Basic Science Research

Compressive Fracture Resistance of Porcelain Laminates Bonded to Enamel or Dentin with Four Adhesive Systems

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Purpose: **To measure the compressive strength of porcelain laminates of 0.5 or 1.0 mm thickness when bonded to enamel or dentin using these resin cements: All-Bond 2 + Choice, Panavia 21, Scotchbond + Opal, and Super-Bond C&B.**

Materials and Methods: **The buccal and lingual aspects of human molars were sectioned to prepare specimens at least 3 × 3 × 3 mm in size. Thirty horizontally flat enamel surfaces were prepared with a diamond disc for each group using a milling machine. Ten enamel specimens were randomly selected to test the fracture strength of 0.5-mm thick porcelain laminates without resin cement, and the data were recorded for a control group. The enamel specimens of each group were divided into two subgroups of 15 specimens to bond with either 0.5- or 1.0-mm thick porcelain laminates. Four resin cements were used for bonding of individual groups. All bonded specimens were stored in 37°C for 24 hours before fracture testing. The horizontally flat dentin surfaces were prepared on the fractured bonded specimens using a diamond disc for each group. Ten 0.5 mm porcelain laminates were randomly selected to test the fracture strength on dentin (control group). The bonded laminates to dentin were prepared using the same procedure as for enamel. The fracture strengths were statistically analyzed at $\alpha = 0.05$.**

Results: **Statistically significant differences in mean fracture strengths between groups were revealed. No significant difference in fracture strengths of control specimens between enamel and dentin was found. Super-Bond C&B provided a higher fracture resistance of porcelain than the other resin cements. Increasing the thickness of porcelain laminate increased the fracture strength. The 0.5-mm thick porcelain bonded to enamel had higher fracture strength than that of 1.0-mm thick porcelain bonded to dentin when using Super-Bond C&B and Scotchbond + Opal cements.**

Conclusions: **Bonding techniques and curing systems of resin cements influenced the fracture resistance of porcelain laminates. Dry bonding with auto-polymerization of Super-Bond C&B resin provided the highest fracture resistance of porcelain. Porcelain bonded to enamel with this resin had a much higher fracture strength than when bonded to dentin.**

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INDEX WORDS: fracture resistance, resin cement, porcelain laminate, compressive strength, enamel bonding, dentin bonding

FOR MORE THAN two decades, resin-bonding systems have been developed to improve the strength and reliability of bonding to tooth structure as well as to dental porcelain. Bonding resin to acid-etched enamel is reliable and provides better adhesion.[1,2] In contrast, bonding to dentin is more complicated because of the different characteristics of demineralized dentin as the bonding substrate.[3-7] Hybridization of dentin with polymethyl methacrylates using citric acid and ferric chloride aqueous conditioner makes bonding to demineralized dentin reliable in both dry and wet conditions.[8-11]

Dentin demineralized using phosphoric acid is easily collapsed when air-dried, resulting in poor permeability for impregnating monomers.[12-15] Wet bonding has been introduced to prevent the collapse of demineralized dentin conditioned with phosphoric acid and to make bonding more

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predictable;[16-18] however, poor resin content in the hybridized layer of wet-bonded dentin led to low-tensile bond strength and durability, which consequently caused bond failure after a short period.[19-21] In other words, incomplete monomer impregnation resulted in remaining demineralized dentin, which then can be hydrolyzed in a short time.[21] Most failures, such as secondary caries, marginal discoloration, and marginal gap/fracture of bonded restorations, occurred at the interface between restoration and prepared tooth.[22] Microleakage contributed to these failures and was initiated by the defects or microspace in demineralized dentin either under set acid–base cements or remaining after incomplete resin infiltration.[23,24]

To prevent the collapse of demineralized dentin and to reduce the numbers of bonding steps, a new bonding system—self-etching and self-priming—was developed.[25] Self-etching conditioners and primers diffuse by demineralizing through the smear layer and into tooth substrates. Therefore, reliable and durable bonds depend on the characteristics and thickness of the smear layer.[26-28]

Bonding evaluation in terms of mechanical strength has mostly been measured via tensile or shear testing.[29-33] One of the major components of masticatory forces is compressive stress. The compressive strength of porcelain veneers dependent on tooth preparation designs has been reported.[34] Whether the different characteristics of either the bonding substrates or resin systems have any effects on the compressive strength of brittle restorations, especially dental porcelain, have not yet been clarified.

