then cast in type IV stone (Durone, Dentsply, York, PA, USA) to produce dies. After the impression, the preparations were temporized with self-curing acrylic resin crowns cemented with non-eugenol provisional cement (TempBond NE, Kerr, Orange, CA, USA). Tooth specimens were stored in distilled water at 37°C for 2 months.

For 10 specimens from each group, IPS empress 2 restorations were fabricated in accordance with the manufacturer's instructions in a dental laboratory. A 0.8-mm lithium disilicate core was made and IPS Empress veneer ceramic (dentin shade) was applied to the core to create a crown thickness of 1.5 mm.

After storage, provisional restorations were removed and preparations were cleaned using pumice slurry until all provisional cement was removed. Trial insertion before luting was performed to ensure an adequate fit for each crown. The intaglio surface of each crown was etched with 10% hydrofluoric acid for 20 s, rinsed and dried. A layer of silane (Clearfil Ceramic Primer, Kuraray Medical Inc., Tokyo, Japan) was applied, followed by gentle air drying for 5 s. The coated surfaces of the preparation (except in Group 1) were then acid etched with 37% phosphoric acid for 10 s and rinsed and dried to remove any debris. A mixture of ED Primer A and B was applied for 30 s and gently air-dried for 5 s. The base and catalyst of Panavia F resin cement were mixed according to the manufacturer's instructions. The crowns were seated using a 2-kg standard load for 2 min. Excess cement was removed with a microbrush and each surface (buccal, lingual, mesial, distal, and occlusal) was light cured for 40 s. The margins were finished with polishing discs and silicone tips (Soft-Lex, 3M Espe, St. Paul, MN, USA). After 2 months of storage in distilled water at 37°C, each specimen was seated in a jig placed on the base of a universal testing machine. A compressive load was applied through a 3.2-mm diameter hardened steel sphere attached to the moving head of the testing machine (model 1123, Instron Corp., Canton, MA, USA). Load was

Table 1: Materials used in the study

Materials	Composition	Manufacturer
Clearfil SE bond	Self-etch primer: 10-MDP, HEMA, hydrophilic dimethacrylate, photo-initiator, water	Kuraray Medical Inc., Tokyo, Japan
	Adhesive: 10-MDP, bis-GMA, HEMA, hydrophilic dimethacrylate, microfiller	
Protect liner F	TEG-DMA, Bis-GMA, methacryloyl fluoride-methyl, methacrylate copolymer	Kuraray Medical Inc., Tokyo, Japan
Panavia F	ED primer A: HEMA, 10-MDP, 5-NMSA, water, accelerator	
	ED primer B: accelerator, water, sodium benzene sulfinate	Kuraray Medical Inc., Tokyo, Japan
	A-Paste: Methacrylate, 10-MDP, quartz-glass	
	Microfiller, photoinitiator	
	Sodium fluoride, chemical initiator	

HEMA: Hydroxyethylmethacrylate, TEG-DMA: Triethylene glycol dimethacrylate, Bis-GMA: Bisphenol-glycidyl methacrylate, 10-MDP: 10-methacryloyloxydecyl dihydrogen phosphate, 5-NMSA: *N*-methacryloxyl-5-aminosalicylic acid

applied at a crosshead speed of 0.5 mm/min. until failure occurred, at which point the maximum load before failure was recorded. The remnant ceramic on the prepared tooth was determined as type I (0%), type II (less than 50%) or type III (more than 50%).

In the other 10 specimens for each group, only a lithium disilicate core was made without veneer ceramic. The crowns were luted to their respective preparations as described above. After storage in 37°C distilled water for 2 months, each crown was sectioned buccolingually through the center of the crown with a diamond blade in an Isomet Saw (Buehler, Lake Bluff, IL, USA), resulting in two portions. One portion of each specimen was placed under a measuring microscope (Profile Projector V-16D, Nikon, Tokyo, Japan), with a measuring sensitivity of 1 µm, under ×100 magnification. The thickness of the adhesive system, low-viscosity microfilled resin and resin cement was measured at 10 positions as shown in Figure 1. Thickness of the resin materials was measured in a direction perpendicular to the dentin surface at each position.

