Effect of parallel surface cuts on bonding to dentine

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The strength of adhesive joints has been found to result from combinations of micromechanical, chemical and diffusion components depending on the system[1]. The development of adhesives that bond dental restorative materials to human dentine has been a major advance in the science of dental materials. The purpose of this investigation was to study the contribution of parallel surface cuts on the joint strength of dentine adhesives. Half of the specimens were finished with 60 grit SiC paper as a control. The other half were polished with 600 grit SiC paper and then finished with an instrument that produced a series of parallel surface cuts. A two-way analysis of variance showed that both the surface preparation and the adhesive system had a significant effect on shear bond strength ($p < 0.0001$). In general, the samples finished with parallel surface cuts gave shear bond strength values about double those finished with silicon carbide alone. For those control samples prepared with a 60 grit surface, the predominant type of failure was at the tooth/adhesive interface. The majority of samples with parallel surface cuts failed cohesively within the adhesive system. The experimental instrument is designed to produce retentive grooves or undercuts in the dentine surface which enhance micromechanical adhesion.

(Keywords: micromechanical adhesion; bonding agents; dentine; surface finishing; finishing tool; bond strength)

INTRODUCTION

The development of materials that bond to teeth has been a major advance in the science of dental materials. Several advantages include the opportunity to use more aesthetic restorative materials and more conservative cavity preparation techniques, and to inflict less trauma on the patient. The bond between the restorative material and the tooth structure can be a combination of mechanical retention and/or chemical bonds. The factors that contribute to mechanical and chemical adhesion have been described by Lee[2]. The contribution of each of these mechanisms for adhesion to dentine is still a matter of speculation. Studies of the nature of the bond to dentine attained by some dentine bonding systems indicate that the bond is the result of diffusion of the adhesive into a hybrid zone[3].

The longevity of a dental restoration is influenced by the quality and durability of the marginal adaptation. Many factors contribute to the quality of marginal adaptation and when these factors are used in optimum combinations, restorations resistant to mechanical and thermal stresses will be produced[4]. The main factor of concern in this study is the surface preparation and resulting adhesion due to micromechanical attachment.

The development of adhesives that bond dental restorative materials to the dentine of human teeth has many clinical applications. The main advantages are that marginal leakage should be reduced and less tooth reduction is required to attain retention for filled resin restorative materials. There have been reports on the effect of surface preparation on the bond strengths to enamel[5–8]. Others have reported on the effect of surface roughness on the tensile and/or shear bond strengths to dentine[8–11].

Improvements in bonding to dentine have been harder to establish, as they are generally lower and more variable than bond strengths to etched enamel. It was the purpose of this study to determine the effect of surface finish on relative bond strengths to dentine. Several commercial adhesive systems were chosen to test the hypothesis that there is a significant improvement in bond strength as a result of the enhanced micromechanical retention provided by a series of parallel surface cuts produced by an experimental instrument. The choice of adhesive systems was arbitrary since there are many commercially available materials and the specific formulations change rapidly.

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EXPERIMENTAL

The instrument for creating the parallel surface cuts is composed of a plurality of cutting edges which, when applied to a surface, forms a series of parallel cuts at an angle to the surface. The experimental instrument employed in this study is shown schematically in *Figure 1a*. It was prepared by mounting seven 6.5 × 0.15 mm double-sided 100 μm diamond discs (manufactured by Brasseler) on a 3.0 mm diameter mandrel separated by 3.15 × 0.5 mm brass spacers.

Six groups of samples were prepared using the adhesive systems listed in *Table 1*. A mixture of freshly extracted human premolars and molars was disinfected with 5% sodium hypochlorite for 4–5 h, rinsed in distilled water and pumiced. The teeth were stored in distilled water until they were mounted in Koldmount (manufactured by Vernon-Benshoff Co.). Half of the teeth were ground using wet 60 grit SiC polishing paper with random grit direction until an area of dentine at least 5 mm in diameter was exposed on the mesial surface. The other half were polished with wet 600 grit SiC polishing paper until the dentine was exposed as above and then finished with an experimental instrument designed to enhance bond strengths (see *Figure 1a*).

