Adhesion of resin cement to dentin: effects of adhesive promoters, immediate dentin sealing strategies, and surface conditioning

Carline RG van den Breemer, DDS, MSc
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands

Mutlu Özcan, DDS, PhD
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands
University of Zurich, Dental Materials Unit, Center for Dental and Oral Medicine,
Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, Zurich, Switzerland

Margot RE Pols, DDS, MSc
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands

Anique R Postema, DDS, MSc
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands

Marco S Cune, DDS, PhD
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands
St Antonius Hospital Nieuwegein, Department of Oral-Maxillofacial Surgery, Prosthodontics
and Special Dental Care, Nieuwegein, The Netherlands
Univeristy Medical Center Utrecht, Department of Oral-Maxillofacial Surgery, Prosthodontics
and Special Care, Nieuwegein, The Netherlands

Marco MM Gresnigt, DDS, PhD
University of Groningen, University Medical Center Groningen, Center for Dentistry
and Oral Hygiene, Department of Fixed and Removable Prosthodontics and Biomaterials,
Groningen, The Netherlands

Correspondence to: **Dr Carline RG van den Breemer**
University of Groningen, University Medical Center Groningen, Centre for Dentistry and Oral Hygiene, Antonius Deusinglaan 1,
Groningen, 9713, AV, The Netherlands; Tel: +31 50 363 2608; Email: c.r.g.van.den.breemer@umcg

Abstract

Purpose: This study evaluated the shear bond strength (SBS) of resin cement to dentin after applying two adhesive (A) systems with a combination of four different immediate dentin sealing (IDS) strategies, and two surface conditioning (SC) methods.
Material and methods: Human third molars (n = 140) were collected and randomly split (n = 70 each) between the two A systems (Clearfil SE Bond; Kuraray [AC] and Optibond FL; Kerr [AO]). The A groups were further divided into four IDS strategies (2 x one adhesive layer (IDS-1L); 2 x two adhesive layers (IDS-2L); 2 x one adhesive layer and one flowable layer (IDS-F); 2 x no adhesive layer (delayed dentin sealing [DDS]). Finally, each strategy group was categorized into one of the two SC methods (only pumice [SC-P] or pumice and silica coating [SC-PS]), except the DDS group, where only SC-P was used. This resulted in 14 groups of 10 specimens each. The occlusal coronal third was removed from each molar crown with a diamond saw (Isomet 1000), and IDS was applied, followed by temporary restorations. These were removed after 2 weeks of water storage, and the IDS surfaces were subsequently conditioned. The standard adhesive procedure (Syntac Primer and Adhesive, Heliobond; Ivoclar Vivadent) was executed, followed by the application of a resin cement (Variolink II; Ivoclar Vivadent) and photopolymerization. All specimens were subjected to thermocyclic aging (10,000 cycles, 5°C to 55°C). Shear force was applied to the adhesive interface in a universal testing machine (1 mm/min). Fracture types and locations after loading were classified. The data were analyzed using analysis of variance (ANOVA) and independent samples t tests.
Results: AO groups exhibited higher mean SBS values (14.4 $\pm$ 6.43) than AC groups (12.85 $\pm$ 4.97) (P = 0.03). ANOVA showed the main effect of the applications on the SBS in the different groups (P = 0.00). Both DDS groups showed significantly lower SBS values compared with all the IDS groups (IDS-1L, IDS-2L, IDS-F). No significant differences in SBS results were found between the IDS groups (P = 0.43) and between the SC methods (P = 0.76). Dentin–cement interface failures diminished with the application of IDS.
Conclusion: IDS improves the SBS compared with DDS. No significant differences were found between the tested conditioning methods.
(Int J Esthet Dent 2019;14:52–63)
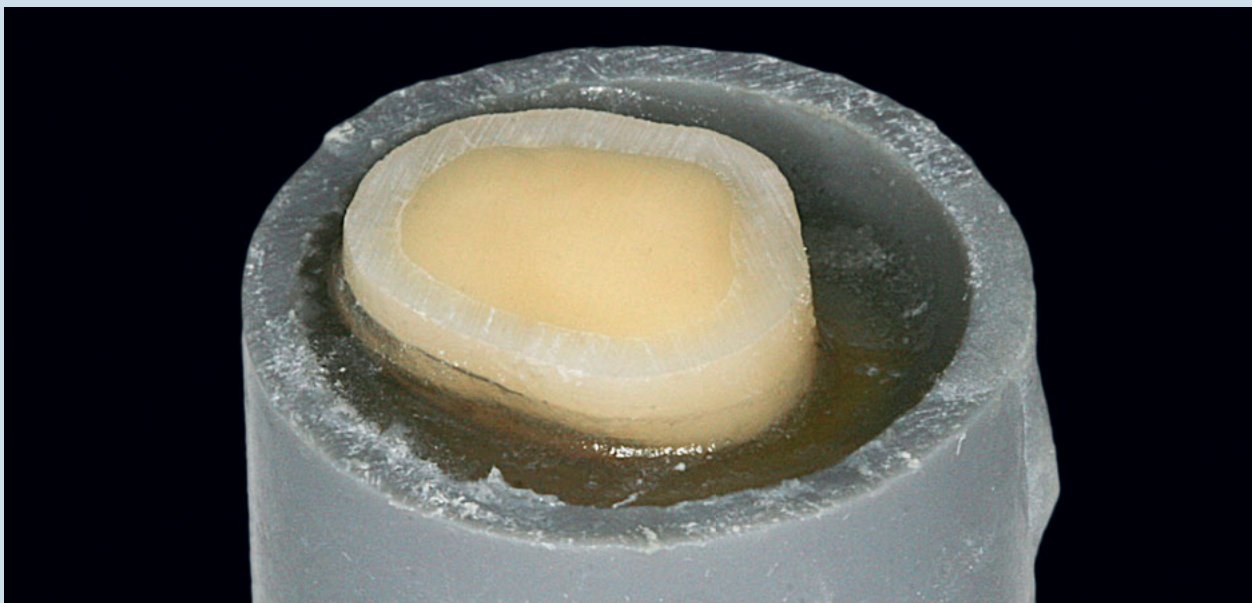
Introduction

