©Operative Dentistry, 2018, **43-6,** 631-641

Incremental and Bulk-fill Techniques With Bulk-fill Resin Composite in Different Cavity Configurations

S-H Han • S-H Park

Clinical Relevance

In high C-factor cavities, the incremental technique for composite restoration showed a higher bond strength on the cavity floor than did the bulk-fill technique. However, in low C-factor cavities, there was no statistical difference in the bond strength between the two techniques.

SUMMARY

Purpose: To compare the microtensile bond strengths of incremental and bulk-fill techniques under different C-factor and compliance conditions.

Methods and Materials: Extracted human third molars were divided into three experimental groups. For group I, Class I cavities were prepared. For group II, MOD cavities of the same size were prepared. For group III, the cavities were prepared the same way as group II only with high compliance cavity walls. The cavity wall compliance of the specimens was evaluated. Each of these groups was divided into four subgroups. The teeth were restored using two different materials: TB (Tetric N-Ceram Bulk Fill; Ivoclar Vivadent, Hanau, Germany) and VB (Venus Bulk Fill; Heraeus Kulzer, Armonk, NY, USA), and two methods, either an incremental or bulk-fill technique. Then, the microtensile bond strengths (μ-TBSs) were measured and compared. The polymerization stresses of the composites were calculated using a custom-made device. The results were statistically analyzed using the Kruskal-Wallis test and Weibull analysis.

Results: In group I, the μ-TBS obtained using the incremental technique was significantly higher than that obtained by the bulk-fill technique ($p<0.05$). In contrast, no difference of the μ-TBS value was observed between the two techniques in groups II and III. The μ-TBS value of group I was significantly lower than those of groups II and III ($p<0.05$). No statistical difference in the μ-TBS was observed when the cavities were filled with either TB or VB ($p>0.05$).

Seung-Hoon Han, St Vincent Hospital, Catholic University of Korea, Dept of Conservative Dentistry, #93 Jungbu-daero, Paldal-gu, Suwon, 16247, Republic of Korea

*Sung-Ho Park, Yonsei University College of Dentistry, Department of Conservative Dentistry and Oral Science Research Center, Seoul, Republic of Korea

*Corresponding author: 50-1 Yonsei-ro, Seodaemun-gu, Seodaemun-gu, Seoul, 03722, Republic of Korea; e-mail: sunghopark@yuhs.ac

DOI: 10.2341/17-279-LR

Conclusions: The incremental technique showed higher bond strength than did the bulk-fill technique in high C-factor cavities. However, no difference was found between the two techniques in the low C-factor cavities. The bond strength in the high C-factor cavities was significantly lower than that of the low C-factor cavities.

INTRODUCTION

The properties of resin composite have improved significantly during the past decade. Nonetheless, polymerization shrinkage of composite resin is still a major cause of restoration failure. To optimally restore a large cavity with composite, incremental techniques have been recommended in order to reduce microleakage and polymerization stress.[1-4] However, some studies have reported that there was no difference when the results of incremental and bulk-fill techniques were compared.[5-9]

Many studies have compared the results of incremental and bulk-fill techniques with respect to bond strength, polymerization stress, cuspal deflection, gap width, and microleakage. Research on bond strength to the cavity floor can be divided into two groups depending on whether the depth of the specimen cavity is more or less than 3 mm. In general, when the microtensile bond strength to the cavity floor was compared using specimens with less than a 3-mm-deep cavity, no differences in the results were obtained, irrespective of the technique used. Loguercio and others compared the incremental and bulk-fill techniques in high and low C-factor cavities with depths of 2 mm.[5] The microtensile bond strength and gap width results obtained by the two techniques were similar in both the high and low C-factor cavities. Van Ende and others investigated the two techniques by comparing microtensile bond strength in 2.5 mm-deep Class I cavities.[10] The results demonstrated that in four out of five groups of composites, the microtensile strength was not significantly different when using incremental vs bulk-fill techniques.

In contrast to the results obtained using specimens with a shallow cavity, the results obtained in studies comparing incremental and bulk-fill techniques using specimens with a cavity depth of more than 3 mm generally differed from those obtained with a 2-mm depth. Nikolaenko and others investigated the effect of the layering technique on the microtensile bond strength in a 4-mm-deep cavity.[2] They found that the bulk-fill technique led to significantly lower adhesion at the cavity floor. According to Reis and others, bulk-fill groups presented the lowest microtensile bond strength with a 5-mm deep cavity.[3] Likewise, Chikawa and others demonstrated that the incremental filling technique was more effective for adhesion to a 5-mm-deep cavity floor than the bulk-fill technique.[4] He and others investigated the effects of cavity size on the microtensile bond strength in Class I cavities using incremental/bulk-fill techniques.[1] They reported that there was no difference in microtensile bond strength in small cavities (3-mm deep). However, there was a significant difference between the two techniques in large cavities (5-mm deep).

