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Immediate Dentin Sealing of Onlay Preparations: Thickness of Pre-cured Dentin Bonding Agent and Effect of Surface Cleaning

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Clinical Relevance

The film thickness of the DBA used for the "immediate dentin sealing" of onlay preparations prior to final impression, making for indirect restorations, presents a vast range of values, depending on both the type of DBA and the topography of the tooth preparation. Curing the DBA in the absence of oxygen (air blocking) is mandatory to maintain a minimum DBA thickness. The filled DBA presented a more uniform thickness compared to the unfilled one. Air abrasion and polishing used for cleaning the pre-cured DBA prior to final cementation reduces the thickness of the DBA in a non-uniform manner.

SUMMARY

This study evaluated the thickness of Dentin Bonding Agent (DBA) used for "immediate dentin sealing" of onlay preparations prior to final impression making for indirect restorations. In addition, the amount of DBA that is removed when the adhesive surface is cleaned with polishing or air abrasion prior to final cementation was evaluated. For this purpose, a standardized onlay preparation was prepared in 12 extracted molars, and either OptiBond FL (Kerr) or Syntac Classic (Vivadent) was applied to half of the teeth and cured in the absence of oxygen (air blocking). Each tooth was bisected in a bucco-lingual direction into two sections, and the thickness of the DBA was measured under SEM on gold sputtered epoxy resin replicas at 11 positions. The DBA layer of each half tooth was treated with either air abrasion or polishing. The thickness of the DBAs was then re-measured on the replicas at the same positions. The results were statistically analyzed with non-parametric statistics (Mann-Whitney U test and Kruskal-Wallis test) at a confidence level of 95% (*p*=0.05).

The film thickness of the DBA was not uniform across the adhesive interface (121.13 ± 107.64 µm), and a great range of values was recorded (0 to 500 µm). Statistically significant differences (*p*<0.05) were noted, which were both material (OptiBond FL or Syntac Classic) and position (1 to 11) dependent. Syntac Classic presented a higher thickness of DBA (142.34 ± 125.10 µm) than OptiBond FL (87.99 ± 73.76 µm). The higher film thickness of both DBAs was at the deepest part of the isthmus (the most concave part of the preparation), while the lowest was at the line angles of

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the dentinal crest (the most convex part of the preparation). OptiBond FL presented a more uniform thickness around the dentinal crest of preparation; Syntac Classic pooled at the lower parts of the preparation.

The amount of DBA that was removed with air abrasion or polishing was not uniform (11.94 ± 16.46 µm), and a great range of values was recorded (0 to 145 µm). No statistically significant differences (*p*<0.05) were found either between different DBAs (OptiBond FL or Syntac Classic) or between different treatments (air abrasion or polishing). As far as the effect of different treatments at different positions, polishing removed more DBA from the top of the dentinal crest, but the difference was not statistically significant. Air abrasion removed less DBA from the corners of the dentinal crest (Positions 4 and 6) than the outer buccal part of the preparation (Positions 1 and 2). Neither air abrasion nor polishing removed the entire layer thickness of the DBA in the majority of the cases.

INTRODUCTION

The demand for tooth-colored restorations has grown considerably during the past decade. Due to residual polymerization stresses, direct resin composite restorations are often contraindicated in large cavities. In these situations, indirect porcelain or polymer restorations are commonly the choice of the dental clinician, as they are more conservative than full coverage crowns. Many aspects of the adhesive luting procedures of such restorations have been thoroughly investigated in order to find the ideal method that would ensure excellent clinical results (Hansen & Asmussen, 1987; Millstein & Nathanson, 1992; Dietschi, Magne & Holz, 1995; Bertschinger & others, 1996; Bachmann & others, 1997; Paul, 1997a,b; Paul & Scharer, 1997a,b; Peter & others; 1997; Dietschi & Herzfeld, 1998; Magne & Douglas, 1999).

Successful adhesion to enamel has been achieved with relative ease. On the contrary, the development of predictable bonding to dentin has been more problematic. Only in the past decade have dentin bonding agents produced results that approach those of enamel bonding and have achieved a predictable level of clinical success with direct resin composite restorations. As earlier bonding agents achieved lower bond strengths when applied to dentin compared to enamel, the presence of dentin in a significant percentage of the luting interface was one of the main issues that made dentists skeptical about placement of indirect bonded restorations in the posterior region. The dentin-adhesive resin interface of indirect restorations has also been thoroughly investigated, and different luting procedures have been proposed. In the case of a substantial accessible area of dentin being exposed by tooth preparation (inlay, onlay or veneer), the local application of a dentin bonding agent (DBA) is recommended. At least two methods have been presented for use of the DBA in order to promote dentin adhesion of indirect restorations.

In the *classical approach*, dentin exposures are initially ignored; the DBA is applied only at the last treatment stage when proceeding to lute the restoration. In this case, the DBA must be initially left uncured to allow for complete seating of the restoration. It is has been postulated that the pressure of the luting composite during the seating of the restoration may create a collapse of demineralized dentin (collagen fibers) and subsequently affect the adhesive interface cohesiveness (Dietschi & Herzfeld, 1998; Dietschi, Magne & Holz, 1995; Magne & Douglas, 1999). Thinning the adhesive layer has been proposed in order to allow its curing before insertion of the restoration. However, because methacrylate resins show an inhibition layer up to ~40µm when they are light-cured (Rueggeberg & Margeson, 1990), excessive thinning can prevent the curing of light-activated DBAs.