Numerous methods have been designed to ensure adequate bonding of adhesive resin to porcelain. These approaches include both mechanical retention and chemical adhesion. Preparations for mechanical retention to porcelain surfaces can be achieved by grinding with a diamond bur,[32] air-abrasion with aluminum oxide,[33] and/or etching with highly acidulated phosphate fluoride[35-36] or hydrofluoric acid.[37-38] The use of silane coupling agents considerably enhanced the bond of resin to porcelain, as they promote chemical adhesion.[39-41]

The retention of resin-bonded porcelain restorations is not so dependent on the cavity preparation geometry when compared with non-adhesively retained restorations. Porcelain laminates with a thickness of 0.5–1.0 mm can be fabricated to provide a natural appearance. Therefore, a more conservative tooth preparation within enamel is possible. Enamel is less permeable than dentin; thus the occurrence of microleakage contributing to hypersensitivity, recurrent caries and pulpal inflammation after restoration is higher with the latter substrate.[23-24] However, one of the critical factors in porcelain restoration failure is fracture. Whether resin bonded to enamel enhances the fracture resistance of porcelain more than when bonded to dentin using different adhesive systems has not been well documented. The hypothesis of this study was that the fracture resistance of porcelain could be increased by the use of proper tooth-bonded resin.

The objective of this study was to determine the fracture strength of porcelain bonded to either enamel or dentin using different thicknesses of porcelain laminate and bonded with four resin adhesive systems.

Materials and Methods

Fabrication of Porcelain Laminate

Porcelain laminates (Dentin powder, Alpha-dur, Vita, Germany) with a surface area of 3 × 3 mm and thicknesses of 0.5 and 1.0 mm were fabricated according to manufacturer's recommendations. Flat surfaces were ground on all specimens to standardize the testing area using 180- to 1000-grit abrasive papers. Then, the surfaces to be cemented were sandblasted with 50 μm alumina oxide.

Testing of Enamel Specimens

Previously frozen human molars collected and stored in deionized water were used within 3 months of extraction. The buccal and lingual aspects were cut into rectangular shapes of 4 × 4 × 3 mm providing a surface of enamel and dentin of at least 3 × 3 mm (Fig 1A). The 0.5 mm inner dentin of each tooth specimen was embedded in a standardized self-cured acrylic block. A horizontally flat enamel surface was prepared on each specimen using a diamond disk (Intensive 170 D, Zurich, Switzerland) and a milling machine (KaVo EWL, Leutkirch, Germany) under air–water spray (Fig 1B).

The enamel samples were randomly divided into four groups of 30 specimens. Ten 0.5-mm thick porcelain and enamel specimens were randomly selected to test

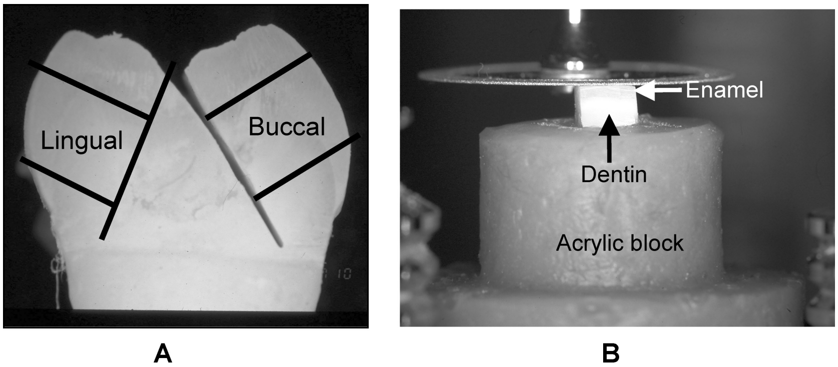

Figure 1. Preparation of tooth specimen (A) sectioning of buccal and lingual aspects (B) preparation of enamel specimen.