The incremental and bulk-fill techniques can also yield different results depending on the cavity configuration of the specimens. No differences in polymerization stress or marginal leakage were observed between the incremental and bulk-filling techniques when they were performed in MO or MOD cavities.[6-9,11] However, studies conducted on the bond strength of Class I cavities demonstrated a difference between the two techniques wherein a higher bond strength was obtained using the incremental technique.[1,2,4,12] We conclude from a brief review of the literature that the effectiveness of the two techniques may differ depending on the cavity size and configuration. Therefore, it was determined that cavities of the same size and shape but with different configurations should be compared to identify the effectiveness of the two techniques.

The C-factor can be used as a criterion to classify cavity configuration. However, the C-factor alone may not represent all the characteristics of the cavity configuration, for example, the cavity wall compliance. Even though cavities have the same C-factor, they can have a different shape and compliance, which is the inverse of stiffness and it can demonstrate how flexible the cavity wall is. A high compliance represents that the deflection of the cavity wall is greater at a given force. It has been reported that the magnitude of the stress developed at the interface is related to the compliance of the surrounding structures.[13] However, polymerization stresses are not uniformly distributed along the cavity walls.[14] Bond strength may also vary in relation to the C-factor and compliance of the cavity,[15] which is the main concern of our study.

Bulk-fill composites, which can be adequately light-cured on the deep cavity floor, can be used to compare the two techniques.[16] A recent development in composite resins is bulk-fill technology, which allows placement of resin composite in a single