More recently, a *new approach* was proposed to optimize the DBA application (Paul, 1997a; Paul & Scharer, 1997a; Bertschinger & others, 1996; Magne & Douglas, 1999). Because the DBA appears to have a superior potential for adhesion when it is precured (Frankenberger & others, 1999) and applied to freshly prepared dentin, its application is recommended immediately after completion of the tooth preparation, before the final impression. A substantial clinical advantage of the so-called "immediate dentin sealing" (Magne & Douglas, 1999; Magne & Belser, 2002a) is that this precautionary measure seals and protects the pulpodentinal organ and, by the same token, prevents sensitivity and bacterial leakage during the provisional phase. Further adhesion of the luting agent to the preexisting adhesive layer must be promoted by surface cleaning just prior to luting (Magne & Douglas, 1999; Magne & Belser, 2002b) in order to remove remnants of provisional cements that may cause a significant decrease in the bond strength of the luting agent (Paul & Scharer, 1997b; Millstein & Nathanson, 1992b). This is especially important when the luting agent contains eugenol, which inhibits resin polymerization (Hansen & Asmussen, 1987; Millstein & Nathanson, 1992).

Initially, pumice slurry was used as a means of removing remnants of provisional cements (Gerbo & others, 1992), even though its efficacy has been questioned (Bachmann & others, 1997). Prophylaxis pastes have also been proposed for cleaning the dental surfaces prior to cementation (Aboush, Tareen & Elderton, 1991). Another fast and effective final cleansing method is the use of an intraoral sandblaster. There are no data, however, providing information about the effect of surface treatments on the thickness of the pre-cured adhesive layer when "immediate dentin sealing" has been applied. Therefore, this study evaluated the effect of surface cleaning on the remaining thickness of the precured DBA. A standardized onlay preparation was chosen to compare filled and unfilled DBAs and evaluate various sites of the cavity. The null hypothesis was that there was no statistically significant difference between the thickness of the different DBAs at various sites of the adhesive interface before and after surface cleaning of the pre-cured DBA.

METHODS AND MATERIALS

Twelve extracted caries-free human lower molars with completed root formation were stored in 0.1% thymol solution for the time between extraction and use in this *in vitro* test. After scaling and pumicing of the root surface, a standardized onlay cavity without a marginal bevel in enamel was prepared. Figure 1 illustrates a bucco-lingual section of the cavity design used in this study. The lingual one-third of each tooth was left unprepared. A deep, straight isthmus was prepared in a mesio-distal direction, which extended all the way to the proximal surfaces of the teeth. To that purpose, 80 µm diamond burs (Universal Prep Set, Intensiv SA, Lugano, Switzerland) were used under continuous water cooling in a direction where their long axis was perpendicular to the long axis of the teeth and parallel to their lingual surface. The isthmus had the same depth across the tooth, to a depth where the proximal enamel was left intact 1 mm from the cemento-enamel junction. The enamel was then prepared at the buccal surface of the teeth to the same horizontal level as proximally. The next step was to remove the occlusal enamel and dentin from the buccal cusps, so as to leave a crest of dentin below the buccal cusps, which was approximately 2 mm in height and width. The height of this dentinal crest was the same across the tooth, with rounded bucco-occlusal and linguo-occlusal line angles. Finally, enamel and dentin were removed at the mesiobuccal and disto-buccal line angles, so as to have a continuous 1 mm rounded shoulder margin at the same horizontal level, which extended from the mesial to the distal side of the tooth. The entire cavity was finished using 25 µm finishing diamond burs (Intensiv). Cavity preparations were checked for marginal imperfections, such as fractures or chipping, under a stereo microscope (Wild M5, Wild AG, Heerbrugg, Switzerland) at 12x magnification. If present, the imperfections were corrected.

The teeth were then randomly divided into two groups according to the DBA that would be applied to them and prepared for simulation of the intratubular fluid flow. To that purpose, the apices were sealed with two coats of nail varnish. Then the teeth were mounted on custom made specimen holders, with their roots in the center, using an auto-polymerizing resin (Paladur, Kulzer & Co, Wehrheim, Germany). A custom-made device assured that the isthmus of the preparation was placed parallel to the base of the specimen holder. A cylindrical hole was drilled into the pulpal chamber approximately in the middle third of the root. A metal tube with a diameter of 1.4 mm was then adhesively luted using a DBA (Syntac Classic, Vivadent, Schaan, Liechtenstein). The pulpal tissue was not removed. This tube was connected by a flexible silicone hose to an infusion bottle placed 34 cm vertically above the test tooth. The infusion bottle was filled with horse serum diluted in a 1:3 ratio with 0.9% PBS (Maita & others, 1991; Pashley & others, 1981) to simulate the dentinal fluid under normal hydrostatic pressure of about 25 mm Hg (Tao & Pashley, 1989; Mitchem, Terkla & Gronas, 1988). Twenty-four hours before starting application of the DBA by using a three-way valve, the pulp

