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Effect of Configuration Factor on Shear Bond Strengths of Self-etch Adhesive Systems to Ground Enamel and Dentin

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Clinical Relevance

Despite recent improvements in self-etch bonding systems, a two-step etch and rinse system gave consistently higher shear bond strengths to both ground enamel and dentin and would be the best system to use clinically.

SUMMARY

Self-etch bonding systems are easy to use and popular in dental practice. The current study examined the *in vitro* shear bond strengths to dentin and ground enamel of four self-etch bonding systems and a two-step etch-and-rinse bonding system. Two hundred extracted non-carious human molars were used. Approximately 0.5 mm of enamel was removed from the buccal surface of 100 teeth and the bond strengths of this enamel surface were determined. The buccal surface of the remaining 100 teeth was ground away to create a standardized smear layer on dentin. Five adhesive systems were used: Adper Single Bond Plus (ASB): two-step etch-and-rinse); Adper Scotchbond SE (AS), Clearfil SE Bond (CSE–both two-step self-etch); XENO V (X) and Adper Easy Bond (AE): both one-step self-etch). Filtek Z250 composite was bonded to the tooth using each adhesive system in a low configuration (C) factor (0.2) and a high C-factor (4.4) mold (10 teeth in each group). The specimens were thermal cycled 2,000x, then subjected to a shear bond strength test. The data were compared with analysis of variance using the Fisher's PLSD multiple comparison tests. A three-factor ANOVA showed that, overall, the shear bond strength was significantly higher in the low C-factor group 4.33 MPa (p<0.0001). There was also a significant difference in the shear bond strengths among the bonding systems (p<0.0001). The higher C-factor molds had the same adverse effect on all bonding systems and on both enamel and dentin, but the bonding systems acted differently on enamel and dentin (three-factor ANOVA p<0.0001). The two-step etch-and-rinse system (ASB) consistently delivered the highest bond strengths (34.6-41.5 MPa). Fisher's PLSD comparisons showed that, in the high C-factor mold, there was no significant difference

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between the shear bond strengths of SB, EB and CSE to dentin, and SB, X and SE to enamel (p>0.05). The one-step self-etch AE system delivered the lowest shear bond strengths (23.9 MPa) to enamel (p<0.05). The two-step self-etch system AS delivered the lowest shear bond strengths (23.9 MPa) to dentin (p<0.05).

INTRODUCTION

Two of the major reasons given for the failure and replacement of resin restorations are microleakage at the margins, followed by secondary caries.[1-3] This suggests that the adhesive bond between the tooth and the restoration has failed. Conventional etch-and-rinse adhesive systems require three steps: an acid conditioner, a dentin primer and a bonding resin. To complete these three steps can be both complicated and time-consuming. This has led to the introduction of simplified two-step bonding systems that use an acid etchant followed by a combined dentin primer and bonding agent. These systems have been reported to be clinically effective[4] and produce acceptable *in vitro* bond strengths.[5] Self-etch adhesive systems that eliminated the acid-etch step by combining the acid conditioner, primers and bonding resin into one or two steps were then introduced. This further simplifies and speeds-up the bonding procedure,[6] and good 10-year clinical results have been reported for some self-etching systems.[7-8] However, other studies have reported that these simplified adhesive systems do not always perform as well as two-step etch-and-rinse systems.[5-6,9-12]

When testing dental adhesives, most studies try to simulate clinical conditions. Some thermal cycle the specimens,[13-14] while others do not.[5-6,15] Some try to simulate intrapulpal pressure[16-17] and others use human teeth,[5,9,15,17-23] while some use bovine teeth.[13-14,24-28] To most accurately represent the tooth substrate, it is best to use the adhesives systems on human teeth,[29-30] but it has been reported that it is not necessary to simulate intrapulpal pressure.[17] Thermal cycling subjects the specimens to alternating temperatures that induce contraction and expansion stresses between the resin restoration and tooth.[31] This offers an accelerated method to test the durability of adhesive systems to tooth structure[24,31-32] and is recommended in the ISO #11405 standard.[33] Studies that have not subjected the specimens to thermal cycling may not have imparted sufficient stress between the resin restoration and the tooth to simulate the intra oral environment. Consequently, their results may not indicate performance of the adhesive in the mouth.

