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Biomechanical behavior of cavity configuration on micropush-out test: A finite-element-study

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Abstract

Objective: The objective of this study was to simulate the micropush-out bond strength test from a biomechanical point of view. For this purpose, stress analysis using finite element (FE) method was performed.
Study design: Three different occlusal cavity shapes were simulated in disc specimens (model A: 1.5 mm cervical, 2 mm occlusal diameter; model B: 1.5 mm cervical, 1.75 mm occlusal diameter; model C: 1.5 mm cervical, 1.5 mm occlusal diameter). Quarter sizes of 3D FE specimen models of 4.0×4.0×1.25 mm^3 were constructed. In order to avoid quantitative differences in the stress value in the models, models were derived from a single mapping mesh pattern that generated 47.182 elements and 66.853 nodes. The materials that were used were resin composite (Filtek Z250, 3M ESPE), bonding agent (Adper Scotchbond Multi-Purpose, 3M ESPE) and dentin as an isotropic material. Loading conditions consisted of subjecting a press of 4 MPa to the top of the resin composite discs. The postprocessing files allowed the calculation of the maximum principal stress, minimum principal stress and displacement within the disc specimens and stresses at the bonding layer. FE model construction and analysis were performed on PC workstation (Precision Work Station 670, Dell Inc.) using FE analysis program (ANSYS 10 Sp, ANSYS Inc.).
Results: Compressive stress concentrations were observed equally in the bottom interface edge of dentin. Tensile stresses were observed on the top area of dentin and at the half of lower side of composite under the loading point in all of the FE models.
Conclusions: The FE model revealed differences in displacement and stress between different cavity shaped disc specimens. As the slope of the cavity was increased, the maximum displacement, compressive and tensile stresses also increased.

Key words: *Finite element analysis, cavity configuration, micropush-out test.*

Introduction

The ability to achieve a strong and durable bond between the restorative material and tooth structure is of paramount importance for the clinical success of many dental restorations (1,2). Of the materials available to restore tooth structure, resin composites are being employed to a large extent in contemporary restorative dentistry and characterized by mechanical properties similar to dentin (1-3). They have good physical properties and can be used in conservative cavity preparation (2,3). Their elastic modulus, ultimate compressive strength and hardness depend on the volume of the filler in the restorative material (2).

Several different mechanical testing methods including microtensile, shear and push-out tests have been used to measure the bond strength of resin composite to dentin (4-6). Amid these tests, the micropush-out test was developed to have fewer premature specimen failures and a lower data distribution variability compared to both trimmed and untrimmed microtensile specimens during the bond strength evaluation (7,8). Nevertheless, some difficulties associated with laboratory test methods led the researchers to try a numerical solution (1). Therefore, finite element analysis (FEA) was used in different aspects of restorative dentistry to determine stress distributions within the teeth and dental restorations, and to study the sensitivity of bond strengths related to specimen design and changes in testing conditions (9,10). In this respect, the advantage of using FEA is that it makes separation of the parameters and its effect possible. However, this possibility does not exist with the experimental test while interaction of the variables is normally unavoidable (11).

The 3D-FEA is the preferred way for an optimal realistic analysis, and undoubtedly represents a more detailed way to obtain useful mechanical information on the stress distribution at the dentin-composite adhesive interface (1). Therefore, previous studies have investigated stress distributions in conventional shear and tensile bond strength tests by using FEA (1,9,12,13). However, no FEA studies to date have assessed the effect of cavity design on micropush-out bond strength of resin composite to dentin.

In this study, a finite element analysis of micropush-out test was performed to understand two aspects; firstly, to give an impulse to standardization and to gain more insight in the biomechanics of the micropush-out test, secondly to identify the stress distributions at different cavity configurations. The null hypothesis was that the micropush-out bond strengths of resin composites to dentin show dependence on the cavity design.