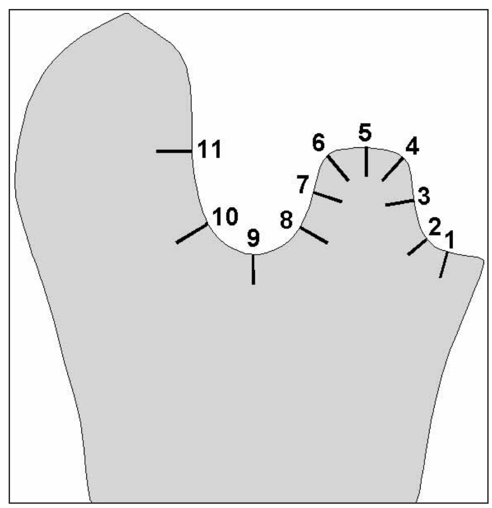

Figure 1. *Bucco-lingual section of the cavity design used in this study. Eleven orientation lines were marked to certain areas of dentin perpendicular to the adhesive layer.according to bacteria strain (error bar = SD).*

Table 1: *Manufacturers, Lot Numbers and Expiration Dates of the Materials Used*

Material	Manufacturer	Lot #	Exp Date
Ultra-Etch	Ultradent Products Inc	35PQ	2003-04
OptiBond FL primer	Kerr USA	008C00	2002-06
OptiBond FL adhesive	Kerr USA	006122A	2001-11
Syntac primer	Vivadent	C16315	2002-10
Syntac adhesive	Vivadent	C15085	2002-08
Heliobond	Vivadent	C06372	2005-02

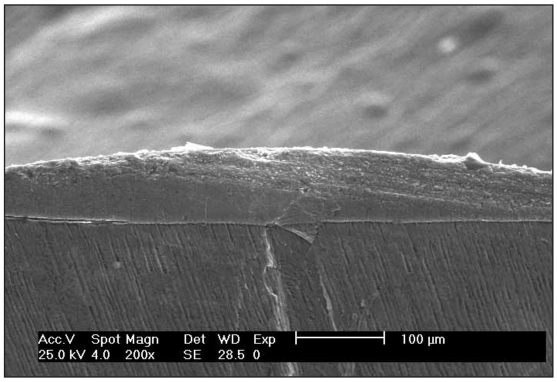

Figure 2. *Film thickness of the DBA was measured in a direction parallel to the orientation line that was marked in dentin adjacent to the adhesive interface (200x magnification).*

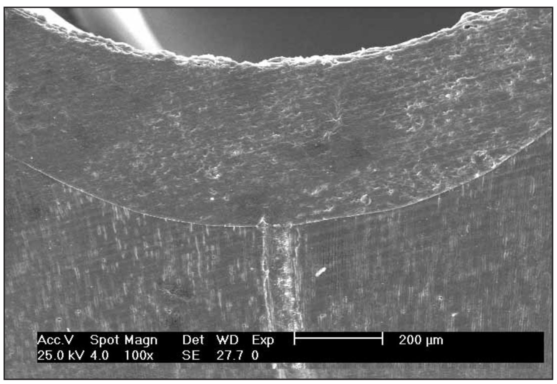

Figure 3. *Film thickness of the DBA at Position 9 prior to application of air abrasion (100x magnification).*

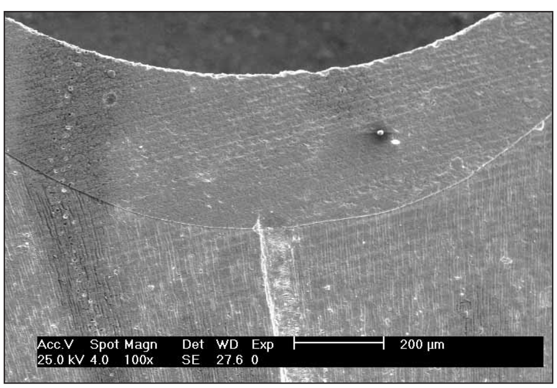

Figure 4. *Film thickness of the DBA at Position 9 after application of air abrasion (100x magnification).*

chambers were evacuated with a vacuum pump and subsequently filled with the diluted, bubble-free horse serum. From this time forward, the intrapulpal pressure was maintained at 25 mm Hg throughout application of the DBA. The manufacturers, LOT numbers and expiration dates of the materials used in this study are listed in Table 1.

OptiBond FL (Kerr, Orange, CA, USA) was applied to the first group of six teeth. Both enamel and dentin were etched with 35% phosphoric acid gel (Ultra-Etch, Ultradent, South Jordan, UT, USA) for 30 and 15 seconds, respectively. The dental surfaces were washed with water for 30 seconds in order to remove the etchant and gently air dried for approximately five seconds, making sure that the dentin was not desiccated. OptiBond FL primer was applied over the enamel and dentin with a light scrubbing motion for 30 seconds using a Kerr Applicator Tip. The dental surfaces were gently air dried for approximately five seconds, being careful once again to not desiccate the dental surfaces. OptiBond FL adhesive was uniformly applied over the enamel and dentin with a Kerr Applicator Tip, attempting to create a uniform thin layer of adhesive resin. The adhesive resin was left to penetrate into the demineralized hard dental tissues for 30 seconds, before being polymerized for 30 seconds, using a tip with an exit window diameter of 11 mm (Demetron 500; Demetron/Kerr, Danbury, CT, USA; irradiance according to the Demetron Curing Radiometer: ~ 800 mW/cm^2). A water soluble glycerin gel (K-Y Lubricating Jelly, Johnson & Johnson Consumer France SAS, Sezanne, France) was applied over the teeth, and the DBA was polymerized for another 30 seconds and subsequently washed and air dried.

