Published in final edited form as:

Dent Mater. 2007 July ; 23(7): 871–877.

Adhesive analysis of voids in class II composite resin restorations at the axial and gingival cavity walls restored under *in vivo* versus *in vitro* conditions

John H. Purk^{a,*}, Vladimir Dusevich^b, Alan Glaros^c, and J. David Eick^b

a Department of Restorative Dentistry, University of Missouri-Kansas City, School of Dentistry, 650 East 25th Street, Kansas City, MO 64108, USA

b Department of Oral Biology, University of Missouri-Kansas City, School of Dentistry, Kansas City, MO, USA

c Kansas City University of Medicine and Biosciences, Kansas City, MO, USA

Abstract

Objectives—Adhesive analysis, under the scanning electron microscope of microtensile specimens that failed through the adhesive interface, was conducted to evaluate the amount of voids present at the axial versus gingival cavity walls of class II composite restorations restored under *in vivo* and *in vitro* conditions.

Methods—Five patients received class II resin composite restorations, under *in vivo* and *in vitro* conditions. A total of 14 premolar teeth yielded 59 ($n = 59$) microtensile adhesive specimens that fractured through the adhesive interface. The fractured surfaces of all specimens were examined and the % area of voids was measured.

Results—Voids at the adhesive joint were highly predictive of bond strengths. An increase in the number of voids resulted in a decrease in the microtensile bond strength. The area of voids at the adhesive interface was as follows: *in vivo* axial $13.6 \pm 25.6\%$ ($n = 12$); *in vivo* gingival $48.8 \pm 29.2\%$ ($n = 12$); *in vitro* axial $0.0 \pm 0.0\%$ ($n = 19$) and *in vitro* gingival $11.7 \pm 17.6\%$ ($n = 16$).

Significance—Composite resin may bond differently to dentin depending upon the amount of voids and the cavity wall involved. The bond to the gingival wall was not as reliable as the bond to the axial wall. An increase in the amount of surface voids was a major factor for reducing microtensile bond strengths of adhesive to dentin.

Keywords

Void analysis; Micro-tensile bond test; Stress; Mechanical; Dental bonding; Dental cavity preparation; Dentin ultrastructure microscopy; Dental restoration failure

1. Introduction

The bond strength of dentin adhesive resins is greatest when the surface of the dentin is slightly moist [1-4]. If the dentin surface is too wet the adhesive resin does not fully penetrate the dentin

*Corresponding author. Tel.: +1 816 235 2168; fax: +1 816 235 5524. E-mail address: purkj@umkc.edu (J.H. Purk).

Publisher's Disclaimer: This article was originally published in a journal published by Elsevier, and the attached copy is provided by Elsevier for the author's benefit and for the benefit of the author's institution, for non-commercial research and educational use including without limitation use in instruction at your institution, sending it to specific colleagues that you know, and providing a copy to your institution's administrator.

tubules or the demineralized dentin [5-11]. Sources of wetness include fluid from the dentin tubules, hydrophilic primers, sulcular fluid, humidity of the mouth, and residual water left from the etching and washing process. The presence of too much water can create small, isolated, blister-like spaces or voids that are trapped along the surface of the hybrid layer [8]. The voids are partially filled with extraneous resin globules dispersed within an amorphous matrix [8] and are often continuous with incompletely sealed tubular orifices. Excess solvent remaining on a primed dentin surface will prevent complete adaptation of bonding resin and may result in non-attachment [12] or voids at the resin–dentin interface [13].

If the demineralized dentin at the gingival location of class II preparations is too wet and not fully hybridized, it can become vulnerable to hydrolytic breakdown and penetration by bacterial enzymes or other toxic substances [11,13], thereby compromising the integrity and strength of the dentin-adhesive bond [14] and ultimately the restoration [14-16]. Gaps between the composite and tooth also increase the risk for restorative failure and secondary caries, and restorations at the gingival margin appear to be especially likely to have such gaps [17-19].