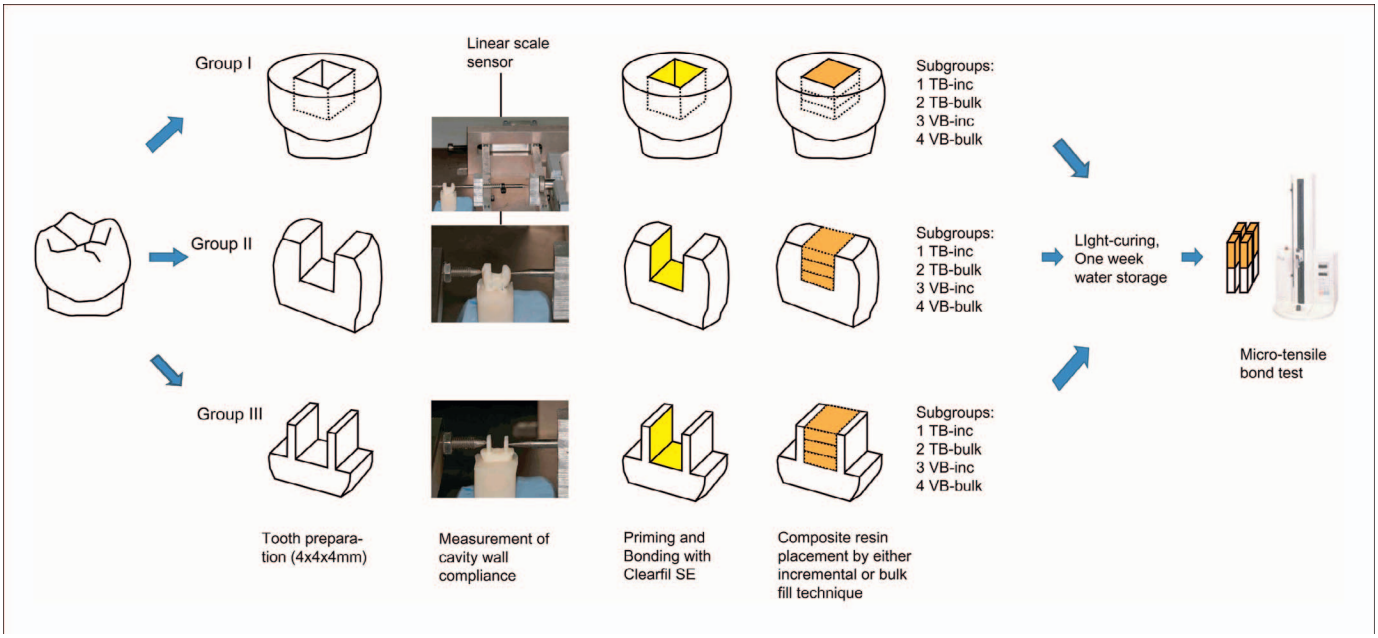

Figure 1. *Experimental procedure employed in this study.*

increment up to 4-5 mm in depth without compromising polymerization efficiency.[17-19] With micro- or nano-hybrid composites, there are concerns that the composite may not be completely light cured over the entire depth of large restorations. Incomplete curing of the composite precludes a valid comparison of the two techniques. Bulk-fill composites can be divided into two categories: flowable types and packable types. In several studies, the two types were shown to have different physical properties, including polymerization stress.[17,20] A final point of interest is whether the bond strength to the cavity floor would be the same with two different types of bulk-fill composites.

The present study was performed to understand how the following factors affect the microtensile bond strength to the cavity floor: incremental vs bulk-fill technique, high C-factor cavity vs low C-factor cavity with different compliances of the cavity walls, and the two different bulk-fill composites. The null hypotheses in this study were

1. There was no difference in bond strength between incrementally cured and bulk-cured composites.
2. There was no difference in bond strength between high C-factor and low C-factor cavities.
3. There was no difference in bond strength between cavities with a low compliance and those with a high compliance.
4. There was no difference in bond strength between two composites of different polymerization stresses.

METHODS AND MATERIALS

Specimen Preparation

The set-up employed in this study is schematically illustrated in Figure 1. Noncarious human third molars were stored in a 0.5% chloramine solution at 4°C. The protocol for use of the teeth was approved by the institutional review board under approval No. VC15EISI0163. The teeth were used in the experiment within 2 months after extraction. Eighty-four teeth were chosen with a buccolingual dimension of 10.5 (±0.5) mm. The teeth were randomly divided into three experimental groups (I, II, and III) with 28 teeth per group. For group I, standard Class I cavities (length, width, and depth: 4×4×4 mm) were prepared with a flat-end, straight diamond bur (6837-016, Komet Brasseler, Lemgo, Germany). For group II, the teeth were reduced on both the mesial and distal sides until the width of the specimen was 4 mm. Then, MOD cavities having the same dimensions were prepared. For group III, the same reductions and preparations employed for group II were performed. Then, the buccal and lingual cusps were reduced with the same-size bur (Brasseler) until the cuspal walls had a 1-mm-thick layer of parallel dentin (group III, Figure 1). The cavity

dimensions of group III were the same as those of group II. However, reduced buccal and lingual cusps represent different compliances of the cavity walls. The resulting C-factors were C = 5 for group I and C = 1 for groups II and III.

Measuring Cavity Wall Compliance

The specimen was positioned in a custom-made device (R&B Inc, Daejon, Korea) to measure the compliance using screws, pins, and a linear scale sensor (inset photographs in Figure 1). The system was designed to detect the amount of cavity wall deflection while an external force was applied. Two measuring pins were kept in contact with the center of the buccal and lingual surfaces of the cusps. An individual specimen stabilizer made of self-curing acrylic resin was used to minimize the mobility of the specimen. When a force of 20 N (2.04 kgf) was applied, the inward cavity wall deflection (μm) was detected by a linear scale sensor (Lie 5, Numeric Jena Gmbh, Jena, Germany). The amount of deflection for each specimen was recorded after the 20 N force was held for 3 minutes. Cavity wall compliances were calculated for all specimens in groups II and III by dividing the deflection amount by the applied force (μm/N). The parameter for compliance of the cavity wall was based on the research presented by Lee and others.[21] The compliance of each specimen was recorded and the relationship between compliance and microtensile bond strength was evaluated.