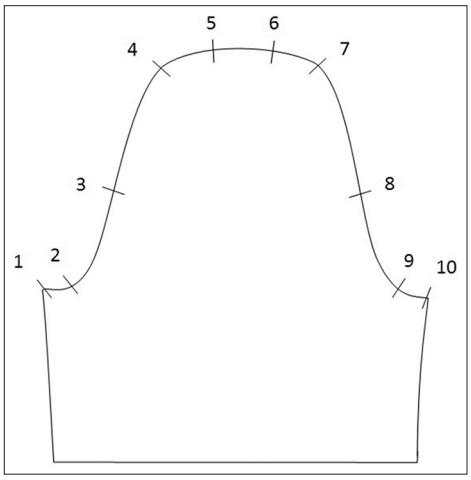

Figure 1: Bucco-lingual section of the preparation. The thickness of the resin cement, adhesive and low-viscosity microfilled resin were measured at 10 different positions along the preparation

The final thickness of the resin materials (adhesive, low-viscosity microfilled resin and resin cement) at the different positions in each group was compared using the Friedman and Wilcoxon signed-rank non-parametric tests. The Kruskal-Wallis and Mann-Whitney U non-parametric tests were also used to compare the final thickness values between the groups in each position. Fracture loads were analyzed using the one-way analysis of variance, followed by Tukey's multiple comparison tests. The correlation between fracture load and the thickness of the resin materials was analyzed by the Pearson correlation test. The significance level was set at 0.01.

RESULTS

The mean film thickness of the adhesive, low-viscosity microfilled resin and resin cement in each position for the different groups is shown in Table 2 and in Figures 2-4. The thickness of the resin cement was higher in positions 5 and 6 than in other positions. The thickness of adhesive was

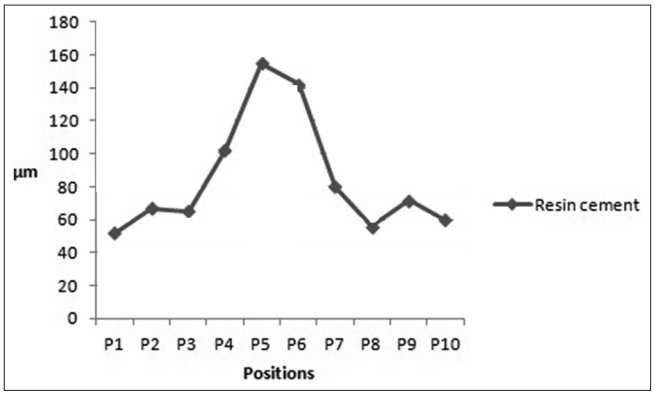

Figure 2: Group 1 - Mean thickness (µm) of the resin cement

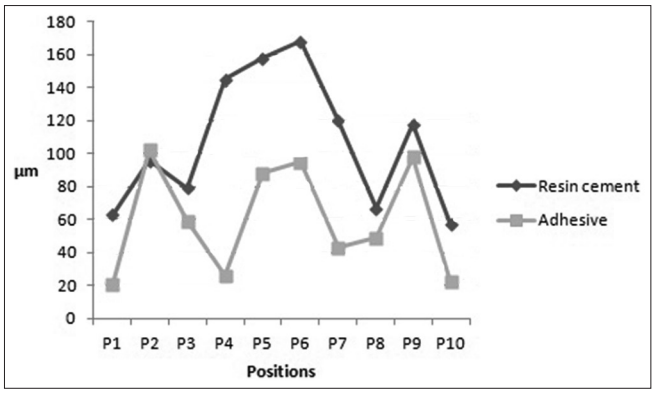

Figure 3: Group 2 - Mean thickness (µm) of the adhesive and resin cement

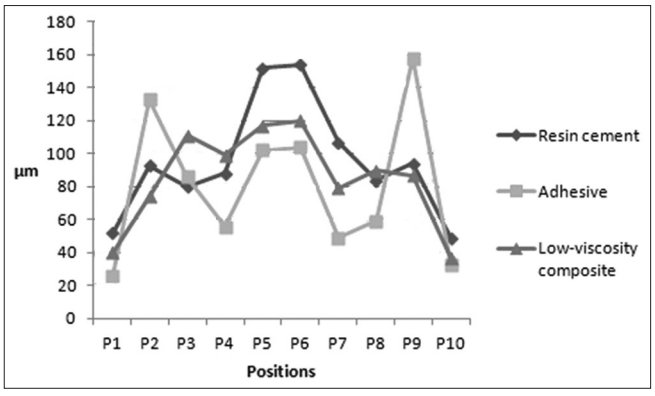

Figure 4: Group 3 - Mean thickness (µm) of adhesive, low-viscosity microfilled resin, and resin cement

Table 2: Mean thickness (μm) and standard deviation of the resin cement, adhesive and low-viscosity microfilled resin of the experimental groups in the different positions