The anatomy of the tooth at the gingival wall may account for the vulnerability of restorations to gaps. The density of dentin tubules 1.0 mm above the CEJ at the gingival cavity wall is 49% greater than at the axial wall [20]. After dentin is acid etched, the surface area of exposed tubules can increase from 1% to 13% at the DEJ and from 22% to 34% close to the pulp [21]. As the number of tubules increases, the pulp can force moisture in the form of intrinsic pulpal fluid to increase on the dentin surface. This excess moisture can reduce the adaptability of the restorative material to the prepared surface.

Most data on dentin bonding come from laboratory studies, and little is known about the differences in the test-fractured surfaces obtained after bonding under *in vivo* conditions at the gingival wall of class II composite restorations. Previous fractographic studies found that as the bond strength increased the area percentage of failure through the top of the hybrid layer decreased [22,23]. Also with higher bond strengths the area percentage of failure through the resin composite, bonding resin, within the hybrid layer and dentin increased [22,23].

In this study, the impact of surface voids on adhesive bond strength was analyzed. It was hypothesized that both location (axial versus gingival) of the bond and the conditions under which the materials were placed (*in vivo* versus *in vitro*) would significantly influence adhesive bond strength. It was further hypothesized that the surface area of voids also affects microtensile bond strength. Multiple regression to assess the relative contribution of these variables on final bond strength was used. The null hypotheses to be tested were: (1) there is no significant difference between the amount of surface area of voids as a function of location of bond (axial versus gingival) and of condition (*in vivo* versus *in vitro*); (2) the amount of surface area of voids does not predict microtensile bond strength.

2. Materials and methods

The design, recruitment of patients, sample preparation, materials and lot numbers used in the study have been previously reported [24]. The research design was a 2×2 (condition {*in vivo* versus *in vitro*} versus location {axial versus gingival}) controlled clinical trial. A minimum sample size of 18 per cell (total $N = 72$) met the criteria for detecting a mean difference of 25%, with $\alpha = 0.05$ and power = 0.80. Five patients received class II resin composite restorations in premolars that were treatment planned for extraction. A total of 14 non-carious human premolars were restored. If the patient had four premolars to be extracted, two (one maxillary and one mandibular) teeth received restorations under *in vivo* conditions and the other two on the opposite side of the arch received restorations under *in vitro* conditions after the teeth were extracted. Teeth were randomly assigned to treatment conditions. All

subjects signed an informed consent form approved by the University's Institutional Review Board.

Teeth were isolated with a rubber dam. Each tooth received separate mesial and distal box preparations separated by an intact isthmus. Interproximal contact was broken at a depth of approximately 4.0 mm. An attempt was made to keep the gingival margin 1.0 mm above the CEJ. The buccal–lingual width of the preparation was approximately 5.0 mm, and the axial depth was 1.5–2.0 mm. Enamel margins were not beveled. A halogen light curing unit (XL 3000, 3M-ESPE, St. Paul, MN) was used to cure all specimens. Light intensity was measured before and after placement of the restoration using a Demetron light meter (Kerr Corp., Orange, CA) to confirm a minimum light intensity of 500 mW/cm². All materials were applied according to manufacturer's directions. Scotchbond Multi-Purpose (SBMP) adhesive (3M-ESPE) was added to the primed enamel and dentin and light-cured for 10 s. Z-100 shade A-3 restorative material (3M-ESPE) was placed in four increments in layers less than 2.0 mm. The first increment was placed parallel to the gingival floor at a thickness of ~1.0 mm. The next three increments were placed at oblique angles until the preparation was restored to its original contours. Between increments and after final polishing, the material was light cured for 40 s each from the buccal, lingual, and occlusal directions. The restoration was finished with a high speed hand-piece under an air/water spray using a 12 bladed finishing bur and polished with finishing discs (Soflex, 3M-ESPE). Occlusion was restored to its pre-operative condition.