Material and Methods

The FEA models were generated using literature data for internal volume and morphology of dentin (9,14). The models were constructed to simulate three different cavity configurations in disc specimens with 1.25 mm thickness: model A with 1.5 mm cervical and 2 mm occlusal diameter; model B with 1.5 mm cervical and 1.75 mm occlusal diameter; model C with 1.5 mm cervical and 1.5 mm occlusal diameter (Fig. 1a). Due to the symmetry, only one quarter of the specimen was simulated. The coordinates of each point of the dentin discs were put into the preprocessor of a FEA program (ANSYS 10 Sp, ANSYS Inc., Houston, USA) to build solid models for the specimen. The solid model was then transferred into a FEA program and meshed with 47.182 elements and 66.853 nodes (Fig. 1b). Finite element models construction and FEA were performed on PC workstation (Precision Work Station M90, Dell Inc., Texas, USA).

The model of dentin disc restored with bonding agent (Adper Scotchbond Multi-Purpose, 3M ESPE) and resin composite (Filtek Z250, 3M ESPE) was subjected to a pressure of 4 MPa from the cervical part of the discs with 1.5 mm diameter, simulating the experimental setup during micropush-out testing. The elements in the mesh were more condensed near the adhesive joint for more detail. It was assumed that the materials used in the model were elastic, homogeneous, and brittle, with isotropic stiffness properties, but differed in ultimate compressive and tensile strength properties. The values of Young's modulus and Poisson's ratio for dentin (18.6 GPa, 0.31), adhesive system (4 GPa, 0.3) and resin composite (11.5 GPa, 0.3) were used (9). The bonding condition at the interface between the dentin and the resin composite was assumed to be a complete bonding achieved with bonding agent layer (30 μm in thickness). Displacement, tensile and compressive stresses between the resin composite and dentin were recorded for each model. The vector directions of stresses in models are illustrated in (Fig. 2).

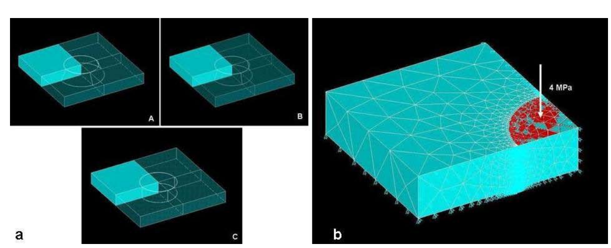

Fig. 1. a. Cavity models: model A. 1.5 mm cervical, 2 mm occlusal diameter; model B. 1.5 mm cervical, 1.75 mm occlusal diameter; model C. 1.5 mm cervical, 1.5 mm occlusal diameter, b. The 3-D finite element mesh generated and used for stress analysis.

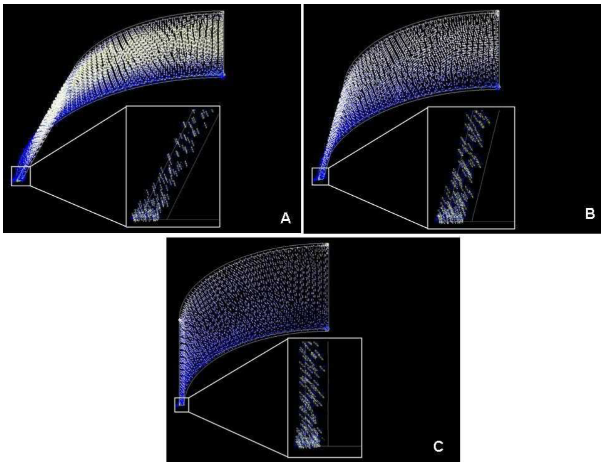

Fig. 2. Vector directions of stresses in three models (model A, B and C).