Restorative Procedures and Subgroups

After measuring the compliance of all specimens, a two-step, self-etch bonding system (Clearfil SE Bond, Kuraray Noritake Dental, Tokyo, Japan) was applied to all the specimens and then the samples were light-cured for 10 seconds (1200 mW/cm^2, Elipar S10, 3M ESPE, St Paul, MN, USA). Next, each group was divided into four subgroups with seven teeth each. For groups II and III, a matrix band was applied before placing the composite. These cavities were filled with either three equal horizontal composite layers or a single placement. For subgroup 1, TB-inc, the specimen was restored with Tetric N-Ceram Bulk Fill (Ivoclar Vivadent, Schaan, Liechtenstein) by an incremental technique, which consisted of three equal increments of horizontal layering. After the first layer of composite (having a thickness of about 1.3 mm) was placed, light curing was carried out for 10 seconds. Then the second layer was placed, followed by 10 seconds of light curing. After the placement of the third layer, light curing was performed for 20 seconds. For subgroup 2, TB-bulk, the specimen was restored with Tetric N-Ceram Bulk Fill composite by the bulk-fill technique. Single placement of the composite resin was followed by light curing for 40 seconds. For subgroup 3, VB-inc, the specimen was restored with Venus Bulk Fill (Heraeus Kulzer, Dormagen, Germany) by applying the same incremental technique used for subgroup 1. For subgroup 4, VB-bulk, the specimen was restored with Venus Bulk Fill by using the same bulk fill technique as that used for subgroup 2. The specimens were stored for 7 days in room temperature water before microtensile bond testing (μ-TBS).

Micro-tensile Bond Test

The specimens were sectioned vertically into 1-mm-thick slices with a low-speed diamond saw (Metsaw, R&B) and then sectioned again at a right angle. Resin-dentin sticks were obtained at the cavity floor interface. The cross-sectional area was calculated exactly for each specimen by measuring the width and length using a digital caliper (Digimatic caliper, Mitutoyo, Japan). Twenty-eight specimens (four beams per tooth × seven teeth) were made for each subgroup. The specimen was attached to a universal testing machine (EZ test, Shimadzu, Kyoto, Japan) with cyanoacrylate adhesive (Zapit, DVA, Anaheim, CA, USA). It was then stressed in the testing device at a crosshead speed of 1 mm/min until failure. The value for μ-TBS (MPa) was obtained by dividing the measured force (N) by the individual bonded area (mm^2). If the specimen failed while being sectioned or attached to the tester, it was recorded as a pretesting failure (PTF), which was given a value of 0 MPa for the statistical analysis.

The mode of failure was determined using a light stereo microscope (S8APO, Leica, Wetzlar, Germany) at 50× magnification. The failure mode was classified into four types according to the characteristics of the fractured dentin side: cohesive failure in resin composite, cohesive failure in dentin, mixed failure, and adhesive failure between the adhesive and dentin. The failure mode was classified as mixed failure when a large region from the surface (>10%) was included as cohesive failure in both dentin and resin.[12] The percentages among each category were then calculated.

Measurement of Polymerization Shrinkage Stress

The polymerization shrinkage stress of the resin composite was measured using a custom-made device and software (R&B).[22] The instrument was driven by a motor and was designed to move a metal

Table 1: *Composition of Resin Composites Used in This Study*

Code	Product	Manufacturer	Base Resin	Filler (Wt/Vol%)
TB	Tetric N-Ceram Bulk Fill	Ivoclar Vivadent, Schaan, Liechtenstein	Bis-GMA, UDMA dimethacrylate co-monomers	78/55% (including prepolymer)
VB	Venus Bulk Fill	Heraeus Kulzer, Dormagen, Germany	UDMA, EBPADMA	65/38%

Abbreviations: Bis-GMA, bisphenol A glycidyl dimethacrylate; UDMA, urethane dimethacrylate; EBPADMA, ethoxylated bisphenol A dimethacrylate. The base resin composition and filler % were supplied by the manufacturers.

bar up and down. The polymerization shrinkage force applied to the acrylic tension rod was measured by a load cell (100 kgf) connected to the bar. The light required for polymerization of the resin composite sample was projected from beneath the transparent disc. The entire process was controlled by software made by R&B.

Prior to the measurements, the setup was switched to the compliance-allowed mode in which the acrylic rod could be moved freely during resin polymerization. The compliance of the system was 0.5 μm/N when the acrylic rod was used. Before connecting the acrylic rod, its surface was roughened with sandpaper (180 grit), treated with adhesive resin (bonding agent, Clearfil SE bond, Kuraray Noritake Dental, Okayama, Japan), and then light-cured for 10 seconds. Next, 0.035 g (12.6 mm^2) of resin composite was placed onto an acrylic disc, and the upper acrylic rod was positioned to ensure that the thickness of the specimen was 1 mm and its diameter was 4 mm. The stress measurement between the tension rod and the resin composite was set to zero before light curing. Then, the resin composite was cured using a light-curing unit (Bluephase, Ivoclar Vivadent; 800 mW/cm^2) for 20 seconds through the transparent disc. While the shrinkage stress was developing, displacement of the acrylic rod was allowed to move as the composite shrank. Along with the load-cell signal, the displacement was continuously recorded by the computer every 0.1 second for a period of 180 seconds. This measurement was repeated five times for each material and then the average value was calculated.