The instrument and each mounted sample were placed in a jig which limited the depth of the parallel surface cuts to 0.6 mm. The surface cuts were placed parallel to the occluding surface of each tooth. Since the width of the cutting surface of the experimental instrument was 3.5 mm, two passes, parallel to each other, were necessary to cut the 5 mm surface to be bonded. A tapered Teflon mould, which was 5 mm in diameter at the bonding interface, was clamped onto the surface prepared according to the recommendations of each manufacturer. The bonding agents were applied according to the procedures recommended for each material, including light curing as required. A button, 2 mm thick, of the corresponding restorative material was cured incrementally with a Command Light (manufactured by Kerr Manufacturing Co.).

The materials were placed in a random order to minimize technique bias. The mould was removed and the samples were stored in distilled water at 37°C for 7 days. The bonded samples were placed in a jig secured in the lower jaw of an Instron universal testing instrument. A wire loop, secured in the upper jaw, was used to apply a shear force, at a crosshead speed of 0.05 cm min^{-1}, parallel to the dentine surface and perpendicular to the direction of the surface cuts (see *Figure 2*). The load at failure was recorded and the stress calculated. The method has been described by Munksgaard *et al.*[12] and Sorensen and Dixit[13]. After failure, the surfaces were examined under a binocular microscope at a magnification of 20×, to determine the type of bond failure.

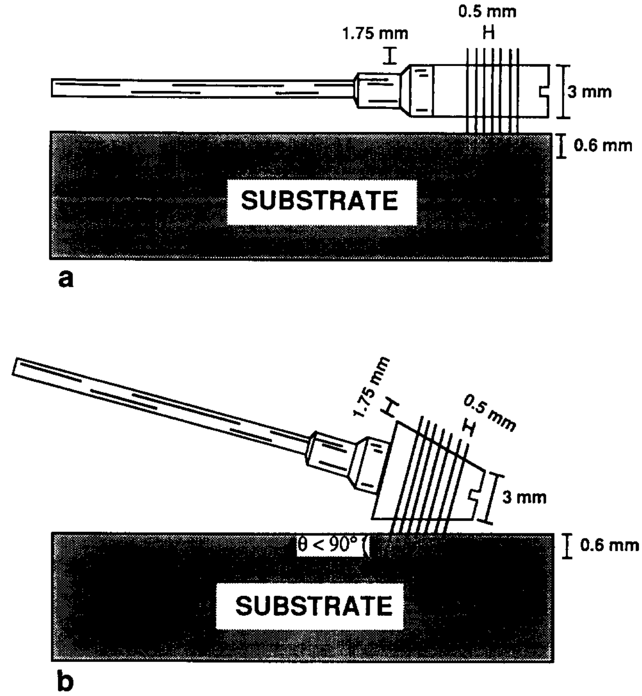

Figure 1 Prototypes of experimental instrument. (a) Prototype used in this study, having double-sided diamond discs of equal diameter that would produce cuts in the dentine perpendicular to the surface. (b) Proposed prototype, having double-sided diamond discs of varying diameters that would produce cuts in the dentine at an angle of less than 90° to the surface

Statistical analysis was performed using an analysis of variance to study the effects of surface preparation and adhesive system on the shear bond strength to dentine. The bond strengths were compared using the Tukey's studentized range (HSD) test to determine if a significant difference existed at the 95% confidence level (SAS statistical software, version 5.16, SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

The shear bond strength results are given in *Table 2* and *Figure 3*. The analysis of variance results are given

Table 1 Adhesive systems used in this study

Manufacturer	Bonding agent (chemical type)	Restorative material
Johnson & Johnson Dental Care Co., New Brunswick, NJ	Light Curing Dentin-Enamel Bonding Agent (phosphate ester)	Adaptic II
Caulk/Dentsply, Milford, DE	Prisma Universal Bond (phosphate ester)	Ful-Fil
3M Health Care, Dental Products Division, St Paul, MN	Scotchbond 2 (BISGMA/HEMA)[a]	Silux
Den-Mat Corporation, Santa Maria, CA	Tenure (aluminium oxalate NPG-GMA/PMDM)[b]	Perfection
Vivadent (USA), Inc., Tonawanda, NY	Dentin Adhesit (polyurethane)	Heliomolar
Kerr Manufacturing Co., Romulus, MI	Bondlite (phosphate ester)	Herculite XR

[a] Bisphenol-A-glycidylmethacrylate/2-hydroxyethyl methacrylate
[b] *N*-phenylglycine and glycidylmethacrylate/pyromellitic acid diethylmethacrylate

