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RESEARCH ARTICLE

EFFECT OF DIFFERENT CAVITY CONFIGURATIONS ON THE TENSILE BOND STRENGTH OF HYBRID AND NANOFILLED COMPOSITES - IN VITRO STUDY

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ABSTRACT

Background: This study was undertaken to evaluate the effect of various cavity configurations on the tensile bond strength of hybrid and nanofilled composites.
Materials and Methods: In this in vitro study eighty extracted molars of the permanent dentition were divided into two main experimental and two control groups (Group I & Control I - Hybrid composite; Group II & Control II - Nanofilled composite). Cavity of 2mm depth and 3mm, 4mm and 6mm diameter was prepared for each experimental group. Accordingly, group I and II were divided into 3 subgroups (n = 10). The teeth were restored with self etch adhesive and Hybrid & Nanofilled composite as per the experimental groups. For the control group specimens, teeth were grounded to expose the dentin surface and the additional composite was placed on the flat surface. All restored teeth were sliced to produce 1mm thick sections which were then trimmed into an hour glass shape with the narrowest portion at the adhesive interface. The specimen was tested for tensile strength at a cross head speed of 1mm/min.
Results: In both the groups 3mm diameter samples showed less strength as compared to the 4mm and 6mm diameter samples. Control groups showed significantly better strength as compared to the experimental groups. ($p < 0.001$)
Conclusion: C-factor affects the tensile strength upto certain limit. Flat surface showed better tensile bond strength as opposed to the cavities. Nanofilled composite showed equal or higher tensile bond strength as compared to the hybrid composite.

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INTRODUCTION

One of the problems inherent to light-cured resin composites is polymerization shrinkage which creates contraction stress in the composite restoration. This disrupts the marginal seal between the composite and the tooth structure which results in postoperative sensitivity, recurrent caries and marginal staining (Davidson *et al*., 1984; Carvalha *et al*., 1996). The internal stress generated in the restricted environment of a tooth cavity can exceed the adhesive bond strength and produce a separation of the restoration interface. In cases where higher bond strength is present, this stress may cause fracture of the marginal tooth substrate and/or the composite restoration itself (Choi *et al*., 2000). The magnitude of stress varies according to the C-factor and elasticity of the structures involved in the bonding process, such as cavity substrate, hybrid layer and bonding resins (Alster *et al*., 1997). When resin bonds to the walls and floor of the cavity preparation, a competition occurs between the opposing walls as the restorative resin shrinks during polymerization and pulls them closer together. The magnitude of this phenomenon depends upon the configuration of the cavity and hence, is called the cavity configuration factor or C-factor. The C-factor is defined as the ratio of the bonded surface area to the unbonded or free surface area (Carvalha *et al*., 1996; Yoshikawa *et al*., 1999).

More contraction stress is created in class I and class V cavities because of higher C-factor.

This C-factor can be calculated by formula (Choi *et al*., 2004),

$$C = 1+4h/d$$

h = Height of the cylindrical cavity.
d = Diameter of the cylindrical cavity.

It is felt by many that stress relief should be accomplished by lowering the C –factor of class I and class V cavities (Ivanovic *et al*., 2004). Choi *et al* studied the effects of cavity configuration on composite restoration. They concluded that

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the mean micro tensile bond strength to dentin decreases with increasing C-factor (Choi *et al*., 2004). Similar results were obtained by Yoshikawa T *et al* who evaluated the effects of dentin depth and cavity configuration on micro tensile bond strength. All groups reported high bond strengths to superficial dentin as compared to the flat deep dentin when the C-factor was 1. When the C-factor was increased to 3 by the creation of a three-dimensional cavity preparation, the bond strengths of all materials fell by 21 to 35% (Yoshikawa *et al*., 1999). Hence, this study was undertaken to evaluate the effect of various cavity configurations on the tensile bond strength of hybrid and nanofilled composites. The above formula is used in present study to control the C-factor. The null hypothesis was that the cavity configuration doesn't have any effect on the tensile bond strength.

MATERIALS AND METHODS

In this *in vitro* study, total eighty extracted human maxillary and mandibular molars of the permanent dentition were used. Teeth with caries, having restorations and fractures were excluded from the study. The debris was cleaned mechanically and the teeth were stored in 10 % formalin. Sixty teeth were randomly divided into two main experimental groups (Group I and Group II), whereas, twenty teeth were divided into two control groups (control I and control II). Thus each of these experimental groups contained thirty teeth and ten teeth in each of the control groups. Teeth in Group I and Control I were restored with hybrid composite (3M ESPE Filtek P6O, St. Paul, U.S.A.), whereas, teeth in Group II and Control II were restored with nanofilled composite (3M ESPE Filtek Z35O, St. Paul, U.S.A.).