the fracture strength without bonding resin (control group). Porcelain laminates either 0.5- or 1.0-mm thick were primed with silane coupling agents and bonded on the etched enamel using different resin cements [All-Bond 2 and Choice (Bisco Inc., Schaumburg, IL), Panavia 21 (Kuraray Co., Osaka, Japan), Scotchbond + Opal (3M ESPE Dental Products Division, Minneapolis, MN), Super-Bond C&B (Sun Medical Co., Shiga, Japan)] for each individual group. The manipulation of cements followed the manufacturers' recommendations (Table 1). A minimal static load of 50 g (0.49 N) was applied for optimal seating of porcelain veneers. The excess cement was removed before the curing of resin. All specimens were polished at the interfacial areas using fine diamonds (Intensive) and then stored in water at 37 ± 2°C for 24 hours before testing the fracture

Table 1. Manipulations of Porcelain, Enamel, Dentin, and Different Resin Bonding Procedures

	Types of Resin Cements			
Procedures	*All-Bond 2 + Choice*	*Panavia 21*	*Scotchbond + Opal*	*Super-Bond C&B*
Porcelain treatment	Porcelain primer, applied 30 s and air-dried applied D/E Bonding resin	Clearfil porcelain bond, applied one coat and dried	Scotchbond ceramic primer, applied one coat and dried, applied adhesive	Porcelain M, applied one coat and dried
Enamel or dentin bonding	10% Phosphoric acid - etched 15 s, rinsed off, - air-dried 1–2 s, kept moist, - mixed primer A&B, applied five consecutive coats, air-dried 5—6 s, light cured 20 s - applied D/E Bonding resin	ED primer A&B - mixed and applied 60 s, – gently air dried	37% Phosphoric acid - etched 15 s, rinsed off, - air-dried 5 s, kept moist, - applied primer, air-dried 5 s - applied adhesive	Enamel: 65% phosphoric acid - etched 30 s, rinsed off - air-dried 10 s Dentin: 10% citric acid and 3% ferric chloride (10-3) - etched 10 s, rinsed off - air-dried 10 s
Cementation	Choice cement - applied on porcelain, fixed on tooth - removed excess cement - light cured, 40 s	Panavia 21 paste (TC) - mixed 20–30 s, applied on porcelain, fixed on tooth - removed excess cement - coated with oxy guard	3M Opal - applied paste A on porcelain, fixed on tooth - removed excess cement - light cured, 60 s	4 META/MMA + TBB + PMMA - mixed four drops + one drop + one cup - applied on porcelain, fixed on tooth - removed excess cement

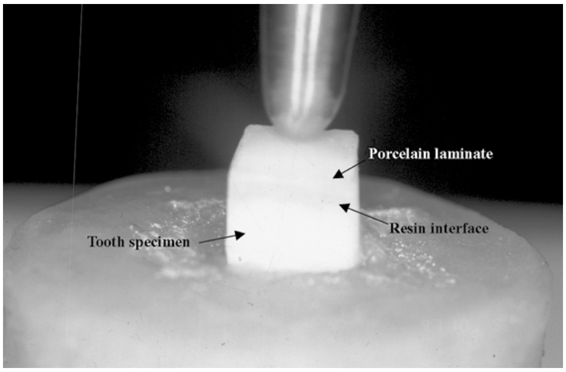

Figure 2. Fracture testing of resin-bonded porcelain under compressive force using a universal testing machine.

strength. Each specimen was aligned to the center of the universal testing machine (Lloyd, Farmingham, UK). A compressive load was applied via a 2 mm diameter crosshead with a constant speed of 1 mm/min (Fig 2). The maximum force before the specimen broke was recorded in newtons.