Position	Group 1	Group 2	Group 3
Resin cement	52.5 (±21.38)	63.9 (±25.15)	52.7 (±27.26)
Adhesive		21.4 (±13.93)	26.2 (±12.99)
Low-viscosity composite			40.20 (±11.17)
Resin cement	67.4 (±25.35)	96.7 (±35.18)	93.8 (±29.18)
Adhesive		102.72 (±45.99)	133.3 (±54.06)
Low-viscosity composite			74.70 (±15.44)
Resin cement	65.3 (±27.88)	79.9 (±26.08)	80.80 (±33.38)
Adhesive		59.1 (±32.55)	86.9 (±40.08)
Low-viscosity composite			111.2 (±53.68)
Resin cement	102.9 (±35.29)	145.5 (±71.35)	88.5 (±37.32)
Adhesive		26.1 (±16.12)	56.4 (±23.22)
Low-viscosity composite			99.40 (±21.39)
Resin cement	155.3 (±54.67)	158.5 (±54.40)	152.4 (±40.97)
Adhesive		88.9 (±47.00)	102.5 (±42.45)
Low-viscosity composite			117.1 (±19.72)
Resin cement	142.4 (±57.92)	168.8 (±52.94)	154.1 (±43.76)
Adhesive		95.3±(45.03)	104.7 (±36.27)
Low-viscosity composite			120.5 (±27.11)
Resin cement	80.7 (±28.36)	120.4 (±49.27)	107.2 (±44.80)
Adhesive		43.6 (±15.46)	49.3 (±26.36)
Low-viscosity composite			79.8 (±20.55)
Resin cement	56.7 (±33.06)	67.6 (±13.33)	84.9 (±25.82)
Adhesive		49.6 (±18.45)	59.5 (±29.62)
Low-viscosity composite			90.3 (±28.24)
Resin cement	72.1 (±27.07)	118.8 (±56.83)	94.3 (±30.94)
Adhesive		98.9 (±52.23)	158.3 (±60.84)
Low-viscosity composite			87.30 (±14.33)
Resin cement	60.1 (±22.34)	57.8 (±17.53)	49.6 (±19.33)
Adhesive		22.50 (±9.91)	33.7 (±13.38)
Low-viscosity composite			37.8 (±14.85)

higher in positions 2 and 9 and lower in positions 1 and 10. Intermediate values were obtained in the other positions. The thickness of the low-viscosity microfilled resin was higher in positions 5 and 6 and lower in positions 1 and 10.

The sum of the resin materials in each position is presented in Table 3. According to the Friedmann non-parametric test, statistically significant differences were noted between the positions ($P < 0.01$). In Group 1, a significantly higher resin cement thickness was obtained in positions 5 and 6. In Group 2 (adhesive + resin cement) and Group 3 (adhesive + low-viscosity microfilled resin + resin cement), significantly lower resin thickness values were obtained in positions 1 and 10. Intermediate values were found in positions 2, 3, 7, and 8. Although no statistically significant difference was observed between these positions and positions 5 and 6 in Groups 2 and 3, a higher thickness of the resin material was observed at the occlusal surface (positions 5 and 6).

Table 3: Sum of thickness of resin material (μm) at different positions

Position/group	Group 1	Group 2	Group 3
P1	$50.5^{a,A}$	$85.5a^{b,AB}$	$113.0^{a,B}$
P2	$64.0^{a,A}$	$199.0^{cde,B}$	$303.5^{bc,B}$
P3	$66.0^{a,A}$	$117.0^{cd,B}$	$248.0^{bc,C}$
P4	$955^{a,A}$	$152.0^{cd,B}$	$249.5^{bc,C}$
P5	$142.0^{b,A}$	$213.0^{de,B}$	$351.5^{c,C}$
P6	$116.5^{b,A}$	$224.0^{e,B}$	$342.5^{c,C}$
P7	$75.0^{a,A}$	$168.0^{cd,B}$	$244.5^{b,B}$
P8	$43.5^{a,A}$	$112.0^{bc,B}$	$236.5^{b,C}$
P9	$69.0^{a,A}$	$219.0^{e,B}$	$330.0^{c,B}$
P10	$56.5^{a,A}$	$82.0^{a,A}$	$120.5^{a,B}$

Medians in the columns followed by the same small letter did not differ statistically according to the Wilcoxon test at a significance level of 1%. Medians in the rows followed by the same capital letter did not differ statistically according to the Mann-Whitney U test at a significance level of 1%

According to Kruskal-Wallis, the thickness of the resin material differed significantly between the groups in all positions ($P < 0.01$). The highest values were obtained in Group 3, which were significantly different than those of Group 2.