Preparing the samples for Experimental Groups

In the experimental groups i.e. Group I (Hybrid composite) and Group II (Nanofilled composite), cavity of 2mm depth and 3mm, 4mm and 6mm diameter was prepared on the buccal surface of molars. Group I and II were further divided into 3 subgroups as per the diameter of the cavity with 10 specimens in each subgroup [Table 1]. For preparing a cavity, buccal surface of the molars were marked with the help of steel cylinders of 3mm, 4mm and 6mm diameter [Figure 1]. The cavity was prepared of 2mm depth and 3mm, 4mm and 6mm diameter with the help of straight fissure diamond point (SF-II, ISO 111/012 Dia Burs Mani, Japan) in water cooled high speed air turbine handpiece (Synea TA-98L, W & H Dentalwerk, Newberg, Austria.). The straight fissure diamond point was marked at 2mm height to get uniform depth of the cavity for all teeth. Specimens that showed any visible pulp exposures during cavity preparation were excluded. This 2mm depth ensured uniform curing throughout the material. The C – factor (C= 1+4 h/ d, where, d and h are the diameter and height of the cylindrical cavities respectively) (Choi *et al*., 2004), was controlled by the diameter of the cavity. The calculated c-factor for 3mm diameter was 3.7, for 4mm diameter was 3.0 and for 6mm diameter was 2.3. Once the cavity was prepared, the self etching adhesive A and B (Adper Easy Bond, 3M ESPE St. Paul, U.S.A.) was mixed together and applied in the cavity using Microtip brush (Composibrush, Prime Dental, Bhivandi, India) and it was then light cured using ART-L3 LED Light curing unit with Light intensity of 1,000 mW/cm^2 and Cure time of 3mm/10 seconds (BonART Medical Tech. Inc., La Puente U.S.A.). The cavity was filled with the composite as per the defined groups (i.e. Group I : Hybrid composite and Group II : Nanofilled composite) using incremental technique and was light cured. Additional increment of composite was added and light cured.

Preparing the sample for control groups

For the control groups (control I and control II) where, the configuration factor C = 1, teeth were grounded with wet 600 grit Silicon carbide paper (Ae Abrasives Edge Pvt. Ltd, Delhi) to expose the dentin surface. The self etching adhesive A and B (Adper Easy Bond, 3M ESPE St. Paul, U.S.A.) was mixed together and was applied on the flat surface using Microtip brush and it was then light cured using ART-L3 LED Light curing unit. The composite resin was placed on the flat surface of the teeth as per the defined groups (i.e. control I:Hybrid composite and control II:Nanofilled composite) and was light cured using ART-L3 LED Light curing unit.

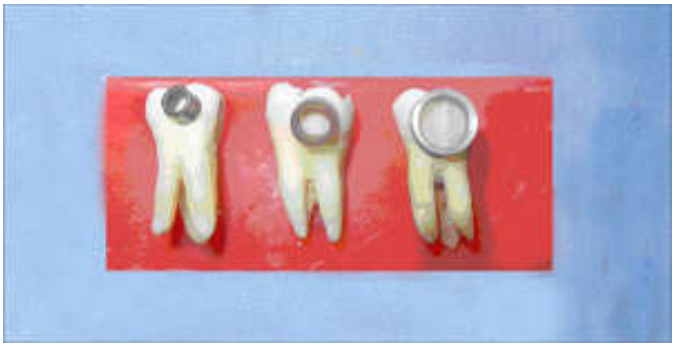

Figure 1. Marking for cavity diameter using 3mm, 4mm and 6mm ring

Figure 2. Hour-glass shaped samples

Figure 3. Tensile bond strength testing on Zwick Universal Testing Machine

Preparing Hour glass shape specimens

All the restored teeth were stored in water at 37^{0}C for 24 hours and were sliced serially perpendicular to bonded surface to

produce 1mm thick sections using diamond disk in contrangle micromotor handpiece (NSK, Zhengzhou Smile Industrial Co. Ltd, Mainland, China) with copious water irrigation. These 1mm thick slices of specimens were trimmed into an hour glass shape with the narrowest portion at the adhesive interface, using a straight diamond point in a high speed air turbine handpiece, producing a bonded area approximately 1mm^2 [Figure 2]. For holding the specimen in the Zwick universal testing machine (Zwick, Materiaprufung 1445, Ulm, Germany), a ligature wire was attached on the composite side of the specimen with the help of additional composite. The specimen was mounted on the testing machine with the tooth part being held in one jaw of the testing machine. The wire attached to the composite portion was held in the other jaw. Stress was then applied to check the tensile bond strength at a cross head speed of 1mm/min [Figure 3]. The results were analyzed using one way ANOVA and independent sample t test.