Syntac Classic was applied to the second group of six teeth. The enamel was etched with 35% phosphoric acid gel (Ultra-Etch) for 60 seconds, washed with water for 30 seconds in order to remove the etchant and air dried for approximately five seconds. Syntac primer was applied over the enamel and dentin with a light scrubbing motion for 15 seconds, and the dental surfaces were thoroughly air dried for approximately five seconds. Syntac adhesive was applied over the enamel and dentin for 10 seconds and dried. Heliobond was applied uniformly with a Kerr Applicator Tip, trying to create a uniformly thin layer of adhesive resin. Heliobond was also left for 30 seconds to penetrate into the demineralized hard dental tissues before it was polymerized for 30 seconds using the same curing unit. A water soluble glycerine gel (K-Y Lubricating Jelly) was applied over the teeth, and the DBA was polymerized for another 30 seconds and subsequently washed and air dried.

Each tooth was bisected in a bucco-lingual direction perpendicular to the long axis of the isthmus and parallel to its long axis with the aid of a slowly rotating diamond disc (Isomet Low Speed Saw 11–1180, AB Bühler Ltd, Chicago, IL, USA) under water cooling. The sectioned surface of each half was polished using rotating sandpaper discs of descending abrasivity to the level of 4000 grit. The surface was relieved using 35% phosphoric acid for one second, washed and dried. Eleven orientation line marks were marked to certain areas of dentin perpendicular to the adhesive layer, as illustrat-

Table 2: *OptiBond FL: Film thickness, means and standard deviations (in microns) prior to the application of air abrasion or polishing at different positions of the adhesive layer.*

Position	1	2	3	4	5	6	7	8	9	10	11
	64	96	69	13	150	35	43	25	25	48	104
	91	106	54	17	153	34	96	222	251	154	54
	74	125	48	15	115	25	24	61	99	96	27
	90	115	44	21	114	20	52	71	56	25	30
	102	118	29	18	179	29	93	188	281	86	115
	206	257	176	17	207	59	79	205	321	240	40
	54	78	53	11	145	30	37	21	17	62	118
	112	119	52	70	157	48	87	219	277	206	130
	92	143	39	9	90	35	35	44	102	49	37
	97	108	48	0	124	36	32	58	82	27	49
	59	101	40	15	125	51	27	87	300	59	117
	199	251	125	23	209	85	40	101	363	260	65
Mean	103.33	134.75	64.75	19.08	147.33	40.58	53.75	108.50	181.17	109.33	73.83
St Dev	49.61	57.95	42.63	17.12	36.92	17.88	27.11	77.60	128.14	84.15	39.63

Table 3: *Syntac classic: film thickness, means and standard deviations (in microns) prior to the application of air abrasion or polishing at different positions of the adhesive layer.*

Position	1	2	3	4	5	6	7	8	9	10	11
	162	182	37	0	245	0	187	417	482	87	31
	311	434	299	9	19	0	92	237	273	62	25
	254	284	147	19	129	0	67	142	178	126	58
	111	124	30	0	0	108	149	316	436	267	40
	331	269	37	25	0	0	103	248	298	121	67
	206	190	107	0	96	0	109	344	413	187	52
	119	196	90	0	245	55	13	248	500	316	138
	332	442	399	0	0	0	13	149	273	153	36
	191	238	246	144	0	125	46	18	64	179	89
	120	119	27	130	115	25	49	209	444	200	28
	228	257	106	28	128	21	35	179	266	214	57
	137	182	193	153	0	84	14	56	226	396	280
Mean	208.50	243.08	143.17	42.33	81.42	34.83	73.08	213.58	321.08	192.33	75.08
St Dev	83.20	104.73	119.53	61.34	93.58	46.59	56.24	114.97	134.32	96.39	71.85

ed in Figure 1. These lines were made with a fine surgical blade (#11 Bard-Parker Stainless Steel Surgical Blades, Becton Dickinson AcuteCare, Franklin Lakes, NJ, USA) under 20x magnification. Impressions were made of the sectioned surface of each half using a polyvinylsiloxane impression material (President light body, Coltène AG, Altstätten, Switzerland). Subsequently, epoxy replicas were prepared for the computer-assisted measurement of the thickness of the adhesive layer in a scanning electron microscope (Philips XL20, Philips, Eidhoven, Netherlands) at 200x magnification. The thickness of the adhesive layer was measured in a direction parallel to the orientation lines that were marked in dentin adjacent to the adhesive interface and which were easily identified (Figure 2).

The adhesive layer of each half of the tooth was treated with one of the two most common methods used for the removal of temporary cement prior to the final cementation of indirect restorations. One half was air abraded with 50 µm aluminum-oxide powder (Dento-Prep Microblaster, Ronvig Dental Mfg, Daugaard, Denmark) that was propelled at 4.5 bars pressure with three Z-shaped sweeping motions over the preparation for approximately five seconds. The other half was cleaned with a prophylaxis paste (Depurdent, Dr Wild & Co AG, Basel, Switzerland) and a rotary nylon brush (Nylon brush, Hawe-Neos, Bioggio, Switzerland) at 1.000 rpm for approximately five seconds. Impressions and epoxy replicas were made from the sectioned surface of each half of the tooth as previously described. The thickness of the adhesive layer was once again