Statistical Analysis

Statistical analysis was performed using SPSS 18 for Windows (SPSS Inc, Chicago, IL, USA). The μ-TBS data were statistically analyzed using a Kruskal-Wallis test followed by the Mann-Whitney U-test to compare the groups at the 0.05 level of significance. Pairwise comparisons were carried out using Bonferroni's correction. Regression analysis was employed to identify whether there was any correlation between the μ-TBS and compliance of the cavity wall.

μ-TBS data were also analyzed by the Weibull analysis using a software package (R3.1.1, R Foundation for Statistical Computing, Vienna, Austria). The PTFs were excluded from the Weibull analysis because they cannot operate with zero values. The slope (β) of the distribution curve was calculated. Pivotal confidence bounds were also defined using Monte Carlo simulations.[23] B10 was calculated at the 10% probability of failure (unreliability) level, and the characteristic strength (scale parameter) at a probability of failure of 0.632 was also measured. The different groups were compared at the 10% unreliability level (B10) and at the characteristic strength.

RESULTS

Microtensile Bond Strength and the Fracture Mode Analysis

Table 2 shows the results of the microtensile bond strength at the cavity floor of each of the three groups using different composite filling methods. The results show significant differences between the incremental and bulk-fill techniques in group I (p=0.024 for subgroups 1 and 2; p=0.019 for subgroups 3 and 4). When each subgroup of group I was compared with that of groups II or III, a statistical difference was also found (p<0.05). No statistical difference was found when the cavity was filled with either TB or VB (subgroup 1 was compared with subgroup 3, and subgroup 2 was compared with subgroup 4 in each of groups I, II, and III; p>0.05). Figure 2 shows the results of the fracture mode analysis after bond testing, revealing that group I demonstrated a relatively high percentage of adhesive failures. In groups II and III, the proportions of adhesive failures and mixed failures were similar.

Compliance of Cavity Wall Results

The average measurement of cavity wall compliance in group II was 5.1 μm/N with a standard deviation of 0.62. The average measurement in group III was 8.7 μm/N with a standard deviation of 0.77.

Table 2: *Microtensile Bond Strengths (MPa)*[a]

Composite-filling Method	Group I	Group II	Group III
1. TB-inc	12.72 (10.75)[a] *†	21.08 (9.31)[b]	20.81 (9.04)[b]
2. TB-bulk	6.35 (8.43)[a]*	18.93 (9.82)[b]	19.03 (9.21)[b]
3. VB-inc	11.81 (10.75)[a] *	19.86 (9.76)[b]	21.17 (8.29)[b]
4. VB-bulk	5.36 (7.93)[a]*	19.25 (9.30)[b]	18.50 (9.57)[b]

**Indicates a statistically significant difference between the incremental and bulk fill techniques in group I (Kruskal-Wallis test followed by Mann-Whitney U test; $p<0.05$).*
[a] An identical lower superscript represents no statistically significant difference among the groups (compared in each row, Kruskal-Wallis test followed by Mann-Whitney U-test; $p>0.05$).
†Values in parentheses represent standard deviations.

Relationship Between M-TBS and Compliance of the Cavity Wall

The compliance of each specimen is plotted against the μ-TBS values of the specimens in Figure 3. The results show that in low C-factor cavities, there was no correlation between μ-TBS and compliance of the cavity wall.

Polymerization Stress of Composite Resins

The average polymerization stress for TB was 1.88 MPa with a standard deviation of 0.14; for VB, it was 2.76 MPa, with a standard deviation of 0.38.

Results of Weibull Analysis

Table 3 shows the PTF (%) and results of the Weibull analysis. PTF (%) is the number of failed specimens in each subgroup divided by the total number of specimens, in percent. The modulus parameter, β, was determined by linear regression of a plot of the ln of the inverse of survival probability (ln[1/survival probability]) against μ-TBS. The scale parameter, η, also called characteristic strength, represents the bond strength at which 63.2% of the specimens failed. B10 indicates the bond strength at a 10% probability of failure. Figure 4 is a representative graph illustrating the Weibull analysis of groups I-1, I-2, II-1, and II-2.