Previous studies to measure resin-dentin bond strengths have used a variety of molds. All of these molds can affect bond strength, physical properties of the cured resin composite and stress generated during resin polymerization. Also, the large, flat surfaces used in most laboratory bonding studies may overestimate the actual clinical bond strengths achieved.[20,34-36] Feilzer and others[37] reported that the ratio of the bonded to unbonded surfaces within the preparation, the configuration (C) factor, can be used to predict which restorations are most likely to exhibit bond failures between the resin and the tooth (Figure 1). According to Feilzer and others,[37] restorations with a C-factor less than one are more likely to survive polymerization contraction stresses and remain bonded to the tooth. This may be a problem, because Class I preparations have a mean C-factor of 4.03 and Class II preparations have a mean C-factor of 1.85.[38] The negative effect of C-factor is supported by He and others,[25] who reported that bulk filling a cavity with a C-factor of five produced the lowest bond strength and more microleakage has been reported as the C-factor increases.[28,39] An *in vivo* study has also reported that the resin-dentin interdiffusion zone was detached from the overlying resin in restorations with a C-factor of five.[18]

In most bonding studies, the resin composite is bonded to the tooth at the bottom of the mold only, not to the sides. This results in a C-factor less than one and imparts little stress on the bond to the tooth as the resin polymerizes.[37] If the resin composite can be bonded to the walls of the mold,[20,26] as occurs in a tooth, this might provide a more clinically relevant test of bond strength.[35,40-41] Additionally, if the mold is made of resin

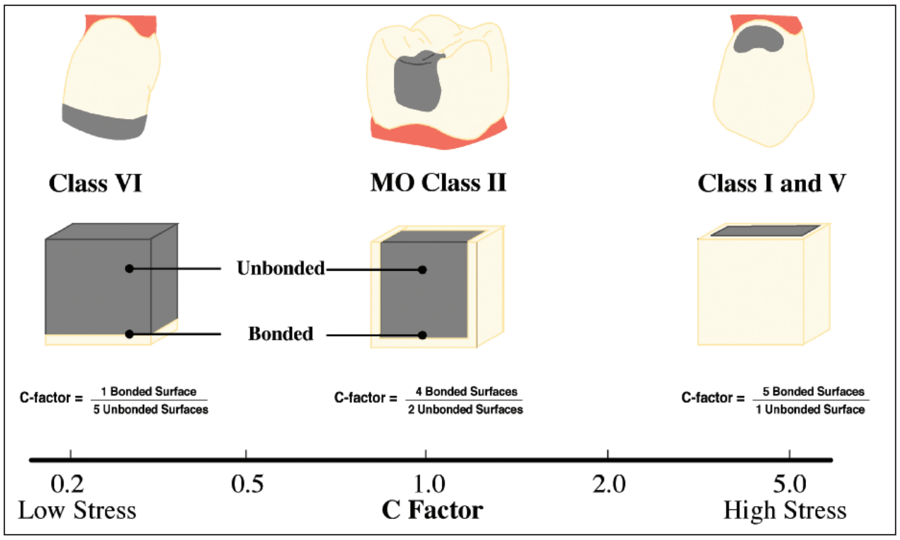

Figure 1. *Examples of how the C-factor changes with different preparation designs (modified after Feilzer & others[37]).*

composite, then a similar amount of light should reach the sides and bottom of the specimen, as would occur in a tooth.[42]

Recently, 3M ESPE (St Paul, MN, USA) introduced new one- and two-step self-etching bonding systems and Dentsply (Milford, DE, USA) introduced a new version of their XENO V self-etching bonding system. The current study determined whether there was any difference in the *in vitro* shear bond strengths to dentin and ground enamel of five brands of adhesive systems (four self-etch and one phosphoric etch-and-rinse one-bottle system) under simulated clinical conditions (with thermal cycling and a high configuration factor). The null hypotheses tested were that: 1) the configuration factor would not significantly affect the shear bond strengths of the adhesive systems and 2) there would be no significant difference between the shear bond strengths produced by the adhesive systems.

