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Laboratory and FEA evaluation of dentin-to-composite bonding as a function adhesive layer thickness

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ABSTRACT

Objective. The aim of this study was to test the hypothesis that microtensile bond strength values are inversely proportional to dentin-to-composite adhesive layer thickness through laboratory mechanical testing and finite element analysis.

Method. Eighteen noncarious third molars were obtained, and occlusal enamel removed perpendicular to the tooth long axis. Two different adhesive systems were utilized as follows ($n = 3$): (1) application of a single layer of Single Bond (3M ESPE Co.) and Clearfil SE Bond (Kuraray Co.) following the manufacturer's directions; (2) application of one layer of both adhesive systems followed by one additional layer; (3) application of one layer of both adhesive systems followed by two additional layers. A 4 mm build up was fabricated in increments on each tooth sample (Z 100 composite, 3M ESPE). Section measurements were performed and specimens were separated into three adhesive thickness groups per material (40, 40–80 and 80–120 μm) for microtensile testing. The bond strength data (MPa) were analyzed by one-way ANOVA and Tukey test. Maximum principal stresses (MPS) were determined through FEA for three different adhesive layer thicknesses (20, 50 and 100 μm).

Results. The bond strength data obtained for Single Bond at 0–40 μm presented significantly higher values compared to higher adhesive layer thickness groups. There were no statistical differences among bond strength values for all Clearfil SE Bond adhesive layer thicknesses. FEA modeling indicated that MPS increased as adhesive layer increased. The hypothesis was accepted for the Single Bond only.

Significance. Correspondence (not tested statistically) between microtensile laboratory testing and FEA model was only observed for Single Bond as increased adhesive layer thickness did not reduce Clearfil SE Bond strength.

1. Introduction

There are several approaches to produce dentin hybridization and adequate dentin bonding for resin-based composite restorations. A common approach is the total etching technique followed by the application of a solution containing primer and adhesive resin to moist dentin [1,2]. An alternative approach is the self-etching priming technique, using an acidic primer followed by an adhesive resin [3]. Both approaches have produced high bond strength values and well-infiltrated hybrid layers in dentin [1].

Prati et al. [4], in 2002, evaluated the morphology of the hybrid layer using several adhesive systems. Their study demonstrated that the collagen fibrils were not completely

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infiltrated by resin after the bonding procedure, and that the presence of non-infiltrated collagen may jeopardize bond strength values over time. Prati et al. [4] also suggested that the thickness of the hybrid layer might not be the most important factor concerning bond strength values, and variables such as the microscopic level interaction between resin, bonding agent, and tooth substrate should be taken into consideration. Until more information becomes available regarding the contribution of hybrid layer thickness to the overall bond strength, the use of thicker adhesive layers seems to provide reduced interfacial stress as determined by tensile bond testing [4–6]. Other factors like variation in different materials' Young's modulus, and contraction stress generated during and after bonding procedures have been cited as affecting the longevity of adhesive bonds to tooth structures [5].

The rationale behind the utilization of thicker dentin adhesive layers is an attempt to provide a relatively flexible, stress-absorbing layer between composite and enamel and/or dentin substrate [7]. It has been demonstrated that thicker adhesive layers resulted in lower interfacial stresses [8]. It has also been shown that filled adhesives usually present thicker layers compared to their unfilled counterparts, which may improve interfacial bond strength [9,10]. Based on these observations [8–10], where different bond strength values may result from variations in adhesive layer thickness, conventional laboratory testing methods should consider the geometry and mechanical properties of each substrate (dentin, adhesive, and resin) in order to provide more practical evidence of bonding failure mechanisms.

It has been demonstrated that the stresses in the dentin–adhesive–composite are complex and sensitive to geometry and size of the bonding interfaces [11,12]. While an appropriate analytical solution taking into consideration different materials' behavior and mechanical properties for the microtensile mechanical test [12] is yet to be developed, finite element analysis (FEA) has been used to validate studies concerning the sensitivity of bond strengths tests to specimen design and changes in materials utilized. Ausiello et al. [13], performed a study using finite element analysis in a tooth-restoration model which demonstrated that a thicker adhesive layer resulted in more uniform stress distribution.

Considering the limited amount of work relating the bond strength to different adhesive layer thicknesses and FEA, this study was conducted testing the hypothesis that a reduction of the microtensile bond strength would be observed as adhesive layer thickness increases.

2. Materials and methods

The materials used in this study are listed in Table 1. Eighteen freshly noncarious third molars were obtained under a protocol approved by the NYU College of Medicine Institutional Review Board, and were sterilized by gamma irradiation [14]. The occlusal enamel of each tooth was removed perpendicular to the tooth long axis using a diamond saw (Buehler Isomet low speed saw with Buehler Diamond Wafering Blade, Series 20 HC Diamond, No. 11-4215, Buehler, USA) to expose a flat dentin surface, which was subsequently polished using a 600-grit silicon-carbide paper (Buehler, Phoenix Beta Polisher and grinder) (Fig. 1A and B). Following these procedures, the specimens were randomly assigned to two groups which were bonded using two different adhesive systems based on the number of adhesive coatings applied ($n = 3$ teeth per group) on the dentin substrate. The specimens were categorized as follows:

SBC: (control): Single Bond (3M ESPE) adhesive system was applied following the manufacturer's instruction.
SB1: Following application and polymerization of a single layer of Single Bond (3M ESPE) adhesive system, an additional adhesive layer was applied and polymerized.
SB2: Following application and polymerization of a single layer of Single Bond (3M ESPE) adhesive system, two additional adhesive layers were applied and polymerized.
SEC: (control): A single layer of Clearfil SE Bond (Kuraray Co.) adhesive system was applied following the manufacturer's instruction.
SE1: Following application and polymerization of a single layer of Clearfil SE (Kuraray Co.) adhesive system, an additional adhesive layer was applied and polymerized.
SE2: Following application and polymerization of a single layer of the Clearfil SE (Kuraray Co.) adhesive system, two

Table 1 – Manufacturer's information of materials utilized in the present study

	Composition	Lot/no.	Company
Single Bond (3M, ESPE Co.)	Bis-GMA; polyalkenoic acid co-polymer; dimethacrylates; HEMA; photoinitiator; ethanol; water	3411; 2GM	St. Paul, MN, USA
Scotchbond Etchant (3M ESPE Co.)	35% phosphoric acid; gel	7523; 2XY	St. Paul, MN, USA
Clearfil SE Bond Primer (Kuraray Co.)	10-Methacryloyloxydecyl dihydrogen phophate (MDP); 2-hydroxyethyl methacrylate (HEMA); hydrophilic dimethacrylate; DL-camphorquinone; *N*,*N*-diethanol-*p*-toluidine; water	61243; 272	New York, NY, USA
Clearfil SE Bond (Kuraray Co.)	10-Methacryloyloxydecyl dihydrogen phophate (MDP); bis-phenol A diglycidylmethacrylate (HEMA); hydrophobic dimethacrylate; DL-camphorquinone; *N*,*N*-diethanol-*p*-toluidine; silanated colloidal silica	61243; 327	New York, NY, USA
Z 100 Composite (3M Co.)	Bis-GMA, TEGDMA resins	20020924	St. Paul, MN, USA
Silicon Paper (Buehler)	600-grit	No: 305118600100	Lake Bluff, IL, USA
Curing Light 2500	–	Serial # 3016930	Oakdale, MN, USA