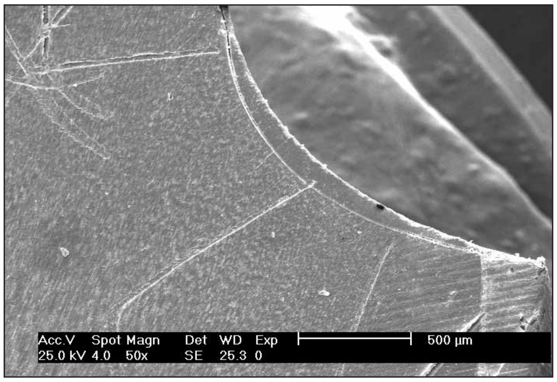

Figure 5. *Representative specimen with "thin" film thickness of DBA at Positions 1, 2 and 3 (50x magnification).*

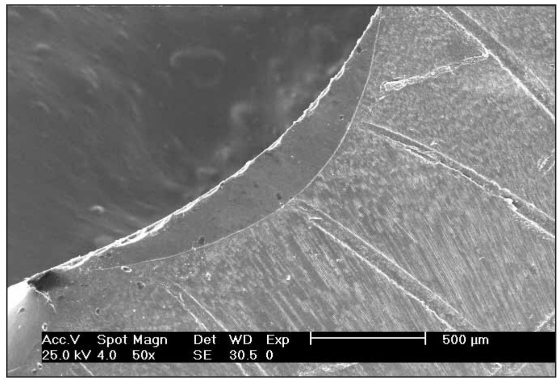

Figure 6. *Representative specimen with "thick" film thickness of DBA at Positions 1, 2 and 3 (50x magnification).*

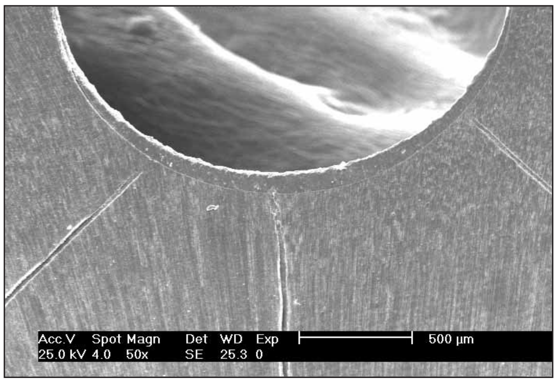

Figure 7. *Representative specimen with "thin" film thickness of DBA at Positions 8, 9 and 10 (50x magnification).*

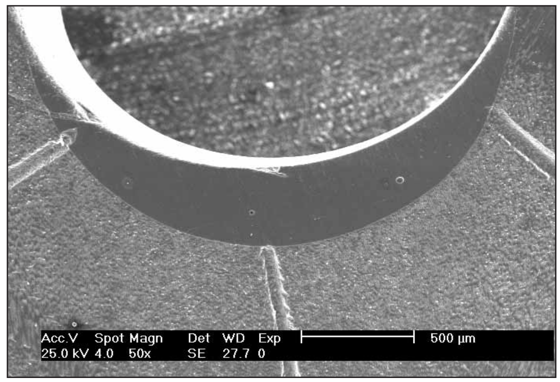

Figure 8. *Representative specimen with "thick" film thickness of DBA at Positions 8, 9 and 10 (50x magnification).*

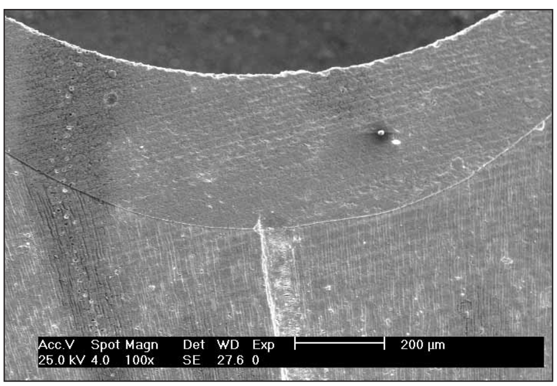

Figure 9. *Representative specimen with "thin" film thickness of DBA at Position 6 (200x magnification). The thickness of the DBA increases at the top-right side toward Position 5.*

evaluated in SEM at 200x magnification in a direction parallel to the same orientation lines. Using these orientation lines assured that the measurements before and after treatment of the adhesive interface with air abrasion or polishing were comparable. The amount of the adhesive layer that was removed by air abrasion or polishing was calculated by subtracting the thickness of the adhesive layer before (Figure 3) and after (Figure 4) each treatment.

As the data for the adhesive layer that was collected did not come from a normal distribution, non-parametric statistics were used for the statistical evaluation. The Mann-Whitney U and Kruskal-Wallis tests were used for comparison of the medians of the sample groups at a confidence level of 95% (p=0.05).

RESULTS

The film thickness of the DBA of OptiBond FL and Syntac Classic at different positions of the adhesive layer prior to application of air abrasion or polishing is presented in Tables 2 and 3. The film thickness of the DBA was not uniform across the adhesive interface (121.13 ± 107.64 µm), and a significant range of values was recorded (0 to 500 µm) (Figures 5 to 9). Statistically significant differences ($p<0.05$) were noted, which were both material (OptiBond FL or Syntac Classic) and position (1 to 11) dependent. Syntac Classic presented statistically significant higher thickness of DBA (142.34 ± 125.10 µm) than OptiBond FL (87.99 ± 73.76 µm).