The use of glass-ceramics in combination with micromechanical and chemical adhesion to dentin facilitates minimally invasive preparation procedures. Good adhesion to dentin and enamel is especially important when bonding partial ceramic restorations. A component of the overall strength of the tooth–restoration complex relies on the quantity and quality of the remaining enamel,[1] and the quality of the adhesive procedure.[2]

Pashley et al[3] postulated that sealing the dentin with a dentin bonding agent immediately after preparation reduces the permeability of the dentin, both in the short and long term. This technique has evolved into what is now known as immediate dentin sealing (IDS).[3,4] It improves bond strength as well as the marginal and internal adaptation of the restoration and reduces postoperative sensitivity.[2,4,5-11] In vitro studies obtained higher bond strength to dentin using IDS (16.34 to 19.04 MPa) compared with delayed dentin sealing (DDS) (0.26 to 14.90 MPa).[12] With the IDS method, maturation of the adhesive interface is possible between the two patient visits (visit 1: tooth preparation/impression; visit 2: restoration delivery). Therefore, the tensile stress on the hybrid layer is postponed for several weeks.[2,5,10] This is different from the DDS method, where the hybrid layer is applied in the second patient visit, and is then immediately loaded on the adhesive surface, possibly resulting in shrinkage that negatively influences the tensile stress. Polymerization of the dentin bonding agent prior to cementation ensures a hybrid layer that is not influenced by stress exerted during cementation.[5,7,9,10] The hybrid layer discourages contamination and denaturation of the dentin until the indirect restoration is seated.[7]

The three-step etch-and-rinse system is seen as the gold standard among adhesive systems, but there is a quest for simpler and less time-consuming techniques.[13] The etching step is omitted with self-etch adhesives, which is considered more user-friendly and less technique-sensitive, and also has a good clinical track record.[13-15] The quality of the bond and the bond strength to dentin can be increased by applying more than one adhesive layer.[1-19] The application of a flowable layer on the adhesive layer also improves adhesive strength (20.8 MPa and 27.2 MPa, compared with 10.5 MPa and 17.7 MPa without flowable composite).[20]

Different surface conditioning methods can be used to reactivate the IDS layer prior to bonding the indirect restoration, which can influence the IDS bond strength.[21-23] Polishing and airborne particle abrasion with silica-coated aluminum oxide or glycine proved to be equally efficient.[24] Airborne particle abrasion with both aluminum oxide and fluoride-free pumice paste systems[6,8,25,26] also yielded good results with respect to bond strength. However, it is unknown which method is most suitable for conditioning the sealed dentin surface.

The objective of this study, therefore, was to compare the effect of different adhesive systems, different IDS application methods, and different surface conditioning methods on the shear bond strength (SBS) to dentin. Three hypotheses were tested: 1) There is no significant difference in effect between the different adhesive systems on SBS; 2) There is no significant difference in the outcome of the IDS strategies regarding SBS; and 3) SBS is not significantly affected by different surface conditioning methods.

Materials and methods

Study design

Three independent variables were tested in this study: Adhesive (A) systems, IDS strategies, and surface conditioning (SC) methods. A total of 140 sound human molars
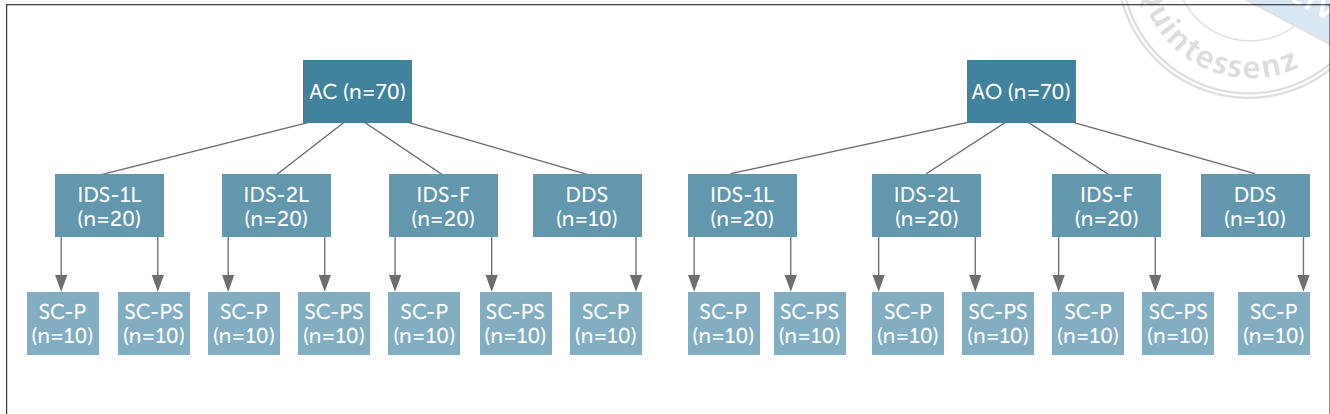
Fig 1 Experimental flowchart showing distribution of groups. (AC: Clearfil SE Bond; AO: Optibond FL; IDS: immediate dentin sealing; DDS: delayed dentin sealing; IDS-1L: one adhesive layer; IDS-2L: two adhesive layers; IDS-F: one adhesive layer and one flowable layer; DDS: no adhesive layer; SC-P: pumice; SC-PS: pumice and silica coating.)

were randomly divided into 14 groups of 10 teeth each. These were subjected to the following experimental protocols:

1. Two adhesive (A) systems (AC: Clearfil SE Bond [Kuraray], and AO: Optibond FL [Kerr]).
2. Four different IDS strategies (one adhesive layer [IDS-1L]; two adhesive layers [IDS-2L]; one adhesive layer and one flowable layer [IDS-F]; no adhesive layer [DDS]).
3. Two different SC methods (only pumice [SC-P]; pumice and silica coating [SC-PS]).