The teeth were extracted 24 h after the placement of the *in vivo* restorations with light forcep pressure on the roots. The teeth were stored in a mixture of 0.9% sodium chloride solution (normal saline) and 0.002% sodium azide (Fisher Scientific, Versailles, KY) at 37 °C. Each tooth was sectioned 24 h after restoration using an Isomet low-speed saw (Buehler Ltd., Lake Bluff, IL) under water with a 4 in × 0.012 in diamond rim blade. Samples were cut to form a flat rectangular plane with a cross-sectional area of 0.5 mm² with no notch at the adhesive junction. The thickness of each section was measured with a digital micrometer (Mitutoyo, Aurora, IL). Three gingival sections were created from one of the proximal boxes, and three axial sections were created from the remaining proximal box. If tooth size permitted, four sections per proximal box were obtained.

Samples were attached to the opposing arms of a Bencor Multi-T testing device (Danville Engineering Inc., San Ramon, CA) using a cyanoacrylate adhesive and accelerator (Zapit, Dental Ventures of America Inc., Corona, CA). Tensile stress was measured on a Universal Instron testing machine Model 1125 (Instron Corp., Canton, MA) using a 4903 N load cell at a crosshead speed of 1.0 mm/min.

The fractured specimens were sputter coated with gold–palladium and imaged using a Phillips XL30 environmental scanning electron microscope-field emission gun (ESEM-FEG) Microscope (FEI Co., Hillsboro, OR) up to 2500 × magnification at 15.0 kV. Using the ESEM, the mode of failure was identified as a cohesive dentin failure, a cohesive composite failure, or an adhesive failure. If any part of the adhesive layer was involved, failure was categorized as an adhesive failure. An adhesive failure could include portions that partially involved composite resin, adhesive, hybrid zone, interface of adhesive and dentin, or an area of the sample that contained voids. Samples containing enamel or Zapit adhesive were discarded. The total area of the fractured surface and the areas containing voids on the SEM microphotographs were measured with image analyzer software Image Tool (University of Texas Health Science Center, San Antonio, TX) and PhotoShop™ (Adobe Systems Inc., San Jose, CA). The area consisting of surface voids was divided by total surface area of the fractured specimen to obtain the percent of the fractured area consisting of voids.

3. Results

During preparation of the 89 microtensile samples with the low speed saw, 19 samples debonded (17 gingival and 2 axial). The debonded samples were not included in the strength or void calculations because the samples were unable to be tested for microtensile bond strength on the Instron. After SEM observation, four samples were discarded due to the presence of either Zapit adhesive or enamel at the adhesive joint. Additionally samples that failed cohesively (7) were also excluded, leaving 59 microtensile samples that failed adhesively for data analysis. Summary data for bond strengths, number of adhesive debonds during sample preparation, the percent area of voids at the fracture site and the variation in the cross-sectional area is presented in Table 1. *In vitro* axial samples demonstrated the highest strength, and *in vivo* gingival samples demonstrated the lowest strength. *In vivo* samples were significantly weaker than *in vitro* samples, and gingival bond strengths were significantly weaker than axial bond strengths ($p \leq 0.001$). The interaction between condition and location was not significant ($p \leq 0.05$). The adjusted R^2 for the model was 0.37.

The proportion of the fracture site occupied by voids is also reported in Table 1. Nearly half of the total area in the *in vivo* gingival group consisted of voids and 83% (10/12) of the samples in this group contained voids. None of the total area in the *in vitro* axial group had voids. A two-way ANOVA found a statistically significant main effects for conditions, locations ($p \leq 0.001$), and for their interaction ($p \leq 0.05$). *In vivo* specimens contained more voids than *in vitro* specimens and gingival specimens contained more voids than axial specimens. Therefore, the first null hypothesis was rejected.

Fig. 1 illustrates voids (1000 $\times$ from a sample in the *in vitro* gingival group. Fig. 2 shows an *in vivo* axial sample that had a microtensile bond strength of 34.8 MPa, Fig. 3 shows an *in vivo* gingival sample that had a microtensile bond strength of 15.4MPa, Fig. 4 shows an *in vitro* axial sample that had a microtensile bond strength of 55.8MPa and Fig. 5 shows an *in vitro* gingival sample with a microtensile bond strength of 30.1MPa. Overall, greater bond strength is associated with fewer voids.