METHODS AND MATERIALS

Following appropriate University Human Research Ethics Board approval, 200 extracted human molars were collected and stored in 0.5% w/v Chloramine-T-Hydrate (Aldrich Chemical Co, Milwaukee, WI, USA) at 6°C prior to their use. The teeth were thoroughly washed in water for seven days and then mounted in acrylic tray resin (Trayresin, Dentsply International Inc, York, PA, USA). The buccal enamel surface of 100 teeth was ground by approximately 0.5 mm using 600 grit silicon carbide papers and copious water coolant. The enamel bond strengths were tested on this ground enamel surface. The buccal surface of the other 100 teeth was removed using a sequence of 120, 240, 400 and 600 grit silicon carbide papers with copious water coolant to approximately halfway between the dento-enamel junction and the pulp. This location was thought to most accurately represent the depth of a typical cavity preparation. Rubbing the exposed dentin on wet 600-grit silicon carbon paper just before bonding created a standardized smear layer. The teeth were rinsed with distilled water to remove any debris. Following preparation, the specimens were coded, randomly assigned into each group and stored in water at 37° ± 1°C.

Mold Design for High and Low Configuration Factors

The current study measured the shear bond strengths of specimens made in molds with low and high configuration (C) factors. A commonly used bonding jig, Ultradent (Ultradent Products Inc, South Jordan, UT, USA),[19,43] was used to produce conditions with a low C-factor. Resin composite molds[20] were used to produce bonding conditions with a C-factor of 4.4 to simulate filling a Class V or a Class I cavity.[38] The 2-mm deep circular ring molds were made from an impression of a 2.1-mm long glass tube that had a 2.4-mm internal diameter. After the impression material had set, the glass tube was removed and this mold was filled with flowable resin composite (Filtek Supreme Plus flowable, Shade A2, 3M ESPE). The flowable composite ring was irradiated for 360 seconds using a halogen curing light (Optilux 501, Demetron/Kerr, Danbury, CT, USA). The composite ring was then removed from the mold and the length of the ring was adjusted to 2.0 mm using 240 grit silicon carbide paper. The internal surface of the resin composite was cleaned and each ring mold was checked with a digital caliper to verify that it had an internal diameter of 2.4 mm and was 2.0 mm deep. The molds were then randomly assigned to each group. The C-factors were calculated using the following formula:

LOW C FACTOR MOLD C=0.2

$$C= \frac{\text{bonded area of composite}}{\text{unbonded area of composite}}$$

$$C= \frac{\text{area of one end bonded to dentin}}{\text{circumference of ring mold x depth + area of one unbonded end}}$$

$$C = \frac{4.337}{14.765 + 4.337} = 0.23$$

HIGH C FACTOR MOLD C=4.4

$$C= \frac{\text{bonded area of composite}}{\text{unbonded area of composite}}$$

$$C = \frac{\text{circumference of ring mold x depth + area of one end bonded to dentin}}{\text{area of one unbonded end}}$$

$$C = \frac{14.765 + 4.337}{4.337} = 4.4$$

Polyester Hi Solvent Resistance Transparent tape (3M Product #853) was stuck around the bottom of each ring to prevent the composite ring from bonding to the tooth. Figure 2 illustrates how the resin composite ring was clamped to the tooth surface.

Each adhesive system was used on 40 teeth under the four conditions (low C-factor dentin, high C-factor dentin, low C-factor enamel, high C-factor enamel), with 10 teeth in each group.

Five different dentin-bonding systems were tested (Table 1). Each bonding system was used in accordance with the manufacturer's instructions (Table 2) on dentin or on ground enamel in a predetermined ran-

