Adhesive Systems: Effect on Bond Strength of Incorrect Use

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Purpose: The aim of this in vitro study was to determine the influence of deviations from the manufacturer's instructions for use of six adhesive systems on the bond strength of resin composite to enamel and dentin.

Materials and Methods: Detailed questionnaires completed by 355 dentists in a survey of the use of adhesive systems in Denmark were analyzed, and the types of deviations from the manufacturer's recommended clinical procedures were categorized for the six most commonly used adhesive systems (Scotchbond Multi-Purpose, Scotchbond 1, Prime&Bond 2.1, Syntac, Gluma Classic, and Gluma CPS). Plane tooth surfaces were treated with one of the six adhesive systems either according to the manufacturer's instructions or with the deviations identified (eg, shortened application times, omission of second layers). Resin composite, which varied with the adhesive system, was then bonded to the treated surfaces. After storage in water at 37°C for 7 days, the bonded specimens were tested to failure to determine shear bond strength (n = 6).

Results: Certain deviations from the manufacturer's protocols significantly reduced bond strength to dentin for three (Scotchbond Multi-Purpose, Scotchbond 1, and Prime&Bond 2.1) of the six adhesive systems, while no negative effects were found on bond strength to enamel for any of the six systems.

Conclusion: The adhesive systems varied regarding sensitivity to deviations from the instructions for use. Bonding to dentin was more technique-sensitive than bonding to enamel. For the most reliable result, the clinical procedure recommended by the manufacturer should be followed meticulously.

J Adhesive Dent 2002; 4: 233–242. *Submitted for publication: 22.03.02; accepted for publication: 13.06.02.*

Adhesion of resin composite to the tooth being restored is required to provide retention and ensure marginal integrity and durability of the restoration. Bonding of resin composite to enamel has been quite a straightforward and reliable task since the introduction of the phosphoric acid etch technique by Buonocore in 1955.[4] Due to the more complex structure of dentin, the search for bonding agents able to effectively bond resin composites to dentin has been longer and more arduous. Breakthroughs came in the 1980s, and incremental but steady improvements since then mean that today, several bonding systems on the market allow for bond strengths between resin composite and dentin as high as that between resin composite and enamel.[1,26] Bonding of resin composites to dentin is accomplished through demineralization of the outermost dentin, followed by infiltration of the partly exposed collagen fibrils with hydrophilic resins under the formation of a so-called hybrid layer.[18,26] For most adhesive systems, demineralization and infiltration have required application of two or three different agents, intermitted by various rinsing and drying procedures. It follows that adhesive systems are complex products that involve multiple steps.

Each commercial adhesive system is accompanied by the manufacturer's instructions for use.

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However, most often these directions leave plenty of room for variations in the application procedure and/or in the way a certain procedure is performed, eg, the force used during a required rubbing motion is bound to vary from operator to operator. Such factors may be one of the reasons that reported bond strengths between resin composite and enamel or dentin vary widely for the same adhesive system from study to study and within the same study between different operators.[6,8,13,21]

Motivated by the complex application procedures of adhesive systems and by the time constraints in many dental offices, two recent in vitro studies have determined the effect of application mistakes of adhesive systems on the bond strength between resin composite and dentin and on the marginal adaptation of resin composite restorations.[10,19] Both studies found the deliberate mistakes to significantly compromise the effect of the adhesive systems.

In a survey of the use of adhesive systems in Denmark, 456 dentists completed a written questionnaire.[20] Based on recollection, 77% of the respondents gave a clinical procedure for their adhesive system which was in accordance with the instructions for use of that particular system. The authors concluded that despite some uncertainty regarding the exact percentage, it could be presumed that some dentists used their adhesive system in a manner that differed considerably from the instructions for use. Several of the 21 different adhesive systems reported in the questionnaires were used by very few of the 456 dentists; only six of the systems were being used by a substantial number of respondents. It was the purpose of the present study to identify and describe the deviations from the instructions for use for these six adhesive systems and to test the effect on bond strength to enamel and/or dentin of the most common of these deviations. It was hypothesized that deviations from the respective instructions for use decrease the bond strength to enamel and dentin.