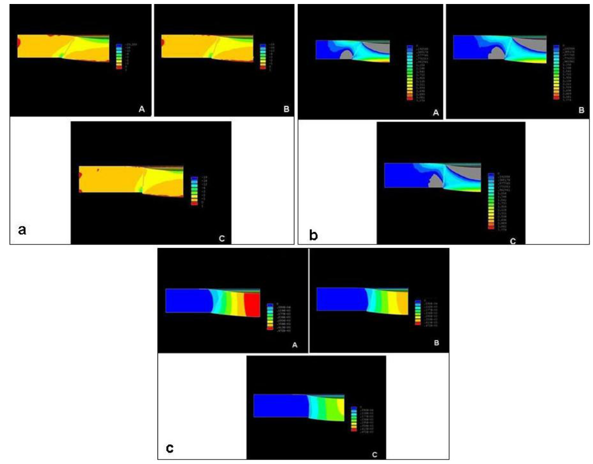

Fig. 3. a. Maximum compressive stress in three models, b. Maximum tensile stress in three models c. Displacement for three models (model A, B and C).

Results

The contours of stress distribution in the vertical direction and displacement due to a uniform push-out load are shown in (Figs. 3a, 3b and 3c). The maximum (+) and minimum principal stresses (-), and displacement from different cavity configurations are presented in (Table 1).

It is apparent that compressive stress concentrations occurred equally in the bottom interface edge of dentin and top of composite under the pressing area for three designs as demonstrated in (Fig. 3a). Minimum principal stress at the top of composite increased from model C to A. In addition, minimum principal stress of bonding agent layer exhibited similar tendency for all models. Maximum tensile stress arose at the lower side of composite under the pressing area in all of the FE models (Fig. 3b). On the other hand, in the model C, maximum tensile stress at the top area of dentin decreased. Maximum principal stress of bonding agent layer increased as the slope was increased.

Distribution of displacement in (Fig. 3c) illustrates that displacement in model A was more than model B and C. In model C, displacement of bonding agent layer was in the range of 0 to 0.059 µm. However, in the model A, displacement of bonding agent layer was in the range of 0.059 to 0.236 µm and the width of the range from 0 to 0.059 µm increased.

The results indicate a trend in the compressive and tensile stresses to increase whenever the occlusal diameter increases. Moreover, as the slope was increased, maximum displacement also increased (model C < model B < model A) (Fig. 3c).

Discussion

Bond strength measurements are widely used to evaluate the effectiveness of adhesive systems and to provide useful information on the adhesion between materials and tooth structure (6). As for the push-out test evaluated in this study, the test was designed as a "micropush-out test" and was a modification of a previous test set-up (15). This method has been suggested to more closely simulate the clinical conditions (5,7). Moreover, micropush-out test minimizes the laboratory time and expense for the production of the specimens (5,7). The stress distribution in the micropush-out test specimens is expected to be uniform and uniaxial, enabling the test measurements to express the true interfacial bond strength between dental tissue and material (13). A study by Soares et al. (7) reported more dependable data with micropush-out test method and minimal dam-

Table 1. Tensile and compressive stresses during 4 MPa loading.

Cavity configuration	Maximum principal stress (Tension MPa)	Minimum principal stress (Compression MPa)	Displacement (mm)
Model A	3.274	-20.285	.472E-3
Model B	2.938	-15.685	.385E-3
Model C	2.466	-12.024	.306E-3