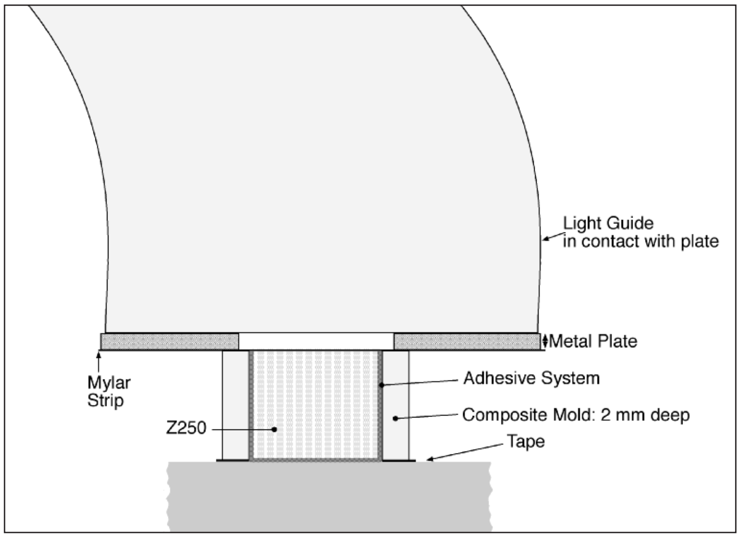

Figure 2. *Schematic showing how a cylindrical resin composite mold was used to make a mold with a C factor of 4.4.*

domized sequence. After the adhesive system had been applied, 2 mm of Filtek Z250 resin composite (3M ESPE, Shade A2) was incrementally packed into the mold and cured in one increment from the top of the mold for 40 seconds with a halogen light (Optilux 501, Demetron/Kerr) equipped with a 13/8 Turbo plus light guide. This 2-mm thick composite was within the manufacturer's recommended maximum thickness for Filtek Z250 (3M ESPE) shade A2, which can be adequately light cured in 40 seconds.[44] The resultant composite specimen bonded to the teeth was the same 2.4 mm diameter and 2 mm height in the low and high C-factor molds.

All the specimens were placed into a 37°C water bath for 24 hours. They were then thermal cycled for 2,000 cycles from 5°C to 55°C with a 30-second dwell time and a 30-second travel time in air temperature of ~21°C. After thermal cycling, they were placed back into the 37°C water bath for 24 hours. Approximately five days elapsed between preparing the specimens and when they were all debonded using a universal testing machine (Instron 1000, Instron, Norwood, MA, USA) using a 0.8-mm thick blade at a crosshead speed of 1.0 mm/minute.[5,9,25] The shear bond strength values (MPa) were calculated from the peak load at failure divided by the surface area of the specimen.

The shear bond strength data for each group were subjected to analysis of variance (ANOVA) and Fisher's post-hoc multiple comparison tests at a significance level of *p*=0.05.

RESULTS

The effect of the high and low configuration factor on the shear bond strength to enamel is shown in Figure 3 and to dentin in Figure 4. Table 3 shows the results of the overall three-factor ANOVA to determine the effects of surface

Table 1: *Products, Lot Numbers and Manufacturers*

Products	Lot #	Manufacturer
Filtek Z250 Shade A2 Composite	7XC	3M ESPE
Adper Single Bond Plus Two-step total-etch adhesive	249352 265599	3M ESPE 3M ESPE
Adper Scotchbond SE Two-step self-etch adhesive	Liquid A–AG Liquid B–AJ	3M ESPE
Clearfil SE Bond Two-step self-etch adhesive	61733 61740	Kuraray Medical Inc Kuraray Medical Inc
XENO V One-step self-etch adhesive	0704000723	Dentsply
Adper Easy Bond One-step self-etch adhesive	P-0304	3M ESPE

Table 2: *Application Protocols for Adhesive Systems Used in The Current Study*

Adhesive System	Application Protocol
3M ESPE Adper Single Bond Plus	Etch: Apply Scotchbond Etchant to enamel and dentin. Wait 15 seconds. Rinse for 10 seconds. Blot excess water. Do not air dry. The surface should appear glistening without pooling of water. Adhesive: Apply three coats of adhesive for 15 seconds with gentle agitation using a fully saturated brush. Gently air thin for five seconds. Light-cure for 10 seconds.
3M ESPE Adper Scotchbond SE	Lightly dry the tooth. Apply liquid A to the entire bonding surface with brush to obtain a continuous red color. With a new brush, apply liquid B and scrub into the entire wetted surface of the bonding area with moderate finger pressure for 20 seconds. Air dry thoroughly for 10 seconds. Apply a second coat of liquid B and lightly thin the adhesive layer. Light cure for 10 seconds.
Kuraray Clearfil SE Bond	Gently rub in primer for 20 seconds. Dry with mild air flow. Apply bond and air thin with a gentle stream of air to make bond film as uniform as possible. Light cure for 10 seconds.
XENO V	Apply two coats to a moist tooth surface, wetting all bonding surfaces uniformly with each application, then gently agitate the adhesive for 20 seconds. Air thin with a gentle stream of air for five seconds. Light cure for 20 seconds.
3M ESPE Adper Easy Bond	Apply the adhesive for 20 seconds. Air thin the adhesive for five seconds until the film no longer moves. Light cure for 10 seconds.