Testing of Dentin Specimens

After fracture testing of porcelain bonded to enamel, all specimens were horizontally cut through the dentin 0.5 mm below the dentinoenamel junction using diamond disks. For a control group, ten 0.5-mm thick porcelain laminates were randomly selected to test the fracture strength on the dentin specimens without resin–cement bonding. In the sample groups, porcelain laminates were bonded to dentin surfaces using the same cements as for enamel (Table 1). The compressive load testing followed the same procedure as for enamel specimens described previously.

The compressive strengths of cemented porcelains associated with different tissue substrates, porcelain thicknesses, and adhesive cements were analyzed using a 3-way ANOVA and Tukey test (SPSS version 10) at $p < 0.05$. Student's t-test was used to analyze the fracture strengths of non-cemented porcelains on enamel and dentin (control groups).

Results

The mean fracture strengths and standard deviations of control specimens and resin-bonded porcelain associated with different resin cements, enamel or dentin substrates, and porcelain thicknesses are presented in Figure 3. Student's t-test demonstrated no significant difference ($p > 0.05$) in mean fracture strengths of porcelain laminates between control groups either supported by enamel (465.8 ± 32.6 N) or dentin surfaces (452.4 ± 90.8 N). The 3-way ANOVA demonstrated statistically significant differences ($p < 0.001$) between groups dependent on substrate, thickness, resin, and their interactions (Table 2).

Porcelain bonded to enamel provided significantly higher fracture strength than that of porcelain bonded to dentin in all cement groups except in All-Bond 2 group. The thicker the porcelain, the greater the fracture resistance. Tukey analysis revealed significant differences in fracture strengths between groups of cements. Super-Bond C&B demonstrated significantly higher mean fracture strength of porcelains bonded both to enamel and to dentin than the other three resin cements. No significant difference in fracture strength of porcelain bonded to dentin was found between

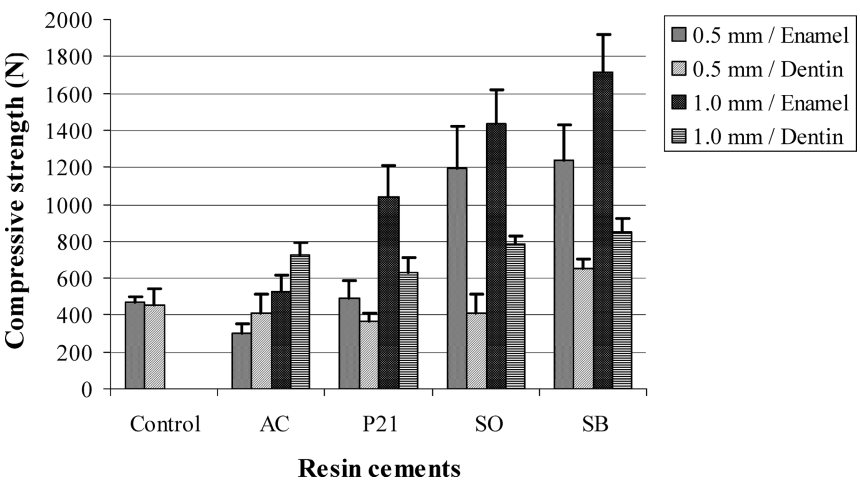

Figure 3. Mean fracture strength of resin-bonded porcelain associated with different substrates, porcelain thicknesses, and resin cements. AC = All-Bond 2 + Choice; P21 = Panavia 21; SO = Scotchbond multipurpose + Opal; SB = Super-Bond C&B; Bars = SD.

Table 2. Tests of Between-subjects Effects Using 3-way ANOVA

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Thickness	6634838.081	1	6634838.081	429.982	0.000*
Substrate	9152773.608	1	9152773.608	593.162	0.000*
Cement	14720185.844	3	4906728.615	317.989	0.000*
Thickness/Substrate	103235.424	1	103235.424	6.690	0.010*
Thickness/Cement	139983.271	3	46661.090	3.024	0.030*
Substrate/Cement	7942440.112	3	2647480.037	171.575	0.000*
Thickness/ Substrate/Cement	575135.416	3	191711.805	12.424	0.000*
Error	3456429.597	224	15430.489		
Total	195467661.100	240			

*Significant ($p < 0.05$).