The lowest values were obtained in Group 1, which differed significantly from those of Group 2 [Table 3].

The fracture load of Group 3 (1300 N) was statistically higher than of Group 1 (1001 N) ($P < 0.01$). Group 2 (1189 N) was not significantly different from Groups 1 and 3 [Table 4]. All fractures occurred through the veneer and the core materials. In Group 1, 3 specimens presented with type I failure and 7 specimens with type II failure. In Group 2, 2 specimens presented with type I failure, 6 with type II and 2 with type III. In Group 3, 4 specimens presented with type II failure and 6 specimens with type III failure [Table 5].

Pearson's correlation coefficient indicated a regular positive correlation between the final thickness of the resin material and the fracture load ($r = 0.549$) [Figure 5].

Table 4: Mean fracture load (*N*) of the experimental groups

Group	*n*	Mean (*N*)	SD
3	10	1300[a]	230
2	10	1189[ab]	198
1	10	1001[b]	186

Means followed by the same letter did not differ statistically according to Tukey's test at significant level of 1%

Table 5: Remnant ceramic (%) on the crown after fracture

Group	*n*	Type I (0%)	Type II (less than 50%)	Type III (more than 50%)
1	10	3	7	0
2	10	2	6	2
3	10	0	4	6

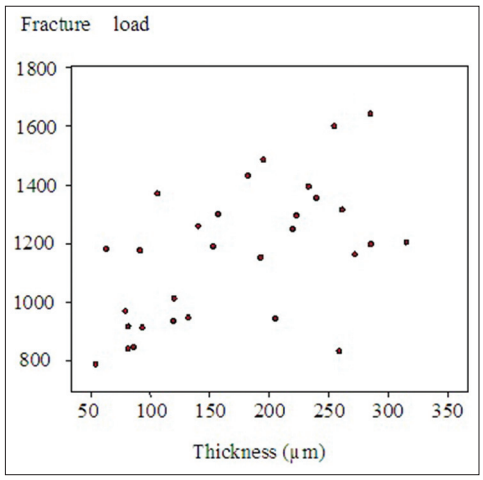

Figure 5: Pearson's correlation coefficient

DISCUSSION

The first hypothesis was accepted because the film thickness values of the 3 resin materials (adhesive, low-viscosity microfilled resin, and resin cement) were different and appeared to be influenced by their positions under the crown. In Groups 2 and 3, the Clearfil SE Bond adhesive system was applied to seal the dentin immediately after tooth preparation. The film thickness of this material presented a vast range of values at different positions of the adhesive layer, which was in accordance with other studies.[6,23,24] Higher thickness was obtained in positions 2 and 9 (concave parts of the preparation), which is consistent with the tendency of the adhesive to pool at the inner angles of the preparation.[23,24] The minimum thickness in both groups was observed in positions 1 and 10 (borders of the preparation). The thinner film of the adhesive at the borders is fortunate because a thicker film would expose more adhesive to the degradation process in the oral cavity.

In Group 2, the thickness of the adhesive could be measured in practically all positions, likely because the application of the glycerine gel allowed the polymerization of the outer layer. In some positions (positions 1, 4, and 10), the film thickness was less than 40 µm [Figure 3], which corresponds to the inhibition layer associated with oxygen inhibition of the radicals that initiate the polymerization reaction.[25] Without the glycerine gel layer, the adhesive would not have polymerized and would have been removed during the cleaning of the adhesive interface, resulting in many areas of exposed dentin. In fact, in Group 2, the adhesive film could not be seen or measured at one of the borders of the preparation in 6 specimens. The film thickness was likely very thin and was removed during the cleaning procedure before luting with Panavia F.[23]

When the adhesive film thickness was compared between Groups 2 and 3, a trend toward higher thickness was observed in Group 3, likely due to the application of the Protect Liner F over the adhesive, which protected the adhesive layer during the cleaning procedure. The cleaning of the adhesive interface was performed with pumice slurry to remove all remnants of the provisional cement. During this procedure, part of the adhesive layer was likely removed and the thickness of the adhesive reduced.[23]