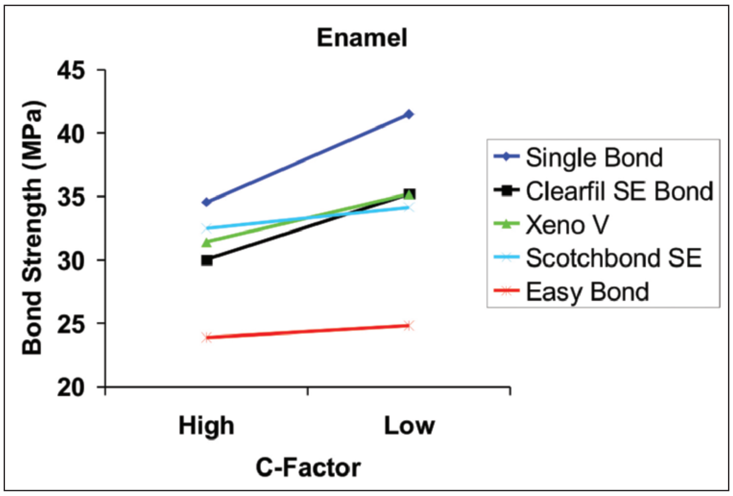

Figure 3. *Effect of C-factor on the shear bond strengths to enamel.*

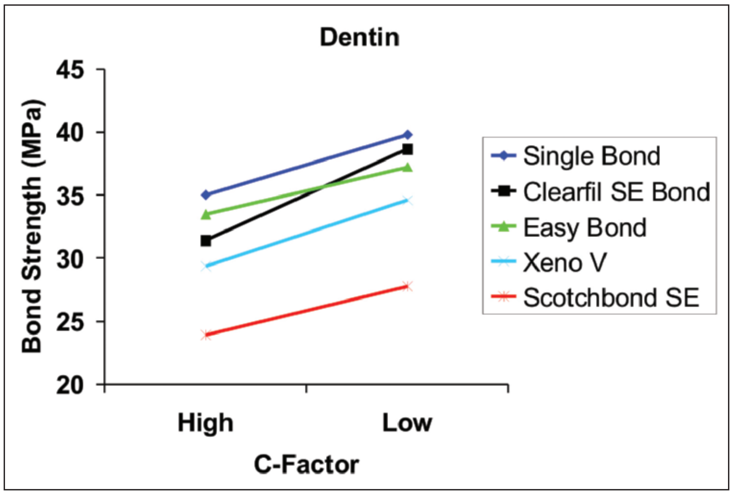

Figure 4. *Effect of C-factor on the shear bond strengths to dentin.*

(enamel or dentin), C-factor and bonding system on the shear bond strength. The effect of the C-factor and the bonding system were highly significant. Overall, specimens made in the low C-factor mold produced a 4.3 MPa greater bond strength ($p<0.0001$). The null hypothesis that the configuration factor would have no effect was rejected.

Figures 3 and 4 and Table 3 show that the higher C-factor molds had the same adverse effect on all bonding systems on both enamel and dentin, but the bonding systems acted differently on enamel and dentin (three-factor ANOVA $p<0.0001$). ANOVA showed that there was a significant difference among the bond strengths of the five adhesive systems. The null hypothesis that there would be no difference in the bond strengths achieved using the five bonding systems to ground enamel and dentin was also rejected.

Since enamel and dentin are different structures, the authors of the current study looked at the effects on enamel and dentin separately. The mean bond strengths to enamel ranged from 23.9 to 41.5 MPa. Table 4 shows that there was a significant difference in the shear bond strengths to enamel among the different bonding systems and that the C-factor had an effect. Since there was no significant interaction between the different bonding systems and the C-factor (two-factor ANOVA $p=0.109$), all of the bond strengths to ground enamel achieved using the different bonding systems were compared using the Fisher's PLSD post-hoc comparisons.