Scotchbond + Opal, Panavia 21, and All-Bond 2, whereas significant differences between them were shown when bonded to enamel (Table 3).

The standardized coefficient (beta) values using multiple regression analysis suggested that the variables in substrate (enamel or dentin) had a greater power effect on fracture strength of resin-bonded porcelain than did the variables in thickness (0.5 or 1.0 mm).

Discussion

No statistically significant difference in fracture strength between control groups was found ($p > 0.05$), but significant differences ($p < 0.05$) among bonded groups associated with thickness, substrate, cement, and their interactions were demonstrated (Table 2). These suggested that the substrate, enamel, or dentin had no effect on the compressive strength of porcelain when it was not cemented with resin cements.

Statistically significant differences in the interactions of thickness/substrate/cement and substrate/cement ($p < 0.001$) were found. A significantly higher fracture strength of porcelain when bonded to enamel than when bonded to dentin was found for all cement groups except All-Bond 2, a wet bonding system. These results suggested that, with different techniques, resin bonded to enamel provided better support for porcelain than resin bonded to dentin. In other words, it is much easier to get a good bonding interface when resin-bonding porcelain to enamel compared with bonding to dentin. It was difficult to get good support when wet bonding using All-Bond 2, even when bonding to enamel.

A statistically significant difference in the highest fracture strength of porcelain bonded with Super-Bond C&B, the dry bonding system, was

Table 3. Statistical Significance of Differences between Mean Fracture Strengths (N) within Combination of Substrates, and Resin Cements at Different Porcelain Thickness

Substrate	*Cement*	*Mean ± SD (N)* 0.5 mm*		1.0 mm*	
Enamel	All-Bond 2 + Choice	301.2 ± 51.7	A	528.1 ± 89.2	E
Enamel	Panavia 21	492.7 ± 95.4	B	1042.5 ± 169.7	F
Enamel	Scotchbond + Opal	1191.0 ± 228.1	C	1438.2 ± 178.3	G
Enamel	Super-Bond C&B	1239.2 ± 188.3	C	1711.4 ± 208.0	H
Dentin	All-Bond 2 + Choice	406.8 ± 103.9	A B	728.4 ± 62.1	I J
Dentin	Panavia 21	364.7 ± 42.8	A B	628.4 ± 85.5	I J
Dentin	Scotchbond + Opal	407.8 ± 103.9	A B	785.0 ± 43.7	JK
Dentin	Super-Bond C&B	648.5 ± 51.2	D	850.2 ± 73.3	K

*Significant ($p < 0.05$).
Difference between groups at 0.5 or 1.0 mm thickness that were not significant using Tukey test ($p > 0.5$) are indicated by the same letter.

found when compared with the wet bonding resin systems, Scotchbond and All-Bond 2, and with self-etch-prime bonding, Panavia 21 (which currently has fluoride added and is marketed as Panavia Fluorocement). This suggests that the bonding systems influenced the fracture resistance of brittle porcelain. For many decades,[1] bonding of acrylic resin to phosphoric acid-etched enamel was originally a dry bonding system, and has been used to increase the micromechanical adhesion of a restoration to a tooth surface;[2] however, dry bonding on dentin using phosphoric acid etching does not provide good adhesion.[42] Super-Bond C&B has been the only dry bonding system that can provide good adhesion to both enamel and dentin since 1982.[3] The dentin surface was demineralized with 10% citric acid and 3% ferric chloride aqueous conditioner (10-3) and bonded with a self-cured 4-methacryloyloxyethyl trimellitate anhydride in methyl methacrylate initiated by tri-*n*-butyl borane (4-META/MMA-TBB) in the presence of polymethyl methacrylate (PMMA) resin (Table 1). Ferric chloride in the dentin conditioner stabilized the polyelectrolytes allowing it to be impregnated into the demineralized dentin.[43] Thus, the permeability of the demineralized dentin was maintained after air-drying, allowing the monomers to entirely impregnate it,[3,4,9,10,28,29] and hybridized enamel and dentin with high bond strength and durability were formed. This suggested that Super-Bond C&B was the best cement support for porcelain in resisting fracture as shown in this study.