The statistically significant differences ($p<0.05$) of the DBA thickness between the different positions of OptiBond FL are presented in Table 4. The smallest film thickness of DBA was found in Position 4 (bucco-occlusal line angle of the dentinal crest), which was statistically different from all other areas. The film thickness of DBA was higher in Position 9 (the deepest part of the isthmus), which was not statistically different from most other areas of the preparation (Positions 5, 2, 1, 8, 10, 11 and 7).

The statistically significant differences ($p<0.05$) of the DBA thickness between the different positions of Syntac Classic are presented in Table 5. Areas located

Table 4: *OptiBond FL: subgroups of statistical significance prior to the application of air abrasion or polishing (Kruskal-Wallis test, p<0.05, n=12).Positions that were different are marked with the - symbol in the table below. Positions with x were not different.*

Position										**SD**
4	19.08	19.08	19.08	19.08						(17.12)
6	40.58	40.58	40.58	40.58	40.58					(17.88)
7	53.75	53.75	53.75	53.75	53.75	53.75				(27.11)
3	64.75	64.75	64.75	64.75	64.75	64.75	64.75			(42.63)
11		73.83	73.83	73.83	73.83	73.83	73.83			(39.63)
1			103.33	103.33	103.33	103.33	103.33			(49.61)
8				108.50	108.50	108.50	108.50	108.50		(77.60)
10				109.33	109.33	109.33	109.33	109.33		(84.15)
2						134.75	134.75	134.75	134.75	(57.95)
5						147.33	147.33	147.33	147.33	(36.92)
9									181.17	(128.14)

Table 5: *Syntac Classic: Subgroups of statistical significance prior to the application of air abrasion or polishing (Kruskal-Wallis test, p<0.05, n=12).Positions that were different are marked with the - symbol in the table below. Positions with x were not different.*

Position							**SD**
6	34.83	34.83					(46.59)
4	42.33	42.33					(61.34)
11	75.08	75.08	75.08				(71.85)
5	81.42						
7	73.08	73.08	73.08				(56.24)
3		143.17	143.17	143.17			(119.53)
10			192.33	192.33	192.33		(96.39)
1			208.50	208.50	208.50		(83.20)
2				243.08	243.08		(104.73)
8			213.58	213.58	213.58		(114.97)
9						321.08	(134.32)

on the dentinal crest (Positions 4, 6 and 5) and inclined planes at the upper half of the preparation (Positions 11, 7 and 3) presented thinner films of DBA with no statistically significant differences among them. Concave parts at the bottom half of the preparation (Positions 9, 8, 2, 1 and 10) presented thicker films of DBA, also with no statistically significant differences among them.

The film thickness of the DBA that was removed after application of air abrasion or polishing at different positions of the adhesive layer is presented in Table 6. The amount of DBA that was removed was not uniform across the adhesive interface (11.94 ± 16.46 µm), and a great range of values was recorded (0-145 µm for polishing and 0-63 µm for air abrasion). In OptiBond FL specimens, air abrasion (8.47 ± 8.63 µm) removed less DBA than polishing (16.45 ± 24.34 µm), but the difference, due to the large standard deviations, was not statistically significant. In Syntac Classic specimens, air abrasion (11.41 ± 14.11 µm) removed similar thicknesses of DBA to polishing (11.42 ± 14.05 µm). The amount of DBA removed by polishing was not dependent on the position. Polishing removed more DBA from the top of the dentinal crest, but the difference was not statistically significant. On the contrary, when air abrasion was used, the amount of DBA removed depended on the position. As Table 7 illustrates, air abrasion removed less DBA from the corners of the dentinal crest (Positions 4 and 6) and more DBA from the outer buccal part of the preparation (Positions 1 and 2).

DISCUSSION

The film thickness of DBAs presented a vast range of values around different positions of the adhesive layer. This was to be expected, as other researchers have reported similar results for direct resin composite preparations (Watson, 1989) and complete coverage preparations (Peter & others, 1997; Pashley & others, 1992). Even though a non-uniform distribution of DBA around the adhesive interface was expected, OptiBond FL and Syntac Classic presented some dissimilarity in their behavior. Both DBAs presented their maximum thickness at Position 9 (the deepest part of the isthmus) and substantial thickness of DBA in concave parts of the preparation (Positions 2, 8 and 10). During the application of the DBA, the teeth were positioned with their vertical axis perpendicular to the horizontal plane, thus resembling the clinical conditions of mandibular molars of a patient whose occlusal plane of the lower arch is parallel to the floor. Therefore, the influence of different inclinations of teeth, as well as the

Table 6: *Means and standard deviations of the film thickness (in microns) of OptiBond FL and Syntac Classic that was removed after the application of air abrasion or polishing at different positions of the adhesive layer (n=6).*

GROUP		1	2	3	4	5	6	7	8	9	10	11
OBFL/AA	Mean	15.83	20.67	16.33	4.33	9.50	1.50	2.00	3.33	5.33	5.00	9.33
	SD	11.53	10.33	13.07	0.95	5.96	2.41	2.29	2.94	3.67	3.68	3.95
SYN/AA	Mean	19.00	15.50	10.83	0.00	5.50	1.17	14.67	20.17	16.00	13.00	9.67
	SD	20.75	9.62	5.68	1.51	6.80	3.18	22.82	19.55	13.47	8.08	7.60
OBFL/PO	Mean	13.83	16.50	7.17	3.00	35.83	13.33	5.00	12.83	26.83	20.33	26.33
	SD	12.70	13.48	10.52	3.85	52.48	10.75	4.27	16.51	27.36	21.94	28.82
SYN/PO	Mean	10.67	15.50	11.33	15.67	14.33	14.50	4.67	11.50	12.00	9.67	5.83
	SD	13.70	14.19	16.46	20.46	16.56	17.05	4.83	11.59	14.03	8.73	5.44

OBFL: OptiBond FL; SYN: Syntac Classic; AA: air abrasion; PO: polishing.