The film thickness of the Protect Liner F (Group 3) presented a more uniform range of values at different positions compared with the adhesive layer. This

material has a higher percentage of filler compared with Clearfil SE Bond as well as a decreased likelihood of pooling at the inner angles of the preparation. Using a microbrush, the material was applied over the adhesive as thinly as possible from a visual perspective. At the borders, a clean microbrush was applied to remove a part of the material and to avoid a thicker layer, which could have considerably increased the amount of material exposed to the oral cavity. The minimum thickness was obtained in positions 1 and 10 (marginal areas of the preparation), which ranged from 19 μm to 67 μm. Glycerine gel was not used, although the surface of the cured low-viscosity microfilled resin was wiped with a cotton pellet soaked in alcohol to remove the unpolymerized layer on the surface.[26] Without this procedure, the film thickness would have been higher. In addition, the surface of the low-viscosity microfilled resin was cleaned with pumice slurry to remove the cement remnants, whereby some micrometers of the material may have also been removed.

The thickness of the resin cement can be influenced by many factors, including margin geometry and the presence of the die spacer. In relation to the margin geometry, a shoulder bevel facilitates better seating than does a shoulder,[27] although the preparation for a lithium disilicate ceramic requires a shoulder or a pronounced chamfer. Thus, a shoulder was used in the present study. The omission of a die spacer affects the proper seating of the restoration while an excessive layer can also enlarge the luting space.[28] The best crown seating was found when 20-40 μm of cement space was provided.[29] In the present study, 2 coats of die spacer were applied, which corresponds to a thickness of approximately 30 μm.[30] However, the thickness of the resin cement was higher in positions 5 and 6 (the occlusal portions of the preparation). This finding corroborates previous reports regarding marginal fit and cement distribution under all-ceramic restorations, which showed the highest cement film thickness was usually located at the occlusal surface underneath the crown.[31]

IDS with Clearfil SE Bond and Protect Liner F (Group 3) had the highest film thickness of the resin material in all positions compared with the other groups [Table 3]. At the borders of the preparation (positions 1 and 10), the median thickness of the resin materials exposed to the oral environment corresponded to 120 μm, 85 μm, and 56 μm for Groups 3, 2, and 1, respectively. The marginal and internal fit of all-ceramic crowns is still very important for conventional and adhesive luted restorations.[32,33] However, marginal fit is one of the most crucial criteria in the clinical decision involving the insertion of a restoration. Controversy exists regarding the clinical relevance of the size of the marginal discrepancies. Most authors agree that discrepancies in the range of 100 μm seem to be clinically acceptable with regard to the longevity of restorations.[34,35] For other authors, however, marginal discrepancies up to 160 μm might be tolerable.[36,37] Using the latter criteria, the results of the present study are within biologically acceptable standards for in all 3 groups.

For the luting procedure with Panavia F, ED Primer was applied on the Clearfil SE Bond adhesive (Group 2) and on the low-viscosity microfilled resin (Group 3). It is likely that this material contributed to the final thickness of the resin materials. However, it was not possible to visualize the layer of ED Primer. In relation to the luting procedure, ED Primer contains water as well as the hydrophilic monomer hydroxyethylmethacrylate. Hence, it would have been more appropriate to apply a hydrophobic adhesive that did not contain water. Nevertheless, according to the study of Okuda *et al*.,[38] ED Primer did not negatively influence the bond strength when it was applied on Protect Liner F for luting with Panavia F while a higher bond strength was obtained in the study of Udo *et al*.[26] The reason for this finding is not clear, but it may be related to the polymerization of Panavia F in the presence of ED Primer.[26] ED Primer contains an aromatic sulfinate salt, which is believed to accelerate interfacial polymerization between the sealed dentin surface and the resin cement.[38]

The second study hypothesis was rejected because a significant upward trend was noted in the fracture load with increasing thickness of the resin material. This finding was not in accordance with other studies that observed a downward trend in the fracture load with increasing thickness of the resin cement.[21] Kim *et al*.[39] observed that increased cement thickness can have an effect on reducing flexural failure load. In the study, the load to failure of silicon bonded to glass with variations in the thickness of the bonding epoxy layer indicated a 50% reduction in strength when this layer was increased from 20 μm to 200 μm. Burke and Watts,[40] evaluated the resin cement thickness of 2-mm ceramic crowns that were submitted to compressive fracture load. The authors concluded that the film thickness did not influence the overall results because the mean film thickness of the best performing material tested was similar to that in a group that did not perform as well. However, such studies evaluated the influence of the thickness of the resin cement on ceramic strength without taking into consideration the film thickness formed by IDS techniques. Therefore, it is difficult to make direct comparisons between

studies because of the different specimen dimensions, types of ceramic, and resin cement systems that were used, especially because numerous factors can affect ceramic fracture resistance behavior.[41]

In the present study, the load was applied on the occlusal regions of the crowns, corresponding to positions 5 and 6. It was at these positions that the highest final thickness of the resin material was recorded for all groups (approximately 130 μm, 250 μm, and 360 μm for Groups 1, 2, and 3, respectively). Because, the resin cement thickness was similar for all groups in positions 5 and 6 (approximately 150 μm), it is thought that the thickness of the Clearfil SE Bond and Protect Liner F influenced the values of the compressive fracture load.