MATERIALS AND METHODS

Identification of Deviations

In a total of 456 completed questionnaires, the use of 21 different adhesive systems was reported. However, only 6 of these systems were used by a substantial number of responding dentists. For analysis, 355 questionnaires were identified in which the use of one of these six adhesive systems (Table 1) was mentioned. In each questionnaire, the dentist named the adhesive system he/she was using at the time, and then described from memory the clinical procedure he/she employed for this specific adhesive system. To aid the dentist, a list of common clinical procedures had been provided which could be placed in the order of choice and commented upon. Exact indications of durations were provided unaided by the respondent. The procedures thus listed in the 355 questionnaires were examined and possible deviations from the respective manufacturer's instructions for use were identified and described.

Effect of Deviations on Bond Strength

Human incisors (for bonding to enamel) and molars (for bonding to dentin) kept in 0.5% chloramine since extraction were embedded in self-curing resin. After setting, flat enamel or dentin surfaces were produced by wet grinding on carborundum paper #1000. The embedded teeth were randomly assigned to 16 enamel bonding groups and 23 dentin bonding groups (n = 6). The tooth surfaces were then treated with one of the six adhesive systems, either according to the manufacturer's instructions (control) or with the deviations identified (Tables 2 to 7). A split teflon mold (d = 3.6 mm, h = 2.5 mm) was clamped to the treated tooth surface and filled with resin composite, which was light cured for 60 s with a light-curing unit (XL 3000, 3M, St Paul, MN, USA). A resin composite from the same manufacturer as the respective adhesive system was used (Table 1). Ten min after the completion of light curing, the bonded specimens were freed from the mold and stored in water at 37°C for 7 days. The shear bond strengths were determined with a Universal testing machine (Instron, High Wycombe, UK) at a crosshead speed of 1 mm/min. A mean value and standard deviation was calculated for the six specimens in each of the 39 experimental groups.

Statistical Methods

For each adhesive system and substrate, the mean shear bond strength values were treated statistically by analysis of variance and, in case of significant differences, by Newman-Keuls Multiple Range test.[3] The different systems were compared in terms of

Table 1 Adhesive systems and composites tested

Adhesive system	Components	Composite	Manufacturer
Gluma Classic	Etchant Cleanser Primer Sealer	Charisma	Heraeus Kulzer, Dormagen, Germany
Gluma CPS	Etchant Primer Sealer	Charisma	Heraeus Kulzer, Dormagen, Germany
Prime&Bond 2.1	Etchant Primer/Bond	Spectrum	Dentsply/DeTrey, Konstanz, Germany
Scotchbond 1	Etchant Adhesive	Z 100	3M Dental Products, St Paul, MN, USA
Scotchbond Multi-Purpose	Etchant Primer Adhesive	Z 100	3M Dental Products, St Paul, MN, USA
Syntac	Etchant Primer Adhesive Resin	Tetric Ceram	Vivadent, Schaan, Liectenstein

bond strength to enamel (control) and to dentin (control) by analysis of variance and Newman-Keuls Multiple Range test. For each system, a Student's t-test was performed to compare the bond strength to enamel (control) with the bond strength to dentin (control). The level of significance was set at $p = 0.05$.

RESULTS

Examination of the questionnaires revealed that for each adhesive system, the majority of the deviations from instructions for use were of the same types and could be assigned to certain categories (Tables 2 to 7). Most deviations saved time, either by shortening the procedures (eg, primers were left on enamel and/or dentin for fewer seconds than recommended or a second layer of primer was not applied) or by simplifying the procedures (primers were applied on enamel as well as on dentin instead of on enamel or dentin only, dentin was etched for as long as enamel, or sealers were not light cured separately).