Table 5 shows that there was also a significant difference in the shear bond strengths to dentin among the different bonding systems and that the C-factor had an effect. The mean bond strengths to dentin among the bonding systems ranged from 23.9 to 39.8 MPa. Since there was no significant interaction between bonding system and C-factor (two-factor ANOVA $p=0.756$), all of the bond strengths achieved using the different bonding systems to dentin were compared using Fisher's PLSD post-hoc comparisons.

The mean bond strength values and standard deviations of each adhesive system for the high and low C-factor groups to enamel are shown in Table 6 and to dentin in Table 7. The Fisher's PLSD post-hoc multiple comparison tests showed significant differences among

Table 3: *Three Factor ANOVA for Bond Strength Comparing the Effects of Enamel and Dentin Surface, High and Low C-factor, and Bonding System. (200 specimens)*

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Surface	1	31.963	31.963	1.747	.1880	1.747	.245
C-factor	1	939.179	939.179	51.328	<.0001	51.328	1.000
Bonding System	4	1769.083	442.271	24.171	<.0001	96.683	1.000
Surface * C-factor	1	19.791	19.791	1.082	.2997	1.082	.169
Surface * System	4	1814.904	453.726	24.797	<.0001	99.187	1.000
C-Factor * System	4	122.388	30.597	1.672	.1584	6.689	.498
Surface * C-factor * System	4	38.135	9.534	.521	.7204	2.084	.171
Residual	180	3293.598	18.298				

Table 4: *Two Factor ANOVA for Shear Bond Strength to Enamel Comparing the Effects of High and Low C-factor and Bonding System (100 specimens)*

	DF	**Sum of Squares**	**Mean Square**	**F-Value**	**P-Value**	**Lambda**	**Power**
C-factor	1	343.151	343.151	22.212	<.0001	22.212	.999
Bonding System	4	1954.940	488.735	31.636	<.0001	126.544	1.000
C-factor * Bonding System	4	120.519	30.130	1.950	.1089	7.801	.560
Residual	90	1390.383	15.449				

Table 5: *Two Factor ANOVA for Shear Bond Strength to Dentin Comparing the Effects of High and Low C-factor and Bonding System (100 specimens)*

	DF	**Sum of Squares**	**Mean Square**	**F-Value**	**P-Value**	**Lambda**	**Power**
C-factor	1	615.819	615.819	29.121	<.0001	29.121	1.000
Bonding System	4	1629.047	407.262	19.259	<.0001	77.035	1.000
C-factor * Bonding System	4	40.004	10.001	.473	.7555	1.892	.155
Residual	90	1903.215	21.147				

the bonding systems. Although two-step etch-and-rinse SingleBond Plus always delivered the highest bond strengths in all four groups, this was only significantly higher (at 41.5MPa) than all of the other systems on enamel using the low C-factor mold ($p<0.05$). There was no significant difference among the shear bond strengths of SingleBond Plus, Clearfil SE and Easy Bond to dentin ($p>0.05$), but Easy Bond generated the lowest shear bond strengths to enamel ($p<0.05$).

DISCUSSION

The current study compared five different adhesive systems, and three of these systems were recently introduced self-etching systems. To provide a clinically relevant test, resin composite was bonded to ground human enamel and dentin using high and low C-factor molds, and the specimens were thermocycled 2,000 times. The high C-factor mold represented a Class I restoration, where the composite was bonded to the side of the mold.[20,38] Overall, the shear bond strength was significantly higher in the low C-factor specimens by 4.33 MPa ($p<0.0001$), indicating that previous studies that have used a low C-factor may have overestimated the bond strength compared to what is achieved in a clinical Class I restoration.