Only SC-P was used in the DDS group because the IDS did not have to be activated; only the temporary cement had to be removed (leading to 14 groups instead of 16).

A flowchart showing the experimental group distribution is presented in Figure 1.

Specimen preparation

Recently extracted, sound human molars (n = 140) were collected, stored in water, and used a maximum of 1 month post-extraction. Each specimen was embedded
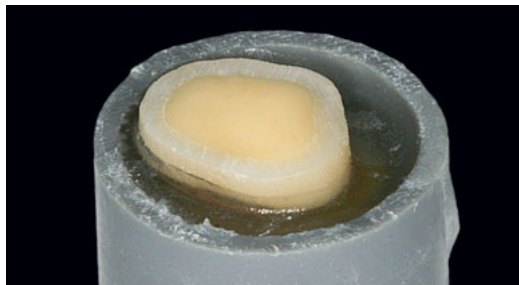
Fig 2 Situation before testing. Tooth embedded in PMMA in a PVC ring. The occlusal coronal third of the crown is removed, thereby exposing a flat dentin surface.

in polymethylmethacrylate (PMMA) in a polyvinylchloride (PVC) ring to facilitate handling and for the seating in the universal testing machine. The occlusal coronal third of the crown was removed with a diamond saw (Isomet 1000; Buehler), thereby exposing a flat dentin surface (Fig 2). The dentin surfaces were polished using Sof-Lex discs (course and medium) (3M ESPE), and verified for the absence of enamel and/or pulp tissue exposition using a stereomicroscope (magnification x35; Wild M5A).

IDS

The brands, types, main chemical compositions, manufacturers, and batch numbers of products used in this study are shown in Table 1.

Table 1 Brands, types, manufacturers, main chemical composition, and batch numbers of products used in this study

Product	Type	Manufacturer	Composition	Batch number
Optibond FL	Adhesive resin	Kerr; Orange, CA, USA	Primer: HEMA, GPDM, PAMM, ethanol, water, photoinitiator Adhesive: TEGDMA, UDMA, GPDM, HEMA, bis-GMA, filler, photoinitiator	3661962
Clearfil SE Bond	Adhesive resin	Kuraray; Osaka, Japan	Primer: HEMA, hydrophilic dimethacrylate, water, photoinitiator Adhesive: MDP, HEMA, bis-GMA, hydrophilic dimethacrylate, water, photoinitiator, silanated colloidal silica	041872
Grandio Flow	Flowable composite	VOCO GmbH; Cuxhaven, Germany	1.6-hexanediylbismethacrylate, BIS GMA, triethylene glycol dimethacrylate	1105070
Liquid Strip	Glycerin gel	Ivoclar Vivadent; Schaan, Liechtenstein	Glycerin gel	
Temp-Bond NE	Zinc-oxide cement	Kerr; Scafati Salermo, Italy	Zinc oxide, mineral oil	3498437 53498433
CoJet Sand	Blasting particles	3M ESPE; St Paul, Minnesota, USA	Aluminum trioxide particles coated with silica, particle size: 30 μm	442859 459719
ESPE Sil	Silane coupling agent	3M ESPE; Seefeld, Germany	Ethyl alcohol, methacryloxypropyl trimethoxysilane	437637
Pumice	Pumice sand	Denteck; Zoetermeer, The Netherlands	Microvesicular glass, silica	
Total Etch	Etching gel, 37% phosphoric acid	Ivoclar Vivadent	37% phosphoric acid (H3PO4)	P14739 P30006 P10807
Syntac Primer	Adhesive resin	Ivoclar Vivadent	Water, acetone, maleic acid, dimethacrylate	P17329
Syntac Adhesive	Adhesive resin	Ivoclar Vivadent	water, glutaraldehyde, maleic acid, polyethylene glycol dimethacrylate	P15364
Heliobond	Adhesive resin	Ivoclar Vivadent	Bis-GMA, dimethacrylate, initiators, stabilizers	P06157
Variolink II base	Adhesive cement	Ivoclar Vivadent	Base: Bis-GMA, urethane dimethacrylate, triethylene glycol dimethacrylate, barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, spheroid mixed oxide, catalysts, stabilizers, pigments Catalyst: Bis-GMA, urethane dimethacrylate, triethylene glycol dimethacrylate, barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, spheroid mixed oxide, catalysts, stabilizers, pigments	N53690 N23645 M54620 N31040

In the AC + IDS-1L groups, primer (Clearfil SE Bond) was applied onto the dentin for 20 s and air dried. A thin layer of adhesive (Clearfil SE Bond) was applied by a light brushing motion, gently air dried, and photopolymerized (Bluephase 20i; Ivoclar Vivadent) for 10 s (1000 mW/cm^2) (Fig 3). The AC + IDS-2L groups received the same initial procedure as the AC + IDS-1L groups, except that an additional layer of adhesive was applied, which was photopolymerized separately. The AC + IDS-F groups also received the same initial procedure as the AC + IDS-1L groups, but then a flowable composite (Grandio Flow; Voco) was administered after adhesive application, followed by photopolymerization. To prevent the formation of an oxygen inhibition layer, glycerin gel (Liquid Strip; Ivoclar Vivadent) was applied after the last photopolymerized layer, and this was finally photopolymerized for another 40 s in all groups. The dentin was not sealed in the AC + DDS group.