age during preparation of the specimens. Similarly, a recent study demonstrated the acceptable data distribution with micropush-out test when compared with the microtensile test (5).
Since the investigation of stress distribution of teeth, in particular after restoration is very complicated due to complex geometry, 3D FEA might be a powerful tool to visualize the problems (16). Nevertheless, FEA models require experimental validation. FEA provides useful information for determination of relative stress concentration at the interface and in the two materials on either side of an interface (9). Stress concentrates where a non-homogeneous material distribution is present, such as the interface regions. The differences of materials with different modulus of elasticity represent the weak point of the restorative system (14).
The results of this study demonstrated that the cavity design affected the stress distribution, leading to the acceptance of the null hypothesis. Considering the compressive and tensile stresses; model A, B and C exhibited similar stress areas (Figs. 3b and 3c). However, model C presented the lowest maximum and minimum stress, and displacement values (Table 1). The main aim of a tapered cavity design in this study was to distribute micropush-out load to a larger area of the restoration. Nonetheless, it was found that a larger surface area resulted in higher compressive and tensile stresses. Regardless of the material tested, recent studies showed that bond strength tends to decrease as the bonding area increases (5,7,17). Soares et al. (7) tested the stress distributions and bond strengths of glass posts to intraradicular dentin by comparing microtensile and micropush-out tests. That study showed lower mean bond strength values with micropush-out test and related these results with larger bonded surface areas. Ghassemieh (11) evaluated microtensile bond strength of dental adhesive systems for different specimen geometries in equal surface areas (stick, dumbell and hourglass geometries) and found the lowest bond strength and highest stress values with the hourglass shaped specimens.
There are some possible reasons for the higher stress and displacement values obtained with model C. Firstly, in each of the models materials have different volumes. Besides, Young's modulus is different between dentin and resin composite (8,13). Young's modulus describes the relative stiffness or rigidity of a material and the stress-strain relationship for a given material under load (18). The tooth itself is a composite of dentin and enamel, which are elastically totally different materials. The one with the lowest Young's modulus which could be used as a standard is dentin with an elastic modulus of 18.6 GPa (9). The Young's modulus of resin composite used in this study was lower than dentin (11.5 GPa). In model A, the volume of low Young's modulus of resin composite is much larger than it is in model C, so model A has higher displacement than model C. Since resin composite's Young's modulus is lower than dentin, model A has much volume of low Young's modulus of resin composite.
Although the displacement of model C demonstrates that the light blue area (0.59e-4 to 0.118e-3) is narrow, this light blue area is getting wider from C to A (Fig. 3c). Therefore, the area of displacement in bonding agent layer and total displacement is getting higher.
Secondly, the direction of stress at the bonding agent layer is different in each model (Fig. 2). In the bonding agent layer of model C, the direction of tensile stress is 45º so main stress direction in this model is shear direction. However, in models A and B, as the angle of direction of tensile stress (< 45º) in the bonding agent layer decreases, the main stress direction changes to tensile stress. It is worthwhile to point out that tensile stress in the bonding agent layer is less desirable. This rationale may explain why the bonding agent layer, which is lowest and weakest material in this study, should be situated parallel to the loading direction. Finally, each model has the same material properties, boundary and loading conditions. Therefore, the important factor that plays a role in stress values could be different cavity design.
Previous studies have shown that the risk of friction is higher with cylindrical versus conical (tapered) posts and reported that the increase in the area of friction may lead to an overestimation of the bond strength (19,20). Similarly, Patierno et al. (4) reported that in micropush-out test, straight-walled cylindrical preparation would present more frictional resistance to restoration dislodgement than would a tapered preparation. However, in this study, the higher tensile and compressive stresses were observed with the more tapered preparation (model A). Conflicting results in these studies could be attributed to the assumption that dentin is an isotropic material. In this sense, results from FEA that have not been validated should be viewed with great reserve, especially in the case of dentin in which the anisotropy due to the dentinal tubule can hardly be modeled as an isotropic material (1). The results from FEA analysis do not exactly mimic what occurs in laboratory mechanical testing. Thus, these results require careful analysis when being compared with what happens in vitro.
The present study investigated the question of how cavity design in dentin discs, might be simulated in the commonly used FEA in order to produce more clinically relevant results. Since, it is impossible to include all of the factors encountered in the oral environment in a computer simulation, further laboratory studies should be performed to validate the experimental model presented in this study. Results of this study may assist researchers in choosing the most reliable cavity design for micropush-out bond strength test.
Within the limitations of this finite element study, the following conclusions were drawn:

1. FEA results demonstrated that different cavity designs might affect the micropush-out bond strengths of resin composites to dentin.
2. The results indicate a trend in compressive and tensile stresses, and displacement to increase whenever the occlusal diameter increases (model C < model B < model A).