RESULTS

The ultimate Tensile bond strength of Control I & Control II and various subgroups of Group I & Group II, are presented in Table 2,3, 4 and 5. The highest mean value was recorded for Control II (37.65 MPa), whereas the lowest mean value was recorded for Subgroup I-A (8.15 MPa). Descriptive statistics were expressed as mean ± standard deviation (SD) for both the control groups and various subgroups of group I and II. Between and within group differences in tensile bond strength was analyzed using one way ANOVA test of significance with Bonferroni correction. The tensile bond strength between the two control groups was analyzed using independent sample t test. In the above test, p value less than or equal to 0.05 ($p \leq 0.05$) was taken to be statistically significant. From Table 2 and 3, it is observed that**,** I-B and I-C showed significantly higher tensile bond strength values as compared to I-A

Table 1. Distribution of the Experimental Groups with subgroups and Control Groups

Experimental Groups							Control Groups				
Groups	Group I Hybrid Composite			Group II Nanofilled Composite			Control I Hybrid Composite			Control II Nanofilled Composite	
Subgroups	I-A	I-B	I-C	II-A	II-B	II-C					
Depth	2mm	2mm	2mm	2mm	2mm	2mm	Flat surface				
Diameter	3mm	4mm	6mm	3mm	4mm	6mm					
No. of Samples	10	10	10	10	10	10	10			10	

Table 2. Statistical comparison of the Tensile Bond Strength (MPa) between various subgroups of Group I

		I A	(n= 10)	I B	(n= 10)	I C	(n= 10)	P value (ANOVA)
Tensile bond strength	(mean ± SD)	8.15 ± 1.41		17.21 ± 5.56		20.13 ± 3.63		<0.001*

Within group comparison (Bonferroni correction), Tensile bond strength (MPa),
I B > I A, p< 0.001* ; I C > I A,p < 0.001* ; I C > I B, p = 0.322. *p≤0.05 is statistically significant

Table 3. Statistical comparison of the Tensile bond Strength (MPa) between various subgroups of Group II

		II A	(n= 10)	II B	(n= 10)	II C	(n= 10)	P value (ANOVA)
Tensile bond strength	(mean ± SD)	13.22 ± 3.70		17.20 ± 3.53		18.79 ± 6.41		0.039*

Within group comparison (Bonferroni correction), Tensile bond strength (MPa),
II C > II B, p = 1.000 ; II C > II A, p = 0.042* ; II B > II A, p = 0.213 *p≤0.05 is statistically significant

Table 4. Statistical Comparison of the Tensile bond strength (MPa) between Control I and various Subgroups of Group I

	I A	(n= 10)	I B	(n= 10)	I C	(n= 10)	Control I	(n= 10)	P value (ANOVA)
Tensile bond strength (mean ± SD)	8.15 ± 1.41		17.21 ± 5.56		20.13 ± 3.63		33.55 ± 1.77		<0.001*

Within group comparison (Bonferroni correction), Tensile bond strength (MPa),
Control I > I C, I B, I A; p < 0.001*; p≤0.05 is statistically significant

Table 5. Statistical Comparison of the Tensile bond strength (MPa) between Control II and various Subgroups of Group II

		II A	(n= 10)	II B	(n= 10)	II C	(n= 10)	Control II	(n= 10)	P value (ANOVA)
Tensile bond strength	(mean ± SD)	13.22 ± 3.70		17.20 ± 3.53		18.79 ± 6.41		37.65 ± 0.96		<0.001*

Within group comparison (Bonferroni correction), Tensile bond strength (MPa),
Control II > II A, II B, II C; p < 0.001* *p≤0.05 is statistically significant

Table 6. Statistical Comparison of Tensile bond strength (MPa) between various subgroups of Group I & Group II and Control I & Control II

	I A (n=10)	I B (n=10)	I C (n=10)	Control I (n=10)	II A (n=10)	II B (n=10)	II C (n=10)	Control II(n=10)	P value (ANOVA)
Tensile bond strength (mean±SD)	8.15 ± 1.41	17.21± 5.56	20.13± 3.63	33.55 ± 1.77	13.22 ± 3.70	17.20± 3.53	18.79± 6.41	37.65± 0.96	<0.001*