DISCUSSION

The incremental filling technique showed a higher μ-TBS than did the bulk-fill technique in the high C-factor cavities (group I). There was no statistical difference between the two techniques in the low C-factor cavities (groups II and III). Thus, the first hypothesis was partially rejected (Table 1). Because the proportion of the unbounded surface was small in the group I cavities, the polymerization stress could not be relieved under the restricted conditions.[24] With the incremental technique, each increment with a reduced volume of resin could provide

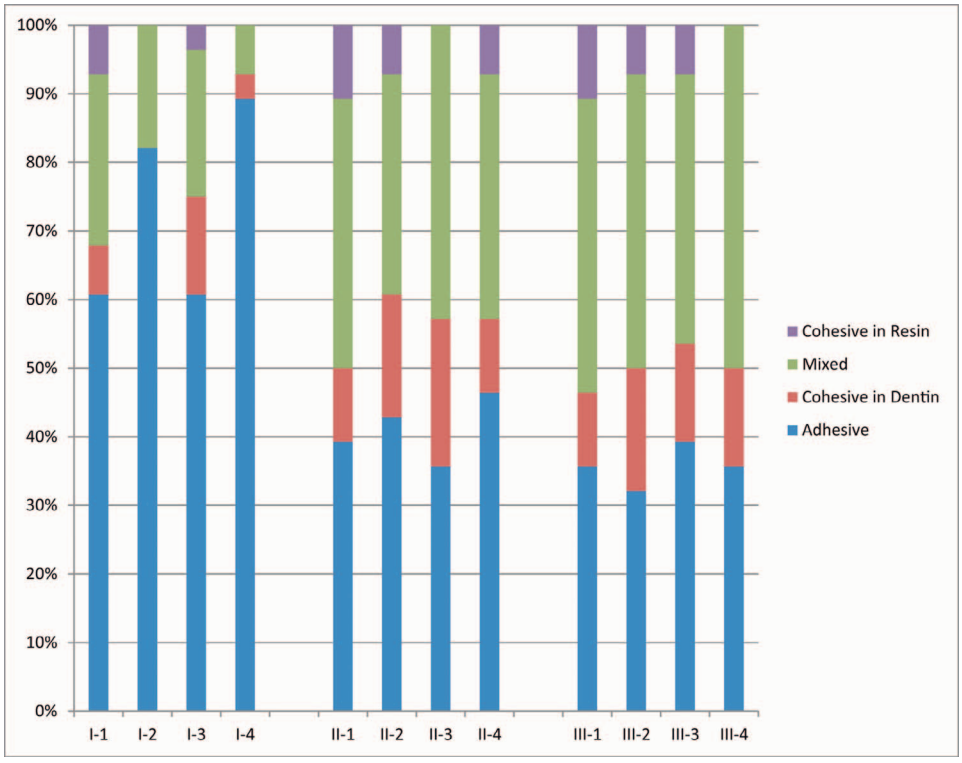

Figure 2. *Analysis of the fracture mode: cohesive in resin, cohesive failure in resin composite; cohesive in dentin, cohesive failure in dentin; mixed, cohesive failure in both dentin and resin; adhesive, adhesive failure between adhesive and dentin. All specimens showing pretesting failure are identified as adhesive failure between adhesive and dentin.*

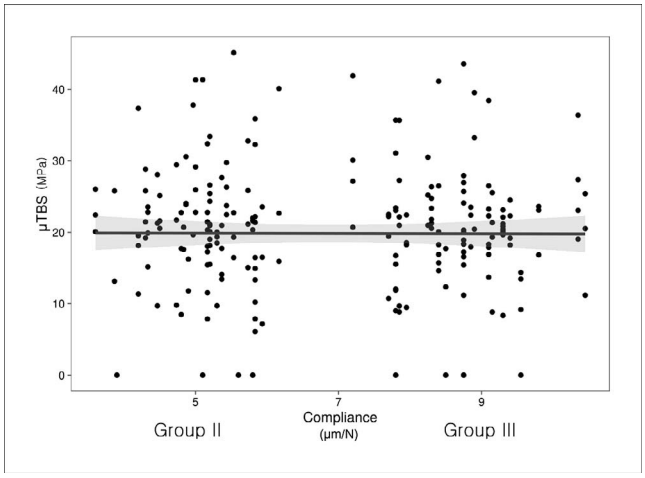

Figure 3. *Compliance of cavity wall vs μ-TBS for groups II and III. Solid line is the regression line resulting from linear regression analysis. Shaded area shows the 95% confidence level.*