References

References with links to Crossref - DOI

1. Silva NR, Calamia CS, Harsono M, Carvalho RM, Pegoraro LF, Fernandes CA, et al. Bond angle effects on microtensile bonds: laboratory and FEA comparison. Dent Mater. 2006;22:314-24.
2. Dejak B, Mlotkowski A. Three-dimensional finite element analysis of strength and adhesion of composite resin versus ceramic inlays in molars. J Prosthet Dent. 2008;99:131-40.
3. Niu Y, Ma X, Fan M, Zhu S. Effects of layering techniques on the micro-tensile bond strength to dentin in resin composite restorations. Dent Mater. 2009;25:129-34.
4. Patierno JM, Rueggeberg FA, Anderson RW, Weller RN, Pashley DH. Push-out strength and SEM evaluation of resin composite bonded to internal cervical dentin. Endod Dent Traumatol. 1996;12:227-36.
5. Cekic-Nagas I, Ergun G, Nagas E, Tezvergil A, Vallittu PK, Lassila LV. Comparison between regional micropush-out and microtensile bond strength of resin composite to dentin. Acta Odontol Scand. 2008;66:73-81.
6. Cekic I, Ergun G, Lassila LV, Vallittu PK. Ceramic-dentin bonding: effect of adhesive systems and light-curing units. J Adhes Dent. 2007;9:17-23.
7. Soares CJ, Santana FR, Castro CG, Santos-Filho PC, Soares PV, Qian F, et al. Finite element analysis and bond strength of a glass post to intraradicular dentin: comparison between microtensile and push-out tests. Dent Mater. 2008;24:1405-11.
8. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, et al. The adhesion between fiber posts and root canal walls: comparison between microtensile and push-out bond strength measurements. Eur J Oral Sci. 2004;112:353-61.
9. Betamar N, Cardew G, Van Noort R. Influence of specimen designs on the microtensile bond strength to dentin. J Adhes Dent. 2007;9:159-68.
10. Betamar N, Cardew G, Van Noort R. The effect of variations in hourglass specimen design on microtensile bond strength to dentin. J Adhes Dent. 2007;9:427-36.
11. Ghassemieh E. Evaluation of sources of uncertainties in microtensile bond strength of dental adhesive system for different specimen geometries. Dent Mater. 2008;24:536-47.
12. Della Bona A, Van Noort R. Shear vs. tensile bond strength of resin composite bonded to ceramic. J Dent Res. 1995;74:1591-6.
13. Neves Ade A, Coutinho E, Cardoso MV, Jaecques S, Lambrechts P, Sloten JV, et al. Influence of notch geometry and interface on stress concentration and distribution in micro-tensile bond strength specimens. J Dent. 2008;36:808-15.
14. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dent Mater. 2006;22:1035-44.
15. Frankenberger R, Strobel WO, Krämer N, Lohbauer U, Winterscheidt J, Winterscheidt B, et al. Evaluation of the fatigue behavior of the resin-dentin bond with the use of different methods. J Biomed Mater Res B Appl Biomater. 2003;67:712-21.
16. Ferrari M, Sorrentino R, Zarone F, Apicella D, Aversa R, Apicella A. Non-linear viscoelastic finite element analysis of the effect of the length of glass fiber posts on the biomechanical behaviour of directly restored incisors and surrounding alveolar bone. Dent Mater J. 2008;27:485-98.
17. Mannocci F, Machmouridou E, Watson TF, Sauro S, Sherriff M, Pilecki P, et al. Microtensile bond strength of resin-post interfaces created with interpenetrating polymer network posts or cross-linked posts. Med Oral Patol Oral Cir Bucal. 2008;13:E745-52.
18. Helvatjoglu-Antoniades M, Papadogiannis Y, Lakes RS, Dionysopoulos P, Papadogiannis D. Dynamic and static elastic moduli of packable and flowable composite resins and their development after initial photo curing. Dent Mater. 2006;22:450-9.
19. De Durâo Mauricio PJ, González-López S, Aguilar-Mendoza JA, Félix S, González-Rodríguez MP. Comparison of regional bond strength in root thirds among fiber-reinforced posts luted with different cements. J Biomed Mater Res B Appl Biomater. 2007;83:364-72.
20. Wakefield CW, Draughn RA, Sneed WD, Davis TN. Shear bond strengths of six bonding systems using the pushout method of in vitro testing. Oper Dent. 1998;23:69-76.

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