Within group comparison (Bonferroni correction), Tensile bond strength (MPa),
II A > I A, p = 0.116; I B ≈ II B, p = 1.000; I C > II C, p = 1.000 Control II > Control I, p = 0.539
*p≤0.05 is statistically significant

(i.e. p<0.001) whereas, no statistically significant difference in I-B and I-C (p =0.322). II-C showed significantly higher tensile bond strength values as compared to II-A (p = 0.042). II-B showed higher values than II-A, whereas, lower values than II-C. The difference is not statistically significant. Control groups showed significantly higher tensile bond strength values as compared to the experimental groups (i.e p<0.01) Table 4 and 5. From Table 6, it is observed that, II-A and control II showed higher tensile bond strength values as compared to I-A and control I respectively. I-C showed higher values than II-C and II-B showed equal values to I-B but the difference is not statistically significant.

DISCUSSION

Since the introduction of Composite resin material in 1960, it dominates the material used for direct esthetic restorations (Craig *et al*., 8th edition). Main disadvantage of all composite is polymerization shrinkage and even the advent of nanotechnology is unable to overcome this. This polymerization contraction shrinkage creates stress as high as 13 MPa between the composite material and tooth interface (Boksman, 2006). This stress can exceed the tensile strength of the enamel and results in stress, cracking and enamel fracture along the interface (Davidson *et al*., 1984; Choi *et al*., 2004; Boksman, 2006). When the curing proceeds, contraction and flow decreases gradually while stiffness increases. As a result, the stress will still grow with time and may cause serious problem for the maintenance of the adhesive bond or may even cause cohesive failure of the restorative material or the surrounding tooth tissue (Boksman, 2006; Feilzer *et al*., 1990). Since the ability of a bonded composite to deform elastically & / or plastically is configuration dependant, the magnitude of polymerization contraction stress will also be configuration dependant (Feilzer *et al*., 1990; Feilzer *et al*., 1987). In cervical cavities, the gingival outline of a cavity is usually bordered by dentin so it is very difficult to obtain a proper and lasting marginal seal of the resin composite. Although the composite resin can be bonded to the dentin, the polymerization contraction stress generally exceeds the bond strength and thus leads to separation of the restoration at the interface (Kemp-Scholte and Davidson, 1988; Kemp-Scholte and Davidson, 1990). The role of cavity configuration (C-factor) on the development of polymerization contraction stresses with a resin composite was demonstrated by Feilzer, de Gee and Davidson (Feilzer *et al*., 1987). If the cohesive failure of the materials is disregarded and the cavity walls are considered rigid, the only source available to relieve the polymerization contraction stress is the elastic deformation of the material and the flow from free, unbonded surfaces. The C-factor can be expressed as a ratio between the total bonded area and total unbonded area (Carvalha *et al*., 1996; Yoshikawa *et al*., 1999). Hence the present study was conducted to determine whether the c-factor has any effect on the tensile bond strength of composite or not. The bonding of composite to tooth structure can be achieved with one of 4 different etching systems: total-etch 3 step, total-etch 2 step, self-etch 2 step and self-etch 1 step (Boksman, 2006). Self etch adhesives make use of acidic monomers that simultaneously condition and prime enamel and dentin and provide vinyl groups for co-polymerization with the resin composite. Their application procedure is less time consuming and less technique sensitive in particular, with regard to keeping the dentin surface in an adequate state of hydration (Boksman, 2006; Swift *et al*., 1995). Hence self etch adhesive was used in the present study.

Microfilled composites are capable of being brought to a high polish due to their extremely small fillers and are thus considered as highly aesthetic, whereas, Hybrid composites show somewhat poor results but shows greater mechanical strength due to “large” fillers. The term 'nanotechnology' was coined by Prof. Kerie E. Drexler. It is engineering at the atomic or molecular scale and is used in dentistry as a nonagglomerated discrete nanoparticle that is homogeneously distributed in resins or coatings to produce Nanofilled Composites. These materials have fillers (nanomers) of 20-75 nm in size. They also contain ultra-fine radiopaque zirconium oxide fillers with a mean size of 2-5 nm. By using nanotechnology it has been possible to attain a filler proportion of approx. 72-78% by weight, which corresponds to that of a commonly used hybrid composite also the shrinkage rate of hybrid composite are unified in this new material (Zhaveri and Balaji, 2005; Christopher, 2004). With the smaller particle size there is a more chameleon-like effect with a greater scattering of light. More scattering allows excellent blending in of the restoration (the “chameleon effect”) and it also gives life-like aesthetics. The other advantage is that the strength is not compromised, with the flexural strength (128Mpa) being similar to many hybrid composites (Christopher, 2004). All these characteristics make the nanofilled composites superior to the conventional composites. Hence in the present study hybrid and nanofilled composites were used as group I and group II to study the effect of these composites on the tensile bond strength as they are used as universal composites. These experimental groups were further divided into three subgroups depending on the diameter of the cavity (i.e. 3mm, 4mm and 6mm), whereas, the depth was kept constant at 2mm. Three different diameter of the cavity was selected for both the groups to control the c-factor which was calculated using the formula, C=1+4h/d where, h – height and d – diameter of the cylindrical cavity. Thus the resultant C-factor calculated was 2.3 for 6mm diameter, 3.0 for 4mm diameter and 3.7 for 3mm diameter cavity.