The effects of the procedural deviations on bond strength are presented in Tables 2 to 7 for the six different adhesive systems. With respect to Gluma Classic (Table 2), the examination of the questionnaires revealed no deviations from the instructions for use as regards treatment of enamel. Consequently, no enamel bond strengths were determined. Of the deviations noted and tested as regards treatment of dentin, none significantly decreased the bond strength as compared to the control. However, reducing the application time of both the cleanser and the primer from the recommended 30 s each to 10 s each yielded a significantly lower bond strength than that obtained when, not according to the instructions but like enamel, the dentin had been etched with phosphoric acid prior to application of the cleanser. For Gluma CPS, none of the deviations tested resulted in significant changes in the bond strength to enamel or dentin as compared to the control procedure (Table 3). Failure to apply a second layer of Prime&Bond 2.1 significantly reduced the bond strength to dentin, while failure to leave Prime&Bond 2.1 for the recommended 30 s significantly increased the bond strength as compared to the control procedure (Table 4). Neither deviation had any significant influence on the bond strength to enamel.

Table 2 Modes of application of Gluma Classic tested for bond strength to dentin

Mode of application	Bond strength to dentin (MPa)
Control: Cleanser applied, rubbed for 30 s, rinsed for 10 s, and excess blown away. Primer applied, left for 30 s and gently dried. Sealer applied and air thinned.	[ab] 11.2 ± 4.4
Cleanser rubbed for 10 s only.	[ab] 10.8 ± 7.8
Primer left for 10 s only.	[ab] 10.1 ± 4.0
Cleanser rubbed for 10 s only and primer left for 10 s only.	[a] 4.6 ± 3.3
Dentin acid etched for 30 s before application of cleanser.	[b] 16.8 ± 6.5

Values designated by the same superscript letter are not statistically different at p = 0.05.

Table 3 Modes of application of Gluma CPS tested for bond strength to enamel and dentin

Mode of application	Bond strength to enamel (MPa)	Bond strength to dentin (MPa)
Control: Etchant applied, left for 30 s, rinsed for 10 s, and excess blown away. Primer applied on dentin only, left for 30 s, and dried. Sealer applied, air thinned, and light cured for 20 s.	[a] 27.1 ± 5.9	[a] 18.2 ± 8.0
Etchant left on dentin for 10 s only.		[a] 17.1 ± 3.1
Primer left for 10 s only.		[a] 11.4 ± 6.6
Primer applied also on enamel.	[a] 22.6 ± 4.0	
Sealer not light cured.	[a] 27.1 ± 6.1	[a] 11.4 ± 6.0

Within each of the two groups of comparison (enamel and dentin), mean values designated by the same superscript letter are not statistically different at p = 0.05.

Regarding Scotchbond 1, failure to apply a second layer of the adhesive significantly decreased the bond strength to dentin as compared to the control procedure (Table 5). The enamel bond strength remained unchanged as a result of the deviations tested. The same held true for Scotchbond Multi-Purpose, whereas all four deviations tested significantly reduced the bond strength to dentin (Table 6). Failure to acid etch or extension of the light cure of the adhesive caused significantly greater decreases in bond strength than did shortening the rinsing time or failure to light cure the adhesive. For Syntac, omission of primer and adhesive application significantly increased the bond strength to enamel, whereas a reduction of the application time of the primer from 15 s to 5 s had no effect (Table 7). Neither of the two tested deviations from the control procedure decreased the bond strength to dentin significantly.

Comparisons between the adhesive systems when used according to the manufacturer's instructions (control) showed that the bond strength to enamel promoted by Syntac (23.7 MPa) was significantly lower than the bond strength promoted by Prime&Bond 2.1, Scotchbond 1, and Scotchbond Multi-Purpose (31.6 to 32.3 MPa). With respect to

Table 4 Modes of application of Prime&Bond 2.1 tested for bond strength to enamel and dentin

Mode of application	Bond strength to enamel (MPa)	Bond strength to dentin (MPa)
Control: Etchant applied, left for 15 s, rinsed for 15 s, and excess blown away. Prime&Bond applied, left for 30 s, gently dried, and light cured for 10 s. A second layer of Prime&Bond applied, gently dried, and light cured for 10 s.	[a] 31.6 ± 2.8	[b] 11.2 ± 5.2
Only the first layer of Prime&Bond applied.	[a] 31.3 ± 3.9	[a] 4.8 ± 3.2
The first layer of Prime&Bond not left for 30 s.	[a] 31.2 ± 3.1	[c] 19.0 ± 2.0

Within each of the two groups of comparison (enamel and dentin), mean values designated by the same superscript letter are not statistically different at p = 0.05.