Table 6: *Fisher's PLSD Comparison of the Effects of C-factor and Bonding System on the Shear Bond Strength to Ground Enamel*

Bondng System	**Bond Strength (MPa)**	**SD**			
Single Bond (L)	41.5	2.4			
Clearfil SE Bond (L)	35.2	2.8	|		
Xeno V (L)	35.2	3.0	|		
Single Bond (H)	34.6	5.3	|	|	
Scotchbond SE (L)	34.2	3.7	|	|	
Scotchbond SE (H)	32.5	3.6	|	|	|
Xeno V (H)	31.4	5.5		|	|
Clearfil SE Bond (H)	30.0	5.0			|
Easy Bond (L)	24.8	3.5	|		
Easy Bond (H)	23.9	3.1	|		

No significant difference, Fisher's PLSD at 5%. |

Table 7: *Fisher's PLSD Comparison of the Effects of C-factor and Bonding System on the Shear Bond Strength to Dentin*

Bondng System	**Bond Strength (MPa)**	**SD**			
Single Bond (L)	39.8	2.1	|		
Clearfil SE Bond (L)	38.7	2.8	|	|	
Easy Bond (L)	37.2	2.1	|	|	|
Single Bond (H)	35.0	4.4	|	|	|
Xeno V (L)	34.6	4.6	|	|	|
Easy Bond (H)	33.5	4.5	|		|
Clearfil SE Bond (H)	31.4	3.5	|	|	
Xeno V (H)	29.4	8.2		|	
Scotchbond SE (L)	27.8	4.9	|	|	
Scotchbond SE (H)	23.9	5.5	|		

No significant difference, Fisher's PLSD at 5%. |

These five bonding systems produced mean shear bond strengths to dentin that ranged from 23.9 to 35.0 MPa in the high C-factor group. These values should be enough to resist the reported 8 to 23 MPa of polymerization contraction stress.[26] Tables 6 and 7 show that two-step etch-and-rinse SingleBond Plus produced the greatest bond strengths in each group (enamel, dentin, high and low C-factor), but this was only significantly greater for SingleBond Plus on enamel using the low C-factor mold. This supports previous studies showing that phosphoric acid etch-and-rinse followed by a bonding agent delivers the highest bond strengths to enamel.[5,11,21,24,45] There was no significant difference between the shear bond strengths of SingleBond Plus, Easy Bond and Clearfil SE to dentin ($p>0.05$). Previous reports, that one-step self-etch adhesives work well on dentin but not as well on enamel, where two-step self-etch adhesives yield higher shear bond strengths than one-step adhesives, were confirmed, as one step self-etch Easy Bond always delivered the lowest shear bond strengths to ground enamel ($p<0.05$). This suggests that greater enamel margin breakdown will occur with one step self-etch Easy Bond. In contrast, the recently introduced one-step self-etch XENO V and two-step self-etch Scotchbond SE Bond produced statistically indistinguishable bond strengths to enamel in the high C-factor mold, compared to the two-step etch-and-rinse SingleBond Plus ($p>0.05$). This suggests that these three systems should suffer from fewer breakdowns at the enamel margins. Depending on the bonding system and the C-factor, the mean shear bond strengths to dentin ranged from 23.9 to 39.8 MPa. There was no significant difference between the shear bond strengths of SingleBond Plus and Clearfil SE to dentin ($p>0.05$). Two-step self-etch Scotchbond SE delivered the lowest mean shear bond strengths to dentin using both C-factors ($p<0.05$). On dentin, one-step self-etch Easy Bond produced greater bond strengths compared to two-step self-etch Scotchbond SE; whereas on enamel, two-step self-etch Scotchbond SE produced greater bond strengths compared to one-step Easy Bond. This confirms that shear bond strengths for the one- and two-step self-etch systems are both product and substrate (enamel or dentin) specific.[5,14,19,21,40]

The two-step etch-and-rinse adhesive system in the current study, SingleBond Plus, uses 35% phosphoric acid with a pH of approximately 0.6. The two-step self-etch adhesive Clearfil SE Bond is classified as a "mild" self-etch with a pH of 2.0. The one-step self-etch adhesives generally have a lower pH of 1.0.[6] Since these self-etch adhesives are less acidic than phosphoric acid, they do not demineralize enamel to the same extent, yielding a less micro-retentive surface and, consequently, a lower bond strength.[6] In addition, the separate etch-and-rinse step completely removes the smear layer, while the combined etch and bonding step in self-etch adhesive systems only partially dissolve the smear layer.[46] Complete removal of the smear layer may allow for more intimate contact of the hydrophilic primer and hydrophobic bonding agent to the tooth.[47] This allows the characteristic micro-retentive resin tags and a hybrid layer to be formed. The low pH of some self-etching systems, which are left on the tooth, may also inhibit polymerization of the resin composite on top of the adhesive layer.[23] Incomplete wetting and an insufficiently thick adhesive layer[48] or phase separation between the hydrophilic and hydrophobic ingredients and resultant sensitivity to hydrolysis may also be a factor.[49]