Table 7: *Air abrasion: subgroups of statistical significance of the film thickness (in microns) of DBA that was removed (n=12). Positions that were different are marked with the – symbol in the table below. Positions with an X were not different.*

Position			SD
6	1.33		(2.31)
4	2.17		(2.37)
7	8.33	8.33	(18.01)
8	11.75	11.75	(16.65)
5	7.50	7.50	(6.88)
9	10.67	10.67	(11.51)
10	9.00	9.00	(7.60)
11	9.50	9.50	(6.30)
3	13.58	13.58	(10.02)
1		17.42	(16.36)
2		18.08	(8.64)

possible effects of gravitational forces while working on maxillary teeth to the thickness of DBA at different positions of the adhesive layer, was not evaluated. Nevertheless, the increased thickness due to pooling of the DBA at the inner line angles of the preparation is in accordance with the dental literature (Peter & others, 1997). The minimum thickness of both DBAs was observed at convex areas of the preparation, such as Positions 4 and 6 (bucco-occlusal and linguo-occlusal line angles of the dentinal ridge). OptiBond FL produced a thicker layer at Position 5, which was located at the top of the dentinal crest (147.33 ± 36.92 µm) than Syntac Classic (81.42 ± 93.58 µm), even though in most positions Syntac Classic surpassed OptiBond FL.

A closer observation of the thickness of DBA in all specimens at the top of the dentinal crest (Positions 4, 5 and 6) revealed that Syntac Classic often failed to produce a measurable layer at these positions, even though substantial thickness of DBA was observed in other positions of the same specimens. The bonding resin of Syntac Classic (Heliobond) did not rest on the position where it was placed, and it pooled to lower parts of the preparation, as lower positions (10, 1, 8, 2 and 9) exhibited increased thickness than higher positions (6, 4, 7, 11, 5 and 3). The pooling of the bonding resin may be attributed to the difference in viscosity between the primers (very low viscosity because of the high solvent and relatively low resin content) and the unfilled Heliobond (low-to-medium viscosity because of its bis-GMA composition) (Paul, 1997b).

A closer observation of the thickness of the DBA in all specimens at the top of the dentinal crest (Positions 4, 5 and 6) revealed that OptiBond FL produced a distinct layer at these positions in practically all specimens. Nevertheless, the observed thickness at Position 4 (bucco-occlusal line angle of the dentinal crest) and Position 6 (linguo-occlusal line angle of the dentinal crest) was most often below 20 µm, and 40 µm, respectively. If no glycerine gel (K-Y Lubricating Jelly) was applied over the teeth, a possible problem could have been observed at these areas, as the inhibition layer of polymerization due to oxygen inhibition of the radicals that normally induce the polymerization reaction has been reported to reach 40 µm (Rueggeberg & Margeson, 1990). As the thickness of the DBA is smaller than that of the oxygen inhibition layer, a significant portion of the top layers of the DBA would be left unpolymerized. The unpolymerized DBA would be subsequently easily removed during cleaning of the adhesive interface by air abrasion or polishing, along with a portion of the thin polymerized lower layers of the DBA. This could result in areas of exposed dentin. Therefore, unless future research indicates otherwise, it seems that using air block at the first stage is mandatory to avoid more dentin exposure during cleaning of the adhesive interface at a later stage.

OptiBond FL exhibited less pooling than Syntac Classic. This could be attributed to the fact that its adhesive resin is less viscous (due to the incorporation of TEG-DMA and filler particles in its composition) and the fact that both OptiBond FL primer and adhesive resin both contain HEMA in their composition.

The maximum thickness of DBA recorded in this study was superior to the that reported in the dental literature. This may be attributed to the fact that, in this study, no air thinning of the DBA was performed prior to its polymerization, which is the recommended clinical procedure when using "immediate dentin sealing" (Magne & Douglas, 1999; Magne, 2005). Air thinning would spread the adhesive beyond the preparations' margins, subsequently altering margin definition and complicating finishing procedures. The decision not to air-thin the DBA was also due to the fact that one of the purposes of this investigation was to examine the effect or air abrasion and polishing, and air-thinning would increase the chance of having very little or no DBA at the bucco- and linguo-occlusal line angles of the dentinal crest. This factor could have complicated the evaluation of the effect of air abrasion and polishing. Additionally, in a subsequent part of this investigation, the effect of whether or not to use a water soluble glycerin gel in order to polymerize the oxygen-inhibited layer would be investigated. In any case, the thickness of the DBA in the borders of the preparation (not reported as placement of the orientation line marks were nearly impossible to be placed perpendicular to the adhesive layer, and they also often damaged the adhesive layer) was well within the range reported in the literature, as the DBA tended to pool in the interior of the preparation. The significant standard deviations in all positions around the adhesive layer well illustrate the point that, even though the experienced operator who performed the research intended to achieve an even distribution of the DBA in all specimens, this was not feasible, even though he worked *in vitro* under ideal conditions. Specimens where Syntac Classic was used as DBA presented a thicker layer of DBA than OptiBond FL. This could result from the fact that the adhesive resin of Syntac Classic (Heliomolar) is practically transparent, thus making the visual evaluation of the quantity of adhesive resin placed onto the preparation difficult. One could only speculate what kind of variation of thickness of DBA would be encountered in clinical cases, as a similar *in vivo* study would be most difficult to complete.