Table 5 Modes of application of Scotchbond 1 tested for bond strength to enamel and dentin

Mode of application	Bond strength to enamel (MPa)	Bond strength to dentin (MPa)
Control: Etchant applied, left for 15 s, rinsed for 10 s, and excess blown away. Two layers of adhesive applied, gently dried, and light cured for 10 s.	[a] 32.3 ± 3.8	[b] 14.8 ± 5.0
Etchant left for 30 s.	[a] 30.4 ± 4.5	[b] 15.7 ± 3.0
Only one layer of adhesive applied.	[a] 31.0 ± 6.1	[a] 8.4 ± 5.0

Within each of the two groups of comparison (enamel and dentin), mean values designated by the same superscript letter are not statistically different at p = 0.05.

dentin, Scotchbond Multi-Purpose (30.2 MPa) and Syntac (27.9 MPa) promoted significantly higher bond strengths than did the other systems (11.2 to 18.2 MPa). Pairwise comparisons of the control values of enamel and dentin bond strength found Scotchbond Multi-Purpose and Syntac to be equally effective in promoting bonds to enamel and dentin, whereas Gluma CPS, Prime&Bond 2.1, and Scotchbond 1 promoted significantly lower bond strengths to dentin than to enamel.

DISCUSSION

This in vitro study determined the effect of deviations from the instructions for use of adhesive systems on the bond strength of resin composite to enamel and dentin. In order for the deviations to be clinically relevant, the study was based on a written questionnaire that, among other things, asked the respondents to recall and list the clinical procedure for the adhesive system they were using at the time the survey took place.[20] As the respondents had to list the clinical procedure from memory, some uncertainty is linked to the reliability of the given procedures. This uncertainty was accepted, since more reliable methods of recording exact clinical procedures followed by a large number of dentists do not seem practicable. Analysis of the listed procedures showed that most deviations were timesaving, cutting down on recommended application times or on the number of layers applied. This indicates a need for manufacturers to further stress the importance and rationale of each step in the clinical procedure and a need to improve the dentist's understanding of how adhesive systems function. It may also indicate a substantial interest in adhesive systems that are simpler and faster to use.

Table 6 Modes of application of Scotchbond Multi-Purpose tested for bond strength to enamel and dentin

Mode of application	Bond strength to enamel (MPa)	Bond strength to dentin (MPa)
Control: Etchant applied, left for 15 s, rinsed for 15 s, and excess blown away. Primer applied and gently dried for 5 s. Adhesive applied, air thinned, and light cured for 10 s.	[a] 32.3 ± 4.2	[c] 30.2 ± 2.9
Etchant not applied.		[a] 9.4 ± 6.9
Rinsed for 5 s only.	[a] 29.3 ± 3.9	[b] 22.4 ± 8.5
Adhesive not light cured.	[a] 27.9 ± 2.4	[b] 21.5 ± 5.1
Adhesive light cured for 40 s.	[a] 26.1 ± 6.1	[a] 10.2 ± 6.9

Within each of the two groups of comparison (enamel and dentin), mean values designated by the same superscript letter are not statistically different at p = 0.05.

Table 7 Modes of application of Syntac tested for bond strength to enamel and dentin

Mode of application	Bond strength to enamel (MPa)	Bond strength to dentin (MPa)
Control: Etchant applied, left for 45 s on enamel and 10 s on dentin. Rinsed for 10 s and dried. Primer applied, rubbed gently for 15 s and gently dried. Adhesive applied and air thinned. Heliobond applied, air thinned, and light cured for 20 s.	[a] 23.7 ± 3.0	[a] 27.9 ± 7.0
Etchant left on dentin for 45 s.		[a] 20.6 ± 7.3
Primer and adhesive not applied.	[b] 32.0 ± 4.3	
Primer rubbed for 5 s only.	[a] 24.0 ± 3.6	[a] 22.2 ± 5.4

Within each of the two groups of comparison (enamel and dentin), mean values designated by the same superscript letter are not statistically different at p = 0.05.