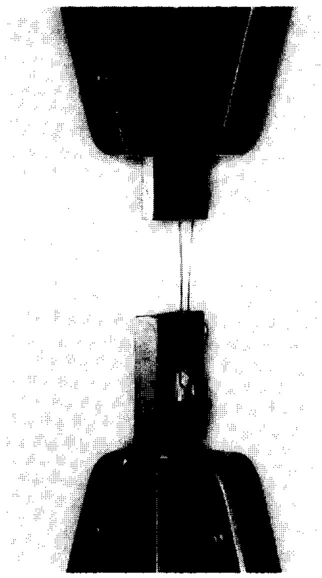

Figure 2 Specimen positioned in the jaws of Instron universal testing instrument prior to application of shear stress

in *Table 2a*. Results of the two factor analysis of variance showed that the shear bond strengths are highly dependent on both the surface preparation and the adhesive system used ($p < 0.0001$) but that interactions were not significant ($p = 0.238$). Therefore, a pair-wise comparison was conducted to rank order the results for the combination of surface preparation and the adhesive system used. For all adhesive systems tested, the bond strengths for the samples finished with the experimental instrument were about double those finished with the 60 grit SiC paper. The J & J, Caulk and 3M materials in conjunction with the experimental instrument provided the highest shear bond strengths to dentine.

The shear bond strengths to the dentine controls obtained in this study are comparable to those reported in an earlier study by Barkmeier and Cooley[14]. After 24 h at 37°C, they measured a shear bond strength of 6.8 ± 3.3 MPa for the J & J Dentin-Enamel Bond/Adaptic II system, 6.5 ± 3.3 MPa for the Caulk Prisma Universal Bond/Fui-Fil system, 8.8 ± 3.4 MPa for the 3M Scotchbond 2/Valux system, 3.2 ± 3.8 MPa for the Vivadent Dentin Adhesit/Heliomolar system and 1.7 ± 1.6 MPa for the Kerr Bondlite/Herculite XR system. The only discrepancy between their data[14] and the data measured in this study was for the shear bond strength of 13.4 ± 3.8 MPa that they reported for the Den-Mat Tenure (2-Step)/Marathon One system.

The frequency of failure types for the various adhesive systems using the two surface preparations are given in *Table 3*. For those samples prepared with a 60 grit surface, the predominant type of bond failure was at the tooth/adhesive interface. The majority of samples prepared with the experimental instrument failed cohesively within the adhesive system. Therefore, for the control samples the weakest site was the interface between the tooth and the adhesive system. For the samples with the retentive surface cuts, the shear bond strength was limited by the cohesive strength of the adhesive system. It was hypothesized that this improvement in strength and the change in type of bond failure was due to an increase in micromechanical retention.

Now that the feasibility of this concept has been demonstrated, the next step would be the design of dental burs which can produce parallel surface cuts. Also of interest is the design illustrated in *Figure 1b*. If the cuts are formed at an angle which is less than 90°, undercuts would be formed which might further enhance the micromechanical engagement between the

Table 2 Comparison of shear bond strengths (in MPa; mean ± SD) as a function of surface preparation[a]

Adhesive system	Surface preparation	*n*	Bond strength (MPa)
Johnson & Johnson	Surface cuts	10	15.3 (6.8)
Caulk	Surface cuts	10	11.5 (2.4)
3M	Surface cuts	10	11.0 (3.1)
Den-Mat	Surface cuts	10	10.0 (2.5)
Johnson & Johnson	60 grit SiC paper	10	7.12 (4.19)
3M	60 grit SiC paper	10	6.43 (4.84)
Vivadent	Surface cuts	10	6.39 (2.21)
Kerr	Surface cuts	11	5.66 (3.15)
Caulk	60 grit SiC paper	12	5.36 (1.71)
Den-Mat	60 grit SiC paper	11	3.99 (2.85)
Vivadent	60 grit SiC paper	10	3.38 (2.15)
Kerr	60 grit SiC paper	11	0.831 (0.491)

[a]Groups joined by vertical lines are not significantly different using Tukey's studentized range (HSD) test at the 95% confidence level

Table 2a Analysis of variance

Source	Sum of squares	Degrees of freedom	Mean square	*F*-ratio	Probability > *F*
Between surface preparation	925.479	1	925.479	82.011	0.0001
Between restorative systems	853.402	5	170.68	15.125	0.0001
Interaction	77.734	5	15.547	1.378	0.238
Error	1275.186	113	11.285		

surface and the solidified adhesive material. Ideally, the grooves or undercuts would be dimensioned in response to the viscosity characteristics of the fluid adhesive material so as to promote flow of the fluid adhesive material into the grooves or undercuts by capillary action and thus ensure complete penetration. Upon solidification of the adhesive material, the micro-mechanical attachment would be formed.