A multiple regression analysis was conducted to predict microtensile bond strengths. The predictor variables were location (axial versus gingival), condition (*in vivo* versus *in vitro*) and percent voids. The overall model was significant, $F(3,55) = 35.59$, $p < 0.001$ and accounted for 64% of the variance (adjusted R^2) in microtensile values. The beta coefficients, t values, and part correlations are presented in Table 2. Part correlations indicate the correlation of each predictor with the effects of the other predictors removed. Percent voids were strongly related to microtensile bond strengths, with location a significant but considerably weaker predictor. As the proportion of voids increased and restorations were placed gingivally, the microtensile bond strength decreased. Therefore, the second null hypothesis was rejected.

4. Discussion

Voids in materials have an impact on the performance of adhesive materials. There were more voids through the adhesive at the gingival wall than the axial wall and under *in vivo* conditions than under *in vitro* conditions; the area of voids significantly predicted microtensile bond strength. Voids result in stress concentrators [25] and incomplete adhesion to dentin. Voids more strongly predict bond strength than location or condition of the restoration. The *in vivo* gingival group had the lowest bond strength and the highest percentage of voids. These voids throughout the adhesive layer, approximately 5–40 μm in diameter, appeared as blister-like spaces and were similar to those reported elsewhere [8].

More voids at the gingival wall may occur under *in vivo* conditions from moisture contamination due to hydrostatic pulpal pressure, dentinal fluid flow after removal of the smear

layer [11,26-29], working in an environment where isolation of the tooth is difficult, pooling of solvents and adhesives at the corners of the preparation box, increased permeability of dentin at the gingival wall [20,21,31], or probably the most important is the inability of air drying to remove excess water at this location. When contaminated with water, bonding resins that contain HEMA and Bis-GMA can undergo phase separation that can reduce the conversion level of the adhesive system by 50% [30]. As little as 9% volume of water added to a HEMA/Bis-GMA bonding resin under wet conditions can weaken the resin by 64% [31].

Previous research shows that resin bonded under *in vitro* conditions in class V lesions to parallel-oriented tubules (occlusal) had higher microtensile bond strengths than resin bonded to perpendicularly oriented tubules (gingival) when the dentin surfaces were treated with phosphoric acid etching systems by ~11–13MPa [32]. Tubule direction may also determine the intrinsic wetness of the surface [33]. The gingival wall of a class II cavity contains predominantly perpendicular oriented tubules [34]. Cutting and etching tubules oriented in a perpendicular direction, such as in gingival walls, might result in a continuous reservoir of fluid that is fed by capillary action resulting in a wetter surface; where cutting and etching tubules in a parallel direction might result in a one time “spilling” of dentinal fluid without a continuous feed. In a separate SEM observation by the author more dentinal tubules on the axial wall were oriented in a parallel direction. These differences in the anatomy of the two locations may also account for the larger number of debonds at gingival sites than at axial sites. The bonding dentin substrate at the gingival margin may contribute little in terms of micromechanical retention [34].

Voids along the tooth–restorative interface from excessive moisture can result in fluid and bacteria movement through the interface that can be experienced by the patient as post-operative sensitivity and recurrent caries [35,36]. Secondary caries are by far more common at the gingival location, regardless of restoration type or restorative material used [37]. Narrow gaps, crevices, ditches, and “microleakage” do not lead to secondary caries, but wide voids may [38].

Clinicians interested in enhancing bond strength must control the amount of wetness on the dentin surface. In order for a good bond to develop between the dentin and adhesive, all excess moisture on the dentin surface should be replaced by monomers in the primer and adhesives during the bonding procedure [39]. It is very difficult for an operator to determine if the dentin surface is ‘too wet’ or ‘too dry’. Rinsing and drying steps are difficult to standardize [5,28] under clinical conditions. Ethanol or acetone adhesives that displace water and are more volatile might behave better in a “too wet” environment at the gingival wall of class II preparations. Reducing the amount of time dentin is etched might also reduce the amount of wetness from the dentinal tubes. Perhaps using a weaker acid for dentin etching (10% maleic) and a stronger acid (35% phosphoric) for enamel etching might result in better adhesion and less voids.