There is no similar study which compares the results of the film thickness of the DBA that was removed after the application of air abrasion or polishing in the dental literature. No difference was found between these two treatments when the authors examined the results of both DBAs. Nevertheless, a closer observation of the results of Tables 6 and 7 revealed that there was a difference in the behavior of these two treatments at different positions. The results of Table 7 reveal that air abrasion removed more DBA from the outer buccal part of the preparation (Positions 2 and 1) than the corners of the dentinal crest (Positions 6 and 4). This may be explained by the fact that the air abrasion particles, in their descending course after colliding with the buccal wall of the dentinal crest, may then be deflected to collide with the lower parts of the preparation at the buccal side, thus maximizing the amount of DBA being removed in these areas. On the other hand, the results of Table 6 show that polishing removed more DBA from the top of the preparation (Position 5 at the mid-height of the dentinal crest and Position 11 at the mid-lingual wall of the preparation), the very lowest parts of the preparation (Position 9 at the depth of the isthmus and Position 2 at the axio-buccal line angle of the dentinal crest) and less DBA from the vertical walls of the dentinal crest (Positions 3 and 7). Once again, few differences were found to be statistically significant due to the large standard deviations. The amount of DBA removed by polishing seemed to be related to the accessibility of the bristles of the rotating polishing brush to specific areas of the preparation.

Polishing removed more DBA than air abrasion in OptiBond FL, even though the difference was not statistically significant due to the ample standard deviations, whereas similar amounts of DBA were removed by the two treatments in Syntac Classic. This may be explained by the fact that OptiBond FL adhesive is a filled adhesive, in contrast to Heliobond, which is a non-filled adhesive resin. The fillers make OptiBond FL more resistant to air abrasion, as they increase its mechanical properties (compressive, tensile strength and elastic modulus). On the other hand, resistance to wear from polishing is a more complex phenomenon that depends on several intrinsic and extrinsic factors. Several possible wear mechanisms have been proposed for dental composites. In one of them, it has been suggested that filler particles transmit considerable stress to the matrix, possibly resulting in microcracking and subsequent loss of material. There are strong indications in the dental literature that adding inorganic filler particles to a resin, even in small amounts, greatly enhances the long-term wear resistance of such materials (Ulvestad, 1977; Raadal, 1978). Nevertheless, as the polishing procedure lasted only five seconds, the presence of filler particles in Optibond FL adhesive resin could have contributed to the significant loss of material in the short term via the aforementioned mechanism.

In the vast majority of cases, both air abrasion and polishing did not remove the entire thickness of the DBA. There were only two exceptions: one specimen in the Syntac Classic—air abrasion group, where 19 µm were removed from Position 5, and one specimen in the OptiBond FL—polishing group, where 11 µm, 145 µm and 30 µm were removed from Positions 4, 5 and 6, respectively. This illustrates the fact that both treatments may be used in the manner described in the Methods and Materials section without fear of removing the entire thickness of the DBA in large areas of the preparation. Even though the measurements of this study were made at only 11 sites of one cross section of the preparation, the visual aspect of all teeth after air abrasion and polishing did not give the impression that the DBA was totally removed from large areas.

CONCLUSIONS

Under the limitations of the experimental set-up, several conclusions may be drawn from this study: the film thickness of the DBA was not uniform across the adhesive interface, and a great range of values was recorded. Syntac Classic presented higher thickness of DBA than OptiBond FL. The higher film thickness of both DBAs was at the deepest part of the isthmus, while the lowest was at the line angles of the dentinal crest. OptiBond FL presented a more uniform thickness around the dentinal crest of preparation, while Syntac Classic pooled at the lower parts of the preparation. The amount of DBA that was removed with air abrasion and polishing was not uniform across the adhesive interface, and a great range of values was also recorded. There was no statistically significant difference in the amount of DBA removed between the two treatments (air abrasion and polishing) for both DBAs (OptiBond FL and Syntac Classic). Even though few differences were found that were related to the effect of air abrasion and polishing to different positions, polishing showed a tendency to remove more DBA from the top of the dentinal crest, while air abrasion tended to remove less DBA from the corners of the dentinal ridge of the preparation. Both treatments did not remove the entire thickness of the DBA in the majority of the cases, and overall, the precured adhesive was maintained despite cleaning with air abrasion or polishing. Nevertheless, emphasis should be given to the fact that, in this study, a glycerine gel was used in order to polymerize the oxygen-inhibited layer; a step that, until proven otherwise, seems to be mandatory in order to avoid more exposure of dentin at later stages, during cleaning of the adhesive interface with either air abrasion or polishing. Taking into consideration all of the above, OptiBond FL treated with air abrasion seems to be more appropriate than Syntac for "immediate dentin sealing," as it produced a more uniform thickness of DBA, which was also visibly detectable, a fact that made easier the evaluation of the DBA during placement, as well as after surface cleaning prior to final cementation.

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