Regarding the AO + IDS-1L groups, the dentin was etched for 15 s with 37% phosphoric acid (Total Etch; Ivoclar Vivadent), then rinsed thoroughly with water and air for 15 s. The surface was air dried, but not desiccated, for 3 s, and primer (Optibond FL Primer) was applied with a light brushing motion for 15 s, withdrawn for 10 s, and suction dried for 15 s. A thin layer of adhesive (Optibond FL Adhesive) was applied onto the surface using a light brushing motion for 15 s, and photopolymerized for 10 s (1000 mW/cm^2). The AO + IDS-2L groups were subjected to the same procedure as the AO + IDS-1L groups, except that a second layer of adhesive was applied, which was photopolymerized separately. The AO + IDS-F groups also underwent the same initial procedure as the AO + IDS-1L groups, but then a flowable composite (Grandio Flow) was applied after adhesive application, followed by photopolymerization. To prevent the formation of an oxygen inhibi-
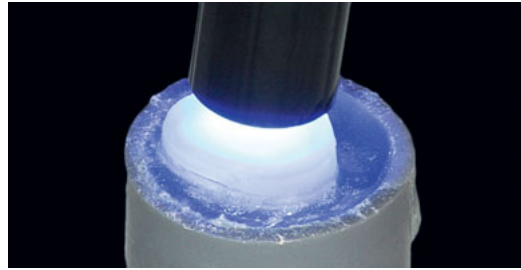
Fig 3 Situation before testing. Photopolymerization of the adhesive layer as part of the application of the IDS layer.
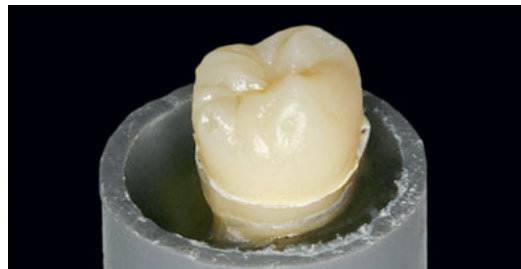
Fig 4 Situation before testing. A temporary restoration is luted onto the flat dentin surface before storage.

tion layer, glycerin gel (Liquid Strip) was applied after the last photopolymerized layer, and this was finally photopolymerized for another 40 s in all groups. The dentin was not sealed in the AO + DDS group.

Temporary restoration

After the IDS application, a temporary restoration (Protemp 4; 3M ESPE) was luted onto the flat dentin surface using a temporary zinc-oxide luting cement (Temp-Bond NE; Kerr) (Fig 4). The specimens were stored in water at room temperature for 2 weeks.
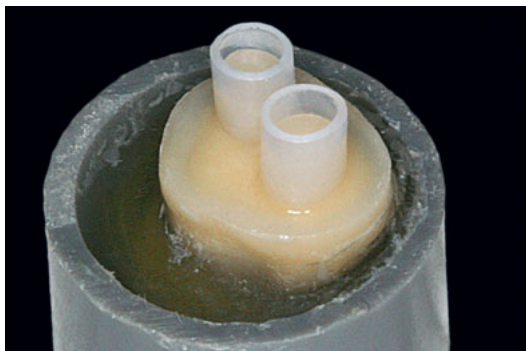
Surface conditioning and build up

The temporary restorations were removed after 2 weeks.

The teeth in the SC-P groups were cleaned using pumice (Pumice Sand; Denteck). The pumice was manually constituted with two small scoops of pumice into a dappen glass with a small amount of water. Any redundant water was removed from the dappen glass with a cotton roll. The pumice was then applied with a rotary brush for 10 s. The teeth in the SC-PS groups were

conditioned using pumice and silica coating (distance 10 mm, angle 45 degrees, 2 bar, CoJet Sand, SiO_2; 3M ESPE). In the DDS groups, SC-P was used to remove the temporary cement.

All specimens were rinsed thoroughly with water and air dried for 15 s. In the SC-PS group, silane (silane coupling agent, ESPE Sil; 3M ESPE) was applied (according to the Özcan et al[36] method) onto the IDS surfaces and left to dry for 5 min.

Primer (Syntac Primer; Ivoclar Vivadent) was then brushed lightly onto all specimens for 15 s and slightly air dried. A thin layer of adhesive (Syntac Adhesive; Ivoclar Vivadent) was applied onto the surface with light brushing motions for 10 s and slightly air dried. Another layer of adhesive (Heliobond; Ivoclar Vivadent) was brushed onto the dentin and not light cured. Two plastic tubes (diameter 3 mm, height 5 mm) filled with composite cement (Variolink II; Ivoclar Vivadent) were placed onto the dentin, and glycerin gel (Liquid Strip) was applied around the tubes to prevent the formation of an oxygen inhibited layer, after which the composite was photopolymerized from all angles for 40 s ($1000mW/cm^2$) (Fig 5).

SBS testing

All the specimens were artificially aged by thermocycling (Willitec): x10,000 cycles between 5°C to 55°C with a dwell time of 30 s.

The specimens were subsequently mounted in a universal testing machine (1 mm/min). The maximum shear force to produce a fracture was recorded (MPa). Specimens that failed before actual testing (pretesting failure) were counted and explicitly noted, which meant they were taken into account when calculating the mean SBS.