The advantage of an *in vitro* model is that it gives well controlled experimental conditions but fails to account for the complexities of conditions that are found under *in vivo* conditions. *In vitro* conditions may over-estimate bond strengths in *in vivo* conditions. Greater effort should be directed to *in vivo* approaches to bond strength testing [40] in order to determine the optimal etchants and etching times for conditioners used on dentin [41]. Reducing the number of voids at the adhesive dentin interface will improve the tensile bond of the adhesive to the dentin and improve clinical outcomes for patients.

Acknowledgements

The authors thank Don Krenkel for his help in conducting this study. Based on a dissertation conducted the first author in partial fulfillment of the requirements for the Ph.D. degree. This investigation was supported in part by USPHS Grant DE07294, DE09696 and DE016324-01A1 and the Rinehart Foundation of the UMKC School of Dentistry. The

authors thank 3M-ESPE Dental Products, St. Paul, MN, for donating a curing light, resin composite and bonding agent used in this evaluation.

REFERENCES

1. Kanca J III. Resin bonding to wet substrate. 1. Bonding to dentin. *Quint Int* 1992;23:39–41.
2. Eick JD, Robinson SJ, Cobb CM, Chappell RP, Spencer P. The dentinal surface: its influence on dentinal adhesion. 2. *Quint Int* 1992;23:43–51.
3. Perdigao J, Frankenberger R. Effect of solvent and rewetting time on dentin adhesion. *Quint Int* 2001;32:385–90.
4. Nakajima M, Sano H, Zheng L, Tagami J, Pashley DH. Effect of moist vs. dry bonding to normal vs. caries-affected dentin with Scotchbond Multi-Purpose Plus. *J Dent Res* 1999;78:1298–303. [PubMed: 10403456]
5. Pereira GD, Paulillo LA, De Goes ME, Dias CT. How wet should dentin be? Comparison of methods to remove excess water during moist bonding. *J Adhes Dent* 2001;3:257–64. [PubMed: 11803713]
6. Tay FR, Gwinnett JA, Wei SH. Micromorphological spectrum from overdrying to overwetting acid-conditioned dentin in water-free acetone-based, single-bottle primer/adhesives. *Dent Mater* 1996;12:236–44. [PubMed: 9002841]
7. Tay FR, Gwinnett AJ, Wei SH. The overwet phenomenon: a transmission electron microscopic study of surface moisture in the acid-conditioned, resin–dentin interface. *Am J Dent* 1996;9:161–6. [PubMed: 9002792]
8. Tay FR, Gwinnett AJ, Wei SH. The overwet phenomenon: a scanning electron microscopic study of surface moisture in the acid-conditioned, resin–dentin interface. *Am J Dent* 1996;9:109–14. [PubMed: 9002800]
9. Tay FR, Gwinnett AJ, Wei SH. The overwet phenomenon: an optical, micromorphological study of surface moisture in the acid-conditioned, resin–dentin interface. *Am J Dent* 1996;9:43–8. [PubMed: 9002816]
10. Van Meerbeek B, Yoshida Y, Lambrechts P, Vanherle G, Duke ES, Eick JD, et al. A TEM study of two water-based adhesive systems bonded to dry and wet dentin. *J Dent Res* 1998;77:50–9. [PubMed: 9437399]
11. Spencer P, Wang Y, Walker MP, Wieliczka DM, Swafford JR. Interfacial chemistry of the dentin/adhesive bond. *J Dent Res* 2000;79:1458–63. [PubMed: 11005728]
12. Walshaw PR, McComb D. Microscopic features of clinically successful dentine bonding. *Dent Update* 1998;25:281–6. [PubMed: 10478022]
13. Walshaw PR, McComb D. Clinical considerations for optimal dentinal bonding. *Quint Int* 1996;27:619–25.
14. Hashimoto M, Ohno H, Endo K, Kaga M, Sano H, Oguchi H. The effect of hybrid layer thickness on bond strength: demineralized dentin zone of the hybrid layer. *Dent Mater* 2000;16:406–11. [PubMed: 10967189]
15. Spencer P, Swafford JR. Unprotected protein at the dentin–adhesive interface. *Quint Int* 1999;30:501–7.
16. Opdam NJ, Roeters JJ, Kuijs R, Burgersdijk RC. Necessity of bevels for box only Class II composite restorations. *J Prosthet Dent* 1998;80:274–9. [PubMed: 9760359]
17. Eick JD, Welch FH. Polymerization shrinkage of posterior composite resins and its possible influence on postoperative sensitivity. *Quint Int* 1986;17:103–11.
18. Roulet JF. Benefits and disadvantages of tooth-coloured alternatives to amalgam. *J Dent* 1997;25:459–73. [PubMed: 9604577]
19. Wilson NH. Conference report. Direct adhesive materials: current perceptions and evidence—future solutions. *J Dent* 2001;29:307–316. [PubMed: 11499388]
20. Garberoglio P. The ratio of the densities of dentinal tubules on the cervical and axial walls in cavities. *Quint Int* 1994;25:49–52.
21. Nakabayashi, N.; Pashley, DH. *Hybridization of dental hard tissues*. Quintessence Publishing Co. Ltd.; Chicago: 1998.