The study found the deviations from the manufacturer's protocols to significantly reduce the bond-promoting effect of three of the six systems tested. For these three systems, the detrimental effects were found on the bond strength to dentin, while no negative effects were measured on the bond strength to enamel. This corroborates the reliability of the enamel acid-etch technique and the higher technique-sensitivity of dentin bonding reported by Peschke et al.[19]

The bond strength to dentin promoted by Gluma Classic was of the same magnitude as that reported in earlier studies with the same test method.[17] Gluma Classic was relatively insensitive to the tested variations in the clinical procedure: shortening the recommended waiting times from 30 s to 10 s of either the cleanser or the primer had no adverse effect on the bond strength. These findings are in agreement with the findings of the developers of Gluma Classic, who reported no differences in bond strength between applications times of 10 s to 120 s for the cleanser and the primer.[17] According to van Meerbeek, the role of the primer is to assure efficient wetting of the exposed collagen fibrils, displace any residual surface moisture, transform a hydrophilic into a hydrophobic tissue state, and sufficiently carry monomers into the interfibrillar channels; this is a time-dependent pro-

cess.[26] For most primers, an application time of at least 15 s is recommended.[26] The fact that 10 s was sufficient priming time for Gluma Classic may be explained by a relatively shallow depth of demineralized dentin created by the EDTA-containing cleanser compared with deeper demineralization zones created by phosphoric acid, and ensuing reduced demands on the primer. Considering the fact that bond strength tended to decrease when the two application times (for cleanser and primer) were reduced simultaneously, general shortening of the application times cannot be recommended.

Gluma Classic may be characterized as a 4-step, separate-etch adhesive system in that only enamel is acid etched, whereas dentin is conditioned with an aqueous solution of EDTA. As it is often very difficult to limit acid etching to enamel and avoid contact between phosphoric acid and dentin, it is reassuring that etching of the dentin with phosphoric acid was found not to jeopardize the bond strength. In fact, acid etching of dentin tended to improve the bond strength, phosphoric acid being a more effective demineralizing agent than EDTA.[7,25] This implies that within the 30 s application time, the primer was able to fully penetrate a deeper zone of demineralized dentin. Indeed, the successor of Gluma Classic, Gluma CPS, abandoned conditioning of dentin with EDTA in favor of phosphoric acid etching.

Gluma CPS may be characterized as a 3-step, total-etch version of Gluma Classic. The similarity between the two systems was reflected in the bond strength measurements: Acid etching of dentin prior to application of Gluma Classic promoted a bond strength to dentin as high as that obtained with Gluma CPS (16.8 MPa vs 18.2 MPa). Like Gluma Classic, Gluma CPS was also statistically insensitive to the tested deviations from the instructions for use. However, shortening of the waiting time for primer penetration from 30 s to 10 s tended to decrease the bond strength as did failure to light cure the sealer before application of composite. Light curing of the adhesive resin (eg, Gluma CPS Sealer) ensures that the resin stays in place in a sufficient thickness for it to function as stress-absorbing layer.[26] Such a relatively flexible resin layer has been proposed to help protect the adhesive joint against early failure caused by the polymerization shrinkage of the subsequently applied composite.[15,16,19,27,28] According to the instructions for use, the primer should only be applied to dentin. As explained above, restricted application is not easily accomplished, and it is therefore clinically important that application of the primer to enamel was not found to jeopardize the bond. The results also showed that demineralization of dentin may be obtained within a shorter application time (10 s) than the one recommended by the manufacturer (30 s). However, enamel requires more aggressive etching than dentin to obtain an optimal microretentive etch pattern of the surface.[19,23,24,26] Evidently, the manufacturer of this adhesive system chose to simplify the clinical procedure by recommending identical etching times for enamel and dentin, advocating an etching time of 30 s as a suitable compromise between the risk of underetching enamel and overetching dentin.