Failure analysis

Failure sites were initially observed using an optical microscope (OPMI pico; Zeiss) at x24 magnification and classified as follows: D (fracture in dentin), DC (fracture interface dentin and cement), DI (fracture interface dentin and IDS), IC (fracture interface IDS and cement), and C (fracture in the cement). Additionally, representative specimens from each group were sputter-coated with a 3-nm layer of gold (80%)/palladium (20%) (90 s, 45 mA; Balzers SCD 030; Balzars) and analyzed using cold field emission scanning electron microscope (SEM) (LEO 440; Electron Microscopy Ltd).

Statistical analyses

Data were analyzed using the SPSS 22 (PASW statistics 18.0.3; Quarry Bay) statistical software package. As the data were normally distributed, parametrical tests were applied to find possible differences between the groups in terms of A (AC; AO) systems (independent-samples t test), IDS strategies (IDS-1L; IDS-2L; IDS-F; DDS) (ANOVA, Student-Newman-Keuls), and SC methods (SC-P; SC-PS) (independent-samples t test) on SBS results.

SBS testing

Disregarding the subgroups, the AC specimens (M = 12.85, SD = 4.97) exhibited lower mean SBS values than the AO specimens (M = 14.4, SD = 6.43, independent-samples
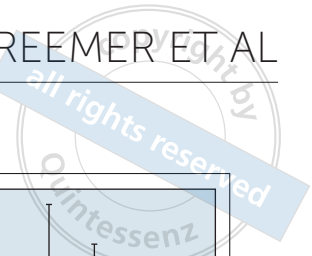
t test, t (256) = 2.23, *P* = 0.03). Analysis of variance (ANOVA) showed the main effect of the different applications on the SBS F(13, 261) = 14.02, *P* = 0.00). Group AC + DDS + SC-P resulted in the lowest SBS, followed by group AO + DDS + SC-P (Student-Newman-Keuls tests). The DDS groups exhibited significantly lower mean SBS values compared with the IDS groups (IDS-1L, IDS-2L, IDS-F). The difference in SBS values among the IDS groups were not statistically significant (Student-Newman-Keuls tests, *P* = 0.43) (Fig 6; Table 2). No significant differences were observed between the SC-P (M = 15.15, SD = 4.99) and SC-PC specimens (M = 14.97, SD = 4.43, independent-samples *t* test, t (233) = 0.30, *P* = 0.76).
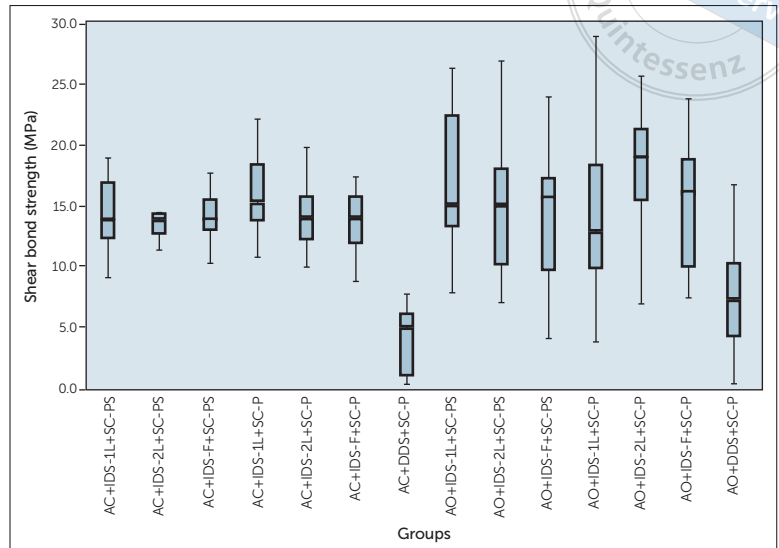

Fig 6 Boxplot of the SBS (MPa) per group. (AC: Clearfil SE Bond; AO: Optibond FL; IDS: immediate dentin sealing; DDS: delayed dentin sealing; IDS-1L: one adhesive layer; IDS-2L: two adhesive layers; IDS-F: one adhesive layer and one flowable layer; DDS: no adhesive layer; SC-P: pumice; SC-PS: pumice and silica coating.)

Table 2 Mean shear bond strength (MPa) with standard deviation (SD) for different groups

Groups	Shear bond strength (MPa)			
	Mean	**SD**	**Min**	**Max**
AC + IDS-1L + SC-PS	14.56	2.91	9.39	19.04
AC + IDS-2L + SC-PS	14.30	2.62	10.39	20.92
AC + IDS-F + SC-PS	14.50	2.17	10.29	19.08
AC + IDS-1L + SC-P	16.05	2.61	10.80	21.72
AC + IDS-2L + SC-P	13.68	4.07	3.13	21.49
AC + IDS-F + SC-P	13.95	3.01	9.01	21.91
AC + DDS + SC-P	3.09	2.46	0.00	6.98
AO + IDS-1L + SC-PS	17.04	5.95	7.63	26.58
AO + IDS-2L + SC-PS	14.91	5.83	6.13	27.43
AO + IDS-F + SC-PS	14.49	5.30	3.01	23.84
AO+ IDS-1L + SC-P	14.49	6.39	2.70	28.66
AO + IDS-2L + SC-P	17.13	6.82	3.37	25.76
AO + IDS-F + SC-P	15.58	5.08	7.44	24.32
AO + DDS + SC-P	7.35	4.57	0.00	16.67