The wet bonding system, All-Bond: fourth generation, was introduced in 1991,[18] because demineralized dentin etched with phosphoric acid collapsed when air-dried. Thus, monomers could not penetrate through the collapsed demineralized dentin to form a hybrid layer to provide good seal and retention. To prevent the collagen collapse, the demineralized dentin was kept moist by air-drying for only a few seconds. The remaining water was eliminated using primers before the application of bonding agents; however, controlling the degree of water in demineralized dentin (kept moist), as well as eliminating the remaining water, meant it was rather difficult to get reliable bonding.[10,19,20] The formation of a blister-like space, which interfered with the penetration of monomers into demineralized dentin has been reported.[44] The low resin content in the demineralized dentin resulted in a low-tensile bond strength and poor durability.[19,20] Furthermore, the degree of conversion in the curing process was reduced 50% because the unfilled resin was contaminated with water.[45] These might be the reasons wet bonding systems All-Bond 2 and Scotchbond Multipurpose yielded lower fracture strengths for porcelain than did dry bonding using Super-Bond C&B.

Keeping the demineralized substrate moist by using only 5 seconds air-drying using Scotchbond provided a significantly higher fracture strength of porcelain bonded to enamel than did 1 second air-drying using All-Bond 2. No significant difference in fracture strength of porcelain bonded to dentin was found between these two cement groups (Table 3). This result also suggested that controlling the degree of wetness in demineralized substrate to get a reliable resin support for porcelain was difficult.

The lower fracture strength of porcelain bonded to enamel using Panavia 21 than using Super-Bond C&B and Scotchbond + Opal (Table 3) implied that self-polymerization using oxy-guard to protect from oxygen contamination gave a weaker resin support for porcelain than the self- and light-cured Super-Bond C&B and Scotchbond + Opal, respectively. Moreover, ED primer (Panavia 21) was bonded through smear layers and plugs that only weakly attached to the tooth substrate. A hybridized smear layer is the weakest layer in tensile strength when compared with resin and hybridized dentin.[11,25-26]

The 1.0-mm thick porcelain provided a significantly higher mean fracture strength than the 0.5-mm thick porcelain when bonded to the same substrate with the same cement (Tables 2 and 3); however the higher significant level of interactions between substrate/cement ($p < 0.001$) than that of thickness/cement ($p < 0.03$) (Table 2) and the higher value of standardized coefficient (Beta) of the substrate effect (0.463) than that of the thickness effect (0.394) suggests that porcelain bonded to enamel mostly resisted the fracture strength better than that bonded to dentin in the range of 0.5–1.0 mm thickness porcelain. The 0.5 mm porcelain bonded to enamel using Super-Bond C&B and Scotchbond + Opal had higher fracture strength than the 1.0 mm porcelain bonded to dentin. Therefore, to restore a tooth with resin-bonded porcelain, minimal preparation just into enamel and bonded with Super-Bond C&B resin cement could reliably achieve the highest fracture resistance during compressive loading.

In this study the outer surface of porcelain laminate was not glazed, but was polished with up to 1000-grit abrasive paper to create the flat plane for a standardized testing area. The rough surface could have a considerable impact on testing outcomes. Thus, with the glazed surface, porcelain laminate might even resist the compressive fracture strength better than that of this study.

Conclusion

Complete hybridization of resin into conditioned substrates not only had effects in shear or tensile bond strength and level of leakage, but also in the fracture resistance of porcelain laminates. The techniques of either bonding or curing of resin cements had effects on the durability of bonding interfaces, which in turn influenced the fracture strength of resin-bonded porcelains. The results of this study suggest that porcelain bonded both to enamel or to dentin using Super-Bond C&B provided the highest resistance to fracture. Minimal preparation just into enamel for 0.5 mm porcelain thickness achieved better fracture strength for resin-bonded porcelain than a deeper preparation into dentin for 1.0 mm porcelain thickness.

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