The bond strength to enamel and dentin obtained with the 2-step, total-etch system Prime&Bond 2.1 used in compliance with the instructions was similar to that obtained in a previous study.[1] According to the instructions, two layers of the primer/adhesive resin are to be applied and the first layer is to be left for 30 s before drying, light curing, and application of the second layer. Prime&Bond 2.1 proved sensitive to variations in this procedure: when only one layer of Prime&Bond 2.1 was applied, the bond strength to dentin dropped significantly. The second layer of Prime&Bond 2.1 probably has functions identical to those of the adhesive resin in 3-step systems, that is, it fills up remaining pores between the collagen fibrils, forms resin tags that seal the opened dentinal tubules, and stabilizes the formed hybrid layer and resin tags.[26] It goes without saying that when a second layer of primer/adhesive resin is not applied, the stabilizing effect is not obtained. The decrease in bond strength found was therefore to be expected. The fact that no negative effect was found on enamel may reflect that only the adhesive resin function of the primer/adhesive resin is needed on acid-etched enamel and that this is fully obtained already by application of the first layer of Prime&Bond 2.1, one layer being sufficient to ensure complete penetration into the microretentive etch pattern of the enamel surface.

Failure to leave the first layer of Prime&Bond 2.1 for 30 s also influenced bond strength to dentin, but quite unexpectedly, this deviation caused a significant increase in bond strength. The primer has to penetrate fully into the partly demineralized dentin to have optimal effect. As penetration is a time-dependent process, it seems obvious that some time is needed before the layer of demineralized dentin has been fully penetrated by the primer. However, this was not found in the present study. The fact that no waiting time was needed corrobo-

rates the excellent penetration capability of the solvent used in Prime&Bond 2.1: acetone. That in fact a better result was obtained when the waiting time was omitted conflicts with the finding of Frankenberger, Krämer, and Petschelt.[10] A possible explanation is that in the present study, the control procedure gave a less than optimal result due to overdrying of the demineralized dentin caused by the great drying capability of acetone.[26] Consequently, the interdiffusion of monomers from the second layer of Prime&Bond 2.1 is hampered.

Scotchbond 1, another 2-step, total-etch system, was found to react negatively to omission of the second layer of the adhesive in terms of bond strength to dentin. As with Prime&Bond 2.1, a second layer of the primer/adhesive resin seems necessary for obtaining the stabilizing and reinforcing effect of an adhesive resin. Like Gluma CPS, Scotchbond 1 was insensitive towards small variations in etching time. The adhesive seemed capable of ensuring complete interdiffusion of a demineralized surface layer that is probably deeper as a consequence of the doubled etching time.[25]

Contrary to the other 3-step, total-etch system tested (Gluma CPS), Scotchbond Multi-Purpose proved very technique-sensitive regarding bond strength to dentin. Failure to acid etch dentin, which may be a deliberate decision based on the point of view predominant some 10 years ago regarding possible damaging effects of phosphoric acid, proved to jeopardize the bond-promoting effect of the adhesive system. This finding was expected and results from an acidity of the subsequently applied primer that is insufficient to replace phosphoric acid. Reducing the rinsing time to 5 s resulted in a decrease in bond strength, most likely caused by insufficient removal of the acid and its by-products and incomplete penetration of primer into the demineralized dentin layer. The bond strength to dentin was also reduced when the adhesive was not light cured prior to application of the composite, presumably because of the absence of a stress-absorbing effect of the adhesive as discussed above. Moreover, extending the light cure to 40 s drastically reduced the bond strength. Thus, the 40 s light cure overcured the adhesive, leaving few methacrylate double bonds to copolymerize with the composite, thereby weakening the bond.