(AC: Clearfil SE Bond; AO: Optibond FL; IDS: immediate dentin sealing; DDS: delayed dentin sealing; IDS-1L: one adhesive layer; IDS-2L: two adhesive layers; IDS-F: one adhesive layer and one flowable layer; DDS: no adhesive layer; SC-P: pumice; SC-PS: pumice and silica coating.)
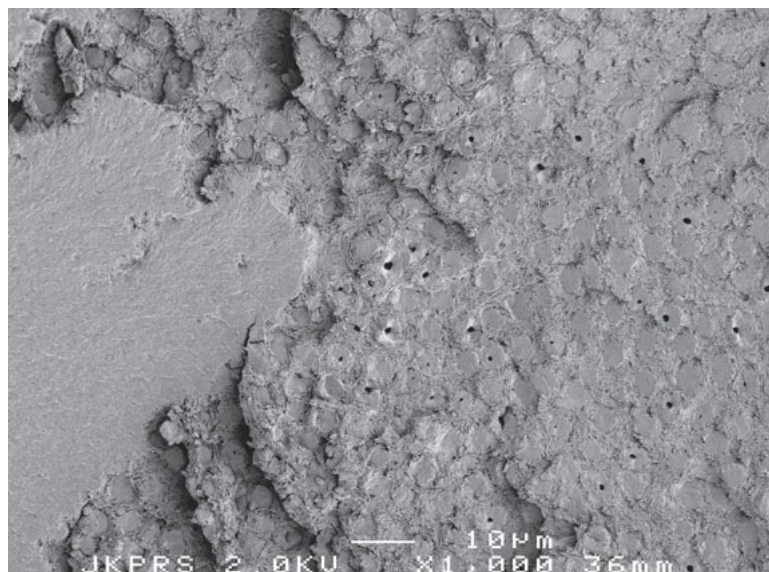
Fig 7 SEM image of adhesive fracture surface between dentin and the IDS layer interface. (D: dentin; I: immediate dentin sealing).

Failure analysis

Dentin–cement interface fractures were seen less frequently with the application of IDS (Table 3). Mainly cohesive failures occurred with AC (Fig 7), but there were hardly any failures in the cement. Regarding AO, the failures were mostly of an adhesive nature in the dentin–IDS interface. All the pretesting failures were in the DDS group.

Discussion

The survival rate of glass-ceramic posterior restorations relies heavily on the strength of the adhesive interface. The weakest link of the interface is the connection of the adhesive to dentin.[1,27,28] The application of an IDS

Table 3 Summary of failures (%)

Groups	D	DC	DI	IC	C	PTF
AC + IDS-1L + SC-PS	70	0	15	15	0	-
AC + IDS-2L + SC-PS	50	0	45	5	0	-
AC + IDS-F + SC-PS	40	0	15	45	0	-
AC+ IDS-1L + SC-P	50	0	50	0	0	-
AC + IDS-2L + SC-P	45	0	15	40	0	-
AC + IDS-F + SC-P	45	0	5	45	5	-
AC + DDS + SC-P	0	80	0	0	0	20
AO + IDS-1L + SC-PS	40	0	60	0	0	-
AO + IDS-2L + SC-PS	40	0	40	0	20	-
AO + IDS-F + SC-PS	20	0	55	5	20	-
AO + IDS-1L + SC-P	30	0	70	0	0	-
AO + IDS-2L + SC-P	30	0	25	15	30	-
AO + IDS-F + SC-P	33	0	6	44	17	-
AO + DDS + SC-P	0	90	0	0	0	10

D: cohesive failure in dentin; DC: dentin–cement failure; DI: dentin–IDS failure; IC: IDS–cement failure; C: cement failure; PTF: pretest failure.
(AC: Clearfil SE Bond; AO: Optibond FL; IDS: immediate dentin sealing; DDS: delayed dentin sealing; IDS-1L: one adhesive layer; IDS-2L: two adhesive layers; IDS-F: one adhesive layer and one flowable layer; DDS: no adhesive layer; SC-P: pumice; SC-PS: pumice and silica coating.)

layer onto freshly exposed dentin increases the bond strength to dentin,[29,30] especially when large dentin surfaces are exposed.[31]

Based on the results of the present study, the hypotheses suggesting that there is no significant difference in effect between the IDS application methods on SBS, and that there is no significant difference in the outcome of the different bonding systems regarding SBS, can both be rejected. The hypothesis that SBS is not statistically significantly affected by different surface conditioning methods can be accepted.

In general, it is very difficult to perform a 'true' SBS test; therefore, SBS is not very reliable.[32] Yet SBS is often used to describe differences between groups, and caution can be taken in the methodology to increase reliability. To avoid adhesive area modification during resin cement pouring in this study, tubes filled with resin cement were attached to the dentin and then photopolymerized. This was thought to overcome resin cement pouring.

The application of IDS in any form improved the SBS of composite cement to dentin. This result was also found in other studies.[2,4,5-9,10,11] Higher bond strength can be explained due to a better adhesion to freshly cut dentin[2-4] compared with dentin that is contaminated by temporary cement.[33] Polymerization of the IDS layer before impression taking prevents the hybrid layer from degradation[2,4,5] and allows it to mature without any tensile forces.[2] Other studies have demonstrated that the use of multiple adhesive layers[17,18] or the use of an extra layer of flowable composite[16,20] results in higher bond strengths. This contrasts with the results of the present study, which is perhaps due to the fact that filled adhesives were used in our study because unfilled adhesives need more layers to completely cover the dentin.[11,18] However, the bond strength results are better when specimens are not aged.[17] Most previous studies have refrained

from thermocycling or have performed thermocycling for only a minimum number of cycles.[2,5,6,9,10] There is a difference between the bond strength in the short and long term. The adhesive strength in the long term is significantly lower because degradation occurs within the adhesive interface.[34] Micromechanical retention is reduced by 30% to 40% in 6 to 12 months.[35] Since the results of the present study prove that the application of an IDS layer (in any form) results in better bond strength than with the use of DDS, our clinical recommendation is to use an extra adhesive layer or flowable composite to create a thick adhesive layer. In clinical practice, a thin IDS layer is more vulnerable when using silica coating, and the dentin may become re-exposed. This, in turn, will be detrimental to the bond strength. A thick IDS layer provides a smooth preparation in little chair time. It is also easier to eliminate undercuts.