Clearfil SE Bond consistently produced high shear bond strength values to enamel and dentin (Figures 3 and 4; Tables 6 and 7). Clearfil SE Bond was included in the current study, because it demonstrated high *in vitro* bond strengths and excellent clinical results.[7] Although Clearfil SE Bond is a "mild" self-etch adhesive, this only partially demineralizes the dentin and allows for a substantial amount of hydroxyapatite crystals to remain in the hybrid layer. The hydroxyapatite crystals chemically interact with 10-methacryloxydecyl dihydrogen phosphate (10-MDP), a constituent of functional monomers in Clearfil SE Bond.[50] This may provide a two-fold micro-mechanical and chemical bonding system for Clearfil SE Bond. This may explain why Van Landuyt and others[6] caution against etching the enamel with phosphoric acid prior to using a self-etching system on enamel, because this may adversely affect the bond strength to dentin.

A possible explanation as to why the two-step self-etch adhesive systems have been reported to yield higher bond strengths compared to one-step self-etch adhesive systems may be due to the proportions of their chemical constituents. Both contain functional monomers, crosslinking monomers, solvent, inhibitors and activators, but in different proportions.[6] The one-step self-etch adhesive systems generally have less crosslinking monomers. These provide most of the mechanical strength, therefore, there is a potential for lower bond strength, but this is product specific and may not apply to the recently introduced systems.[15,22]

It has been reported that bond strengths to bovine teeth are not the same as to human teeth.[29-30] Therefore, in contrast to many other dentin bonding studies that used bovine teeth,[13-14,24-28] the current study used human teeth. Although it has been reported that thermocycling has no significant effect on bond strength, this conclusion was based on testing specimens made with a low C-factor and after only 500 thermal cycles.[13] The effects of thermocycling may also be product specific.[41] The current study showed that C-factor did have a significant negative effect on shear bond strength, possibly because the 2000 thermal cycles generated sufficient additional stress within the specimens to cause premature failure. This is supported by other reports showing that, when the C-factor is increased, the bond strength of adhesives is adversely affected and microleakage increased.[20,25,27-28,39] Additional studies are required to further investigate the relationship between the number of thermal cycles[32] and the effect on bond strengths using molds with different C-factors.

The current study used two mold designs. The Ultradent bonding jig[19,43] was used to produce conditions with a low C-factor. In contrast, resin composite molds[20] were used to mimic a tooth cavity with a high C-factor. The shear bond strengths for all systems were significantly lower by 4.3 MPa in the high C-factor molds, indicating that the commonly used low C-factor molds may overestimate bond strengths. These high C-factor molds are relatively easy to make and can be used in both shear and microtensile bond strength studies to investigate the effect of C-factor on bond strength. In the low C-factor mold, the blade used to apply the shearing force was in direct contact with the composite specimen. In the high C-factor mold, the blade contacted the composite mold surrounding the specimen. Further studies are in progress to determine if the blade contacting the mold that then transmitted the shearing force to the specimen has an effect compared to when the blade contacts the specimen directly. Further studies are also in progress to determine the effect of mold design and shade on the amount of light energy arriving at the tooth to resin interface

CONCLUSIONS

Within the limitations of this *in vitro* study, it was concluded that:

1. Overall, the shear bond strength was significantly higher in the low (0.2) C-factor compared to the high (4.4) C-factor mold by 4.3 MPa (p<0.0001).
2. One-step self-etch Easy Bond delivered the lowest mean shear bond strengths to enamel using both configuration factors (p<0.05).
3. Two-step self-etch Scotchbond SE delivered the lowest mean shear bond strengths to dentin using both configuration factors (p<0.05).
4. The two-step etch-and-rinse adhesive SingleBond Plus consistently delivered the highest bond strengths with both configuration factors (34.6-41.5 MPa), but they were not always significantly greater than all the other systems. Out of the five systems tested, overall, SingleBond Plus would be the preferable system to use clinically.

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