The sixth adhesive system tested, Syntac, may be characterized as a 4-step, total-etch system. Whereas none of the deviations from the instructions for use reduced the bond strength, the bond strength to enamel was actually increased when applications of primer and adhesive were omitted and the enamel was only acid etched prior to application of the resin, Heliobond. Thus, the application of primer and adhesive between acid etching and resin application was not just ineffective, but even contaminated the etched enamel surface. When it comes to ensuring a bond to enamel, application of Syntac Primer and Syntac Adhesive should be avoided and efforts made to restrict application of these two components to dentin only. The same effect was observed with Gluma CPS, where a tendency for primer application to reduce the enamel bond strength was measured. Extending the acid etch of dentin from 10 s to the 45 s recommended for enamel did not reduce the bond strength to dentin significantly. This relative insensitivity of changes in etching time is in keeping with the results found with the other adhesive systems for which this parameter was tested, and accidental application of phosphoric acid to dentin is not expected to have any detrimental effects. Reducing the rubbing time of the primer from 15 s to 5 s also did not decrease the bond strength significantly, implying an excellent penetrating ability of the water and acetone-based primer.

Following the instructions of the manufacturer (control) and using exactly the same batches of the Syntac adhesive system and Tetric Ceram, as well as the same test conditions, another operator working in our laboratory found significantly lower bond strength to enamel (19.9 MPa vs 23.7 MPa) and to dentin (11.6 vs 27.9 MPa) than did the operator who carried out the tests of the present study. This proves the Syntac adhesive system to be an operator-sensitive system. Even though the tested deviations from the clinical procedure recommended by the manufacturer did not harm the bond-mediating capacity of Syntac, this capacity may be expected to vary significantly from operator to operator. Possible explanations for the differences between the two operators include variations in the degree to which the tooth was dried after etching and rinsing, the force applied during rubbing of the primer, and the pressure used during air thinning of the adhesive and resin. These factors were not investigated in the present study, but the findings with Syntac indicate that such factors may also be expected to broaden the range of results obtained with other adhesive systems. However, some systems may be more sensitive to these variations than other systems; for instance, acetone-based primers have been found to

be very sensitive to excessive drying of the acid-etched dentin whereas some primers based on water and/or ethanol have been found to be rather tolerant in this respect.[5,9,11,14,22]

The results also allow for a comparison between the different adhesive systems. However, when comparing the systems, it should be kept in mind that different composites were used. Thus, differences between adhesive systems do not only reflect differences in the efficacy of the systems themselves but may also reflect differences between the composites with respect to mechanical properties.[2,12,29] Because of the negative influence of primer and adhesive application, Syntac mediated a bond strength to enamel that was significantly poorer than most other systems. On the other hand, Syntac together with Scotchbond Multi-Purpose mediated the significantly highest bond strengths to dentin. This finding is in agreement with Frankenberger, Krämer and Petschelt, who found these two adhesive systems to be superior to Prime&Bond 2.1.[10] However, it was not a general finding of the present study that 2-step systems yielded lower bond strengths than did 3-step or 4-step systems.

Two out of five adhesive systems mediated a bond strength to dentin as high as they did to enamel. The other three systems mediated lower bond strengths to dentin than to enamel, documenting the greater challenge in creating durable bonding to such a complex substrate as dentin. In light of the increasing understanding of dentin bonding, new adhesive systems would be expected to be equally effective in bonding to enamel and dentin, although efforts to simultaneously simplify the systems is a complicating factor.

Based on these in vitro measurements of bond strength, it may be concluded that some adhesive systems were more sensitive to variations in the clinical procedure than others as regards the bond-mediating capacity to dentin. Thus, the hypothesis put forward in the introduction was accepted for three of the six adhesive systems studied and rejected for another three systems. Scotchbond Multi-Purpose reacted negatively to all the deviations from the manufacturer's instructions, Prime&Bond 2.1 and Scotchbond 1 reacted negatively to some deviations, while Syntac, Gluma Classic, and Gluma CPS did not react negatively to any of the deviations tested for these systems. Indeed, some adhesive systems reacted positively to certain deviations from the control procedure, and it seems tempting to recommend that these incorrect procedures be preferred over the procedure recommended by the manufacturer. However, a dentist will not know whether a given system reacts negatively or positively to changes in the recommended clinical procedure, and to which changes it reacts. To recommend a change that applies only for one adhesive system seems unwise, as it is likely to create confusion. Despite differences between adhesive systems, the overall recommendation based on a summary of the results of this study is to meticulously follow the manufacturer's instructions for use.

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