The present study could not prove that one conditioning method was superior to another. Looking at the clinical application, the use of silica coating is recommended over the use of pumice. Cement residues are easier to remove using silica coating compared with pumice because, with sandblasting, it is easier to reach difficult parts of the preparation than it is with the use of a rotary brush in the application of pumice. Therefore, we recommend creating a thick IDS layer that is conditioned with silica coating because the clinical application is easier, not because of a higher bond strength. In the literature, silica coating in combination with silanization is often described as a better alternative to sandblasting only. Silica coating enlarges the adhesive surface area by depositing silica particles onto the composite surface, which enables better mechanical retention.[36] This is in contrast to sandblasting with alumina, where loss of filling particles may occur and thereby reduce the interaction with silane. This, in

turn, reduces the composite-to-composite bond strength.[37]

Optibond FL resulted in a significantly higher bond strength compared with Clearfil SE Bond; however, the standard deviation (SD) of Optibond FL is much higher. Clinically, this means that the consistency of Clearfil SE Bond is slightly better. Although less time-consuming techniques are popular,[13] the three-step etch-and-rinse system is seen as the gold standard in the literature[38-40] and in fact attained the highest bond strengths in the present study. Optibond FL is a filled adhesive resin with a uniform film thickness of around 88 μm.[11]

Fewer dentin–cement interface failures were seen with the application of IDS, but more failures were seen with the application of IDS in the dentin, the dentin–IDS interface, and the cement–IDS interface. The presence of cohesive failures in the dentin could indicate that the actual bond strength to dentin surpasses the maximal dentin strength and does not provide actual strength at the interface. Cohesive failures were not excluded from the failure analysis, and this may have influenced the results of our study. Failures in the substrate are seen more often in SBS studies because this test creates a non-homogenous stress distribution on the surface. This may lead to non-valid (worse) results.[41,42] In some of the control groups, the tubes detached sponta-neously during thermal cycling. This pretest failure could have been caused by insufficient dentin adhesion or technical malfunction. No pretest failures were described by studies on adhesion of resin cement to an IDS layer.[2,6-10]

Conclusions

The following can be concluded from this study:
1. Applying Optibond FL yields the highest SBS; however, Clearfil SE Bond showed a smaller SD.
2. IDS improves SBS, compared with the DDS strategy.
3. No significant differences were found on conditioning the IDS layer with pumice or silica coating.

Clinical relevance

When bonding a glass-ceramic partial indirect restoration, using an IDS layer improves the bond strength to exposed dentin. From the several methods tested to reactivate the IDS layer, no single procedure obtained superior SBS values.

Disclaimer

This study was fully supported by the authors' institution.

References

1. Dumfahrt H, Schäffer H. Porcelain laminate veneers. A retrospective evaluation after 1 to 10 years of service: Part II – clinical results. Int J Prosthodont 2000;13:9–18.
2. Magne P, Kim TH, Cascione D, Donovan TE. Immediate dentin sealing improves bond strength of indirect restorations. J Prosthet Dent 2005;94:511–519.
3. Pashley EL, Comer RW, Simpson MD, Horner JA, Pashley DH, Caughman WF. Dentin permeability: sealing the dentin in crown preparations. Oper Dent 1992;17: 13–20.
4. Paul SJ, Schärer P. The dual bonding technique: a modified method to improve adhesive luting procedures. Int J Periodontics Restorative Dent 1997;17:536–545.
5. Dietschi D, Monasevic M, Krejci I, Davidson C. Marginal and internal adaptation of class II restorations after immediate or delayed composite placement. J Dent 2002;30:259–269.
6. Duarte S Jr, de Freitas CR, Saad JR, Sadan A. The effect of immediate dentin sealing on the marginal adaptation and bond strengths of total-etch and self-etch adhesives. J Prosthet Dent 2009;102:1–9.
7. Lee JI, Park SH. The effect of three variables on shear bond strength when luting a resin inlay to dentin. Oper Dent 2009;34: 288–292.
8. Magne P. Immediate dentin sealing: a fundamental procedure for indirect bonded

restorations. J Esthet Restor Dent 2005;17: 144–154.

9. Magne P, Douglas WH. Porcelain veneers: dentin bonding optimization and biomimetic recovery of the crown. Int J Prosthodont 1999;12:111–121.

10. Magne P, So WS, Cascione D. Immediate dentin sealing supports delayed restoration placement. J Prosthet Dent 2007;98: 166–174.

11. Stavridakis MM, Krejci I, Magne P. Immediate dentin sealing of onlay preparations: thickness of pre-cured Dentin Bonding Agent and effect of surface cleaning. Oper Dent 2005;30:747–757.

12. Bertschinger C, Paul SJ, Lüthy H, Schärer P. Dual application of dentin bonding agents: effect on bond strength. Am J Dent 1996;9:115–119.

13. Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt KL. State of the art of self-etch adhesives. Dent Mater 2011;27:17–28.

14. Cardoso MV, de Almeida Neves A, Mine A, et al. Current aspects on bonding effectiveness and stability in adhesive dentistry. Aust Dent J 2011;56(suppl 1):31–44.