All the data was statistically analyzed. In both the experimental groups 3mm diameter samples (C-factor 3.7) showed less tensile bond strength values as compared to the 4mm and 6mm diameter samples (C-factor 3.0 and 2.3 respectively). 4mm diameter samples in both the groups showed less tensile bond strength values as compared to the 6mm diameter samples. Thus this result indicates that as the c-factor decreases the tensile bond strength values increases to certain limit. According to Feilzer *et al* (1987), restorations with C<1 are the only ones likely to survive polymerization contraction stresses. When C>1, the results are unpredictable under clinical situations because the stress generated by polymerization contraction has been reported to be about 13-17 MPa, which is higher than many dentin bond strengths (Davidson and de Gee, 1984; Boksman, 2006; Feilzer *et al*., 1993; Davidson *et al*., 1984). Generally, the less the free, unbonded area there is in a cavity, the less will be the ability of resin to flow and therefore the greater will be the contraction stress at the bonded surfaces. In general, class 2 and class 3 composite restorations achieve C-factors in the range of 1.0 to 2.0, whereas, shallow class 5 composite restoration C-factor less than 1 (Carvalha *et al*., 1996). Therefore, the C – factor for cavity 6mm diameter is approximately 2.3, for diameter 4mm is 3.0 and for 3mm diameter is approximately 3.7. Hence, tensile bond strength for the cavity having diameter of 6mm is higher than the cavity having diameter of 3mm and 4mm also the tensile bond strength for the cavity having diameter of 4mm is higher than

the cavity having diameter of 3mm for both the groups. Control samples (control I & control II) showed statistically significant higher tensile bond strength values when compared with various subgroups of group I and group II. This result indicates that the two dimensional samples i.e flat surface showed greater tensile bond strength values as compared to the three dimensional samples i.e cavity. This result supports the statement of Carvalha *et al*. (1996) 'the greater the free, unbonded area there is in a cavity, the greater will be the ability of resin to flow and therefore the lesser will be the contraction stress at the bonded surfaces'. Similar results were obtained by Yoshikawa T *et al* in 1999, who also studied and compared the micro tensile bond strength of flat surface and three dimensional model (Yoshikawa *et al*., 1999). Thus the null hypothesis that the cavity configuration doesn't have any effect on the tensile bond strength is rejected.

In the present study, Nanofilled composite samples showed higher or equal tensile bond strength values when compared with hybrid composite samples. Currently available composite resins referred to as "nanofilled composites" are produced with nanofiller technology and formulated with nanomer and nanocluster filler particles. Nanomers are discrete nanoagglomerated particles and nanoclusters are loosely bound agglomerates of nano-sized particles. The manufacturer suggests the combination of nanomer and nanocluster formulations reduces the interstitial spacing of the filler particles providing increased filler loading and better physical properties. Clinically, the nanofilled resin has a proper resistance in high stress–bearing areas, which is typical in the posterior area. The resinous components and filler loading of nanofilled composite resins make their polymerization shrinkage less (Boksman, 2006; Lopes and Oliveira, 2006). This explains the higher or equal tensile bond strength values of Nanofilled composite when compared with hybrid composite samples. Present study evaluated the effect of various cavity configurations on the tensile bond strength of hybrid and nanofilled composites. This study design has limitations for simulating the clinical situation. Further investigations under more closely simulated clinical conditions are necessary.

Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. Two-dimensional model i.e. flat surface showed better tensile bond strength as opposed to the Three-dimensional model i.e. cavities.
2. Reduction in C-factor for composite restoration, increases its tensile bond strength upto certain limit.
3. Cavity configuration affects the tensile bond strength of any type of composite whether it is hybrid or nanofilled composite.
4. Nanofilled composite showed equal or higher tensile bond strength than hybrid composite.

Thus this study showed that for good tensile bond strength C-factor should be low.

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