22. Hashimoto M, Ohno H, Kaga M, Sano H, Endo K, Oguchi H. The extent to which resin can infiltrate dentin by acetone-based adhesives. *J Dent Res* 2002;81:74–8. [PubMed: 11820372]
23. Hashimoto M, Ohno H, Kaga M, Sano H, Endo K, Oguchi H. Fractured surface characterization: wet versus dry bonding. *Dent Mater* 2002;18:95–102. [PubMed: 11755587]
24. Purk J, Dusevich V, Glaros A, Spencer P, Eick J. In vivo versus *In vitro* microtensile bond strength of axial versus gingival cavity preparation walls in class II resin-based composite restorations. *J Am Dent Assoc* 2004;135:185–93. [PubMed: 15005434]
25. Anusavice, Kenneth, editor. *Phillips' science of dental materials*. 10th ed.. W.B. Saunders Company; Philadelphia, PA: 1996. p. 71-2.
26. Hannig M, Friedrichs C. Comparative in vivo and in vitro investigation of interfacial bond variability. *Oper Dent* 2001;26:3–11. [PubMed: 11203774]
27. Xie J, Powers JM, McGuckin RS. In vitro bond strength of two adhesives to enamel and dentin under normal and contaminated conditions. *Dent Mater* 1993;9:295–9. [PubMed: 7995480]
28. Perdigao J, Lopes M. Dentin bonding—questions for the new millennium. *J Adhes Dent* 1999;1:191–209. [PubMed: 11725668]
29. Maroli S, Khera SC, Krell KV. Regional variation in permeability of young dentin. *Oper Dent* 1992;17:93–100. [PubMed: 1437697]
30. Jacobsen T, Soderholm KJ. Some effects of water on dentin bonding. *Dent Mater* 1995;11:132–6. [PubMed: 8621034]
31. Paul SJ, Leach M, Rueggeberg FA, Pashley DH. Effect of water content on the physical properties of model dentine primer and bonding resins. *J Dent* 1999;27:209–14. [PubMed: 10079627]
32. Ogata M, Nakajima M, Sano H, Tagami J. Effect of dentin primer application on regional bond strength to cervical wedge-shaped cavity walls. *Oper Dent* 1999;24:81–8. [PubMed: 10483444]
33. Ogata M, Okuda M, Nakajima M, Pereira PN, Sano H, Tagami J. Influence of the direction of tubules on bond strength to dentin. *Oper Dent* 2001;26:27–35. [PubMed: 11203773]
34. Cagidiaco MC, Ferrari M, Vichi A, Davidson CL. Mapping of tubule and intertubule surface areas available for bonding in Class V and Class II preparations. *J Dent* 1997;25:379–89. [PubMed: 9241956]
35. Tay FR, Gwinnett AJ, Pang KM, Wei SH. Variability in microleakage observed in a total-etch wet-bonding technique under different handling conditions. *J Dent Res* 1995;74:1168–78. [PubMed: 7790594]
36. Lutz F, Krejci I. Resin composites in the post-amalgam age. *Compendium* 1999;20:1138–44. [PubMed: 10850266]1146, 1148
37. Mjor IA. The location of clinically diagnosed secondary caries. *Quint Int* 1998;29:313–7.
38. Mjor IA, Toffenetti F. Secondary caries: a literature review with case reports. *Quint Int* 2000;31:165–79.[see comment]
39. Van Meerbeek B, Vargas MW, Inoue S, Yoshida Y, Peumans M, Lambrechts P, et al. Adhesives and cements to promote preservation dentistry. *Oper Dent Suppl* 2001:119–44.
40. Pashley DH. In vitro simulations of in vivo bonding conditions. *Am J Dent* 1991;4:237–40. [PubMed: 1810334]
41. Bouillaguet S, Ciucchi B, Jacoby T, Wataha JC, Pashley D. Bonding characteristics to dentin walls of class II cavities, in vitro. *Dent Mater* 2001;17:316–21. [PubMed: 11356208]