15. Peumans M, De Munck J, Van Landuyt KL, Poitevin A, Lambrechts P, Van Meerbeek B. Eight-year clinical evaluation of a 2-step self-etch adhesive with and without selective enamel etching. Dent Mater 2010;26: 1176–1184.

16. De Goes MF, Giannini M, Di Hipólito V, Carrilho MR, Daronch M, Rueggeberg FA. Microtensile bond strength of adhesive systems to dentin with or without application of an intermediate flowable resin layer. Braz Dent J 2008;19:51–56.

17. Hashimoto M, Sano H, Yoshida E, et al. Effects of multiple adhesive coatings on dentin bonding. Oper Dent 2004;29:416–423.

18. Ito S, Tay FR, Hashimoto M, et al. Effects of multiple coatings of two all-in-one adhesives on dentin bonding. J Adhes Dent 2005;7:133–141.

19. Pashley EL, Agee KA, Pashley DH, Tay FR. Effects of one versus two applications of an unfilled, all-in-one adhesive on dentine bonding. J Dent 2002;30:83–90.

20. Jayasooriya PR, Pereira PN, Nikaido T, Tagami J. Efficacy of a resin coating on bond strengths of resin cement to dentin. J Esthet Restor Dent 2003;15:105–113.

22. Amaral R, Ozcan M, Valandro LF, Balducci I, Bottino MA. Effect of conditioning methods on the microtensile bond strength of phosphate monomer-based cement on zirconia ceramic in dry and aged conditions. J Biomed Mater Res B Appl Biomater 2008;85:1–9.

22. Radovic I, Monticelli F, Goracci C, et al. The effect of sandblasting on adhesion of a dual-cured resin composite to methacrylic fiber posts: microtensile bond strength and SEM evaluation. J Dent 2007;35:496–502.

23. Sun R, Suansuwan N, Kilpatrick N, Swain M. Characterisation of tribochemically assisted bonding of composite resin to porcelain and metal. J Dent 2000;28:441–445.

24. Falkensammer F, Arnetzl GV, Wildburger A, Krall C, Freudenthaler J. Influence of different conditioning methods on immediate and delayed dentin sealing. J Prosthet Dent 2014;112:204–210.

25. Dagostin A, Ferrari M. Effect of resins sealing of dentin on the bond strength of ceramic restorations. Dent Mater 2002;18: 304–310.

26. Dillenburg AL, Soares CG, Paranhos MP, Spohr AM, Loguercio AD, Burnett LH Jr. Microtensile bond strength of prehybridized dentin: storage time and surface treatment effects. J Adhes Dent 2009;11:231–237.a

27. De Munck J, Van Landuyt K, Peumans M, et al. A critical review of the durability of adhesion to tooth tissue: methods and results. J Dent Res 2005;84:118–132.

28. Gresnigt MM, Cune MS, de Roos JG, Özcan M. Effect of immediate and delayed dentin sealing on the fracture strength, failure type and weilbull characteristics of lithiumdisilicate laminate veneers. Dent Mater 2016;32:e73–e81.

29. Kitasako Y, Burrow MF, Nikaido T, Tagami J. The influence of storage solution on dentin bond durability of resin cement. Dent Mater 2000;16:1–6.

30. Shono Y, Terashita M, Shimada J, et al. Durability of resin-dentin bonds. J Adhes Dent 1999;1:211–218.

31. Armstrong SR, Keller JC, Boyer DB. The influence of water storage and C-factor on the dentin-resin composite microtensile bond strength and debond pathway utilizing a filled and unfilled adhesive resin. Dent Mater 2001;17:268–276.

32. Tian T, Tsoi JK, Matinlinna JP, Burrow MF. Aspects of bonding between resin luting cements and glass ceramic materials. Dent Mater 2014;30:e147–e162.

33. Paul SJ, Schärer P. Effect of provisional cements on the bond strength of various adhesive bonding systems on dentine. J Oral Rehabil 1997;24:8–14.

34. Breschi L, Mazzoni A, Ruggeri A, Cadenaro M, Di Lenarda R, De Stefano Dorigo E. Dental adhesion review: aging and stability of the bonded interface. Dent Mater 2008;24:90–101.

35. Carrilho MR, Carvalho RM, Tay FR, Yiu C, Pashley DH. Durability of resin-dentin bonds related to water and oil storage. Am J Dent 2005;18:315–319.

36. Özcan M, Barbosa SH, Melo RM, Galhano GA, Bottino MA. Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dent Mater 2007;23: 1276–1282.

37. Rodrigues SA Jr, Ferracane JL, Della Bona A. Influence of surface treatments on the bond strength of repaired resin composite restorative materials. Dent Mater 2009;25:442–451.

38. De Munck J, Luehrs AK, Poitevin A, Van Ende A, Van Meerbeek B. Fracture toughness versus micro-tensile bond strength testing of adhesive-dentin interfaces. Dent Mater 2013;29:635–644.

39. De Munck J, Poitevin A, Lührs AK, et al. Interfacial fracture toughness of aged adhesive-dentin interfaces. Dent Mater 2015;31: 462–472.

40. Sarr M, Kane AW, Vreven J, et al. Microtensile bond strength and interfacial characterization of 11 contemporary adhesives bonded to bur-cut dentin. Oper Dent 2010;35:94–104.

41. DeHoff PH, Anusavice KJ, Wang Z. Three-dimensional finite element analysis of the shear bond test. Dent Mater 1995;11: 126–131.

42. Valandro LF, Ozcan M, Amaral R, Vanderlei A, Bottino MA. Effect of testing methods on the bond strength of resin to zirconia-alumina ceramic: microtensile versus shear test. Dent Mater J 2008;27: 849–855.