During the curing process, the resin cement is transformed from a liquid to a solid state, thereby causing volume change and shrinkage of the material. Studies have shown that shrinkage stress may cause rupture of the bonded interfaces.[42,43] The additional film thickness formed by the adhesive and the low-viscosity microfilled resin may have favored greater absorption of stresses generated by the shrinkage of the resin cement,[42,44] contributing to greater stress relief at the interfaces. According to Rees and Jacobsen,[45] high shrinkage stress, even over a small area of an interface, is sufficient to induce crack formation. This becomes an area of stress concentration and is liable to induce further failures under occlusal loading. The integrity of the ceramic-resin cement interface is predicted because of the great bond strength between the composite material and silanized ceramic. However, crack formation may have been possible at the dentin-resin cement interface during shrinkage of the resin cement,[45] especially in the group that did not receive IDS (Group 1), which may explain its lower fracture load.

Another factor that could have contributed to the higher fracture load in Group 3 was the fact that IDS with the adhesive system and low-viscosity microfilled resin significantly improved the bond strength of indirect restorations bonded to dentin using the resin cement.[13,38] Increasing the bond strength of the luting material helps to increase the fracture strength of the restorative material.[46] Kitayama *et al*.[47] concluded that IDS with another adhesive system, Clearfil Tri-S Bond, increased the bonding durability of the resin cement to dentin against occlusal loading, which may reduce the possibility of fracture of all-ceramic crowns in clinical situations.

In all specimens, crown fractures occurred through the veneer and core ceramics. The classification of fractures used in the present study was based on the remnant ceramic on the prepared tooth because this was the main difference observed between the groups. More than 50% of the ceramic crown remained bonded to the preparation after the compressive fracture load test in most specimens in Group 3. This provides support for the idea that IDS with Clearfil SE Bond and Protect Liner F may promote a stronger bond between the ceramic crown and the dental preparation than does IDS with Clearfil SE Bond (Group 2) or does uncoated specimens (Group 1), in which less than 50% of the ceramic crown remained bonded to the preparation.

One advantage of the IDS technique is that the thickness of the resin materials is considered before the restoration is fabricated because it is captured in the impression. Even so, the thickness of the resin materials can be a concern for crowns. A part of the tooth preparation was observed to be occupied by Clearfil SE Bond and Protect Liner F. As a consequence, a part of the space designated for the ceramic core was occupied by Clearfil SE Bond and Protect Liner F in Group 3, especially at the concave part of the preparation (positions 2 and 9). Despite this, Group 3 had the highest compressive fracture load. This alteration in the geometry of the ceramic could be a concern for unreinforced ceramics such as IPS Empress leucite and feldspathic ceramics.

IPS Empress 2 ceramic was used in the present study because reinforced ceramics tend to be used in clinical practice for full crowns on posterior teeth. Recently, this ceramic has been replaced by IPS e. max ceramic, which has a similar composition as IPS Empress 2.[48] For this reason, the results of the present study may have been similar if IPS e. max ceramic had been used.

The IDS technique should not be recommended with other reinforced dental ceramic systems such as glass infiltrated aluminum oxide, high-purity alumina, and zirconia ceramics. The main reason is that these reinforced ceramics resist the formation of microretentive surfaces after hydrofluoric acid etching and airborne particle abrasion,[49] which are important surface treatments for adhesive luting. Therefore, an interesting study could evaluate the influence of IDS with feldspathic ceramic crowns, which have lower fracture resistance.

CONCLUSIONS

Despite the limitations of this *in vitro* study, the following conclusions can be drawn:

- The film thickness of Clearfil SE Bond was higher at the concave and occlusal portions of the crown preparation and thinner at the borders
- Protect Liner F had a more uniform range of values at different positions except at the borders of the preparations, where the film thickness was thinner
- The film thickness of Panavia F resin cement was higher at the occlusal portion of the crown preparation
- The film thickness formed by Clearfil SE Bond and Protect Liner F increased the fracture load of IPS Empress 2 ceramic crowns.

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