This study demonstrates an improvement of shear bond strengths of six adhesive systems to dentine that were finished with an experimental instrument compared to the control samples. Examination of the surfaces under magnification after failure indicated that the majority of those samples prepared with the experimental instrument had cohesive failure within the adhesive system which was sheared at the tooth surface. It was hypothesized that the parallel surface cuts produced projections of the adhesive material into the dentine that helped resist the shear forces perpendicular to those surface cuts.

CONCLUSIONS

The relative *in vitro* bond strength to dentine of six dentine adhesive systems was improved by the new surface finishing method described in this paper. The samples finished with a series of parallel retentive cuts gave shear bond strength values about double those

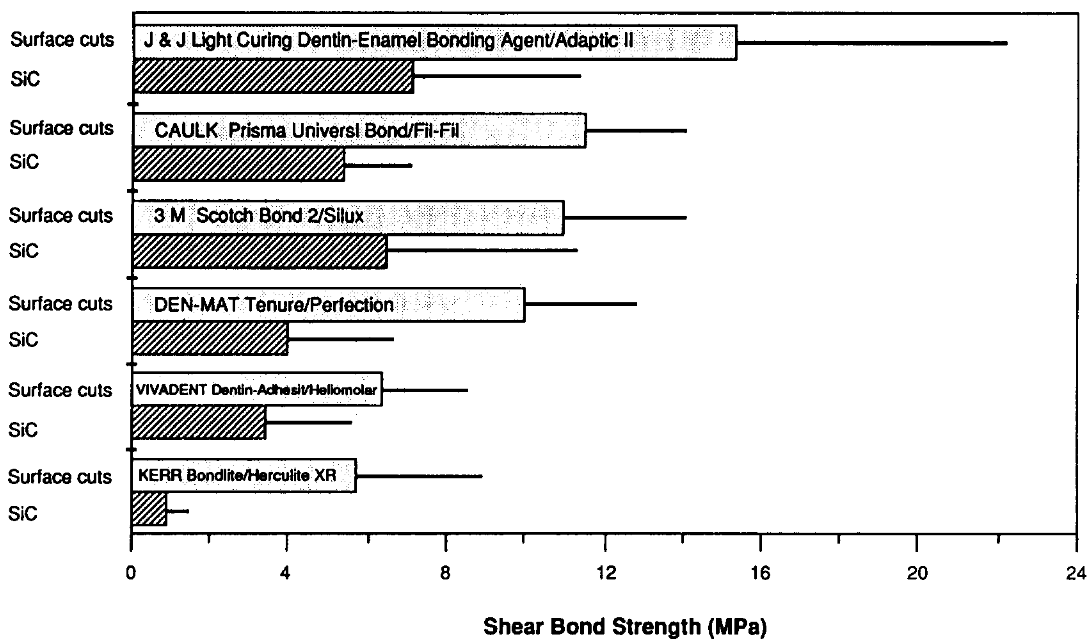

Figure 3 Mean shear bond strengths and standard deviation as a function of surface preparation

Table 3 Frequency of failure type

Adhesive system	Classification of failures[a] (%)					Surface preparation
	A	B	C	D	E	
Johnson & Johnson	90	10				60 grit
Caulk	100					
3M	90		10			
Den-Mat	90		10			
Vivadent	100					
Kerr	100					
Totals	95	2	3			
Johnson & Johnson	10			60	30	Surface cuts
Caulk	10	20		70		
3M				60	40	
Den-Mat				70	30	
Vivadent	20			80		
Kerr				100		
Totals	6	3	0	75	16	

[a]A = tooth/adhesive interface
B = mixed (interfacial + cohesive within adhesive system)
C = mixed (interfacial + cohesive within tooth)
D = cohesive within adhesive system
E = mixed cohesive (adhesive system + tooth)

finished with silicon carbide alone. The experimental instrument is designed to produce retentive grooves or undercuts in the dentine surface which enhance micromechanical adhesion.

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