Fig 1.
An *in vitro* gingival group sample magnified at 1000× showing an area of voids on the sample.

In-vivo axial (VA) – 34.8 Mpa
Surface area of voids in % = 13.6 ± 25.6

Blue = voids
Yellow = composite
Pink = adhesive
Green = hybrid
Brown = interface adhesive /dentin

Fig 2.

An *in vivo* axial sample that had a microtensile bond strength of 34.8 MPa. This group had $13.6 \pm 25.6\%$ of the total surface area occupied by voids.

In-vivo gingival (VG) - 15.4 Mpa
 Surface area of voids in % = 48.8 ± 29.2

Blue = voids
 Yellow = composite
 Pink = adhesive
 Green = hybrid
 Brown = interface adhesive /dentin

Fig 3.

An *in vivo* gingival sample that had a microtensile bond strength of 15.4MPa. This group had $48.8 \pm 29.2\%$ of the total surface area occupied by voids.

In-vitro axial (TA) - 55.8 Mpa
Surface area of voids in % = 0.0 ± 0.0

Blue = voids
Yellow = composite
Pink = adhesive
Green = hybrid
Brown = interface adhesive /dentin

Fig 4.
An *in vitro* axial sample that had a microtensile bond strength of 55.8MPa. There were no voids present when the total surface area was analyzed for voids in this group.

In-vitro gingival (TG) - 30.10 Mpa
 Surface area of voids in % = 11.7 ± 17.6

Blue = voids
 Yellow = composite
 Pink = adhesive
 Green = hybrid
 Brown = interface adhesive /dentin

Fig 5.

An *in vitro* gingival sample with a microtensile bond strength of 30.1MPa. This group had $11.7 \pm 17.6\%$ of the total surface area occupied by voids.

Table 1
Microtensile bond strength results and summary of % area of voids observed by ESEM

Condition	N	Mean (MPa) (S.D.) ^a	Number of adhesive debonds during sample preparation	% area of voids (S.D.) ^b	# with voids (% with voids)	Mean (mm ²) cross-sectional area (S.D.)
<i>In vivo</i> axial	12	36.8 (16.4)	2	13.6 (25.6)	5 (42)	0.49 (0.09)
<i>In vivo</i> gingival	12	18.4 (11.6)	8	48.8 (29.2)	10 (83)	0.47 (0.05)
<i>In vitro</i> axial	19	47.1 (10.7)	0	0.0 (0.0)	0 (0)	0.49 (0.07)
<i>In vitro</i> gingival	16	34.0 (13.1)	9	11.7 (17.6)	5 (31)	0.50 (0.07)

^aTwo-way ANOVA: *in vivo* < *in vitro* ($p \leq 0.001$); gingival < axial ($p \leq 0.001$).

^bTwo-way ANOVA: *in vivo* < *in vitro* ($p \leq 0.001$); gingival < axial ($p \leq 0.001$); interaction significant ($p < 0.05$).

Table 2

Regression analysis

Predictor	β -Coefficient	<i>t</i>	Part correlation
Percent voids	-0.671	-6.55 ^a	-0.515
Location	-0.199	-2.23 ^b	-0.176
Condition	0.074	0.80	0.063

^a $p < 0.001$.

^b $p < 0.05$.