an additional free surface for the composite to relieve the polymerization stress. Ferracane and others indicated that maximizing the free surface is likely to enhance stress relief by allowing increased flow of material.[25] However, in groups II and III, the incremental technique was not proven to be as effective as in group I. This may be because the MOD cavity already had enough free surfaces for the composite to relieve the stress. Nayif and others speculated that the polymer network formation was partly interrupted during polymerization under restricted conditions.[26] Rearrangement of the polymer network may be differently related to the bond strength in high and low C-factor cavities.

While the cavity configuration is undoubtedly one of the most important reasons for the difference, light attenuation may be another cause for the differences obtained between the two techniques for group I. Light curing of a bulk-fill composite can be affected by several variables associated with the light source, including distance, radiant exposure (known as energy density), radiant emittance (as power density), curing time, and the interval of light curing. Light attenuation may vary with the layer thickness or layering method.[2,3,9,27] It was previously demonstrated that the first increment of the composite on the bonding layer may play the most important role with regard to bond strength.[4] Van Ende and others asserted that less light was attenuated at the cavity bottom when a thin increment was cured first. As a result, this layer may polymerize adequately.[12] When the first layer was thinner than the following layer, a higher bond strength was observed.[1,4] In the bulk-fill technique, if a composite layer is relatively thick, there may not be enough double bonds for the composite to link to the adhesive layer.[28,29] A lower bond strength was also observed with shorter light-curing times.[10,30] According to several studies, low radiant emittance generates a small number of free radicals, resulting in longer polymeric chains with a low cross-linking density.[31,32] Thus, there may be both quantitative and qualitative differences of bond structure.

Differences of the μ-TBS were observed between group I and group II or group III. Hence, the second hypothesis was rejected. The bond strength of low C-factor cavities was higher than that of high C-factor

Table 3: *PTF (%) and Weibull Analysis Results of μ-TBS*[f]

	Subgroup	PTF (%)[a]	β[b]	η[c]	B10[d]	Characteristic Strength[e]
Group I	TB-inc	9 (32.1%)	2.87	20.99	9.6 [5.7-13.4][b,c]	21.0 [17.6-25.1][a,b]
	TB-bulk	14 (50%)	2.43	13.77	5.4 [2.6-8.5][c]	13.8 [10.8-17.8][b]
	VB-inc	10 (35.7%)	2.88	20.52	9.4 [5.5-13.2][b,c]	20.5 [17.2-24.7][a,b]
	VB-bulk	16 (57.1%)	2.28	13.68	5.1 [2.1-8.4][c]	13.7 [10.3-18.4][b]
Group II	TB-inc	2 (7.1%)	3.18	25.39	12.5 [8.6-16.3][a]	25.4 [22.3-29.1][a]
	TB-bulk	3 (10.7%)	3.02	23.74	11.3 [7.5-15.0][a,b]	23.7 [20.6-27.5][a]
	VB-inc	2 (7.1%)	3.14	23.75	11.6 [7.9-15.2][a]	23.8 [20.8-27.2][a]
	VB-bulk	2 (7.1%)	3.08	23.07	11.1 [7.5-14.6][a,b]	23.1 [20.1-26.6][a]
Group III	TB-inc	2 (7.1%)	3.66	24.74	13.4 [9.6-16.9][a]	24.7 [22.0-27.8][a]
	TB-bulk	2 (7.1%)	3.36	22.64	11.6 [8.1-14.9][a]	22.6 [20.0-25.7][a]
	VB-inc	1 (3.6%)	3.41	24.39	12.6 [8.9-16.1][a]	24.4 [21.6-27.6][a]
	VB-bulk	3 (10.7%)	3.29	23.0	11.6 [8.0-15.1][a]	23.0 [20.2-26.3][a]

[a] *PTF indicates pretesting failures, the number of failed specimens (as a percentage).*
[b] *Modulus, shape, or slope of the Weibull analysis.*
[c] *Eta or scale of the Weibull analysis.*
[d] Estimation and 95% confidence interval at a 10% probability of failure.
[e] Characteristic strength and 95% confidence interval at B63.2 (63.2% unreliability).
[f] An identical superscript represents no significant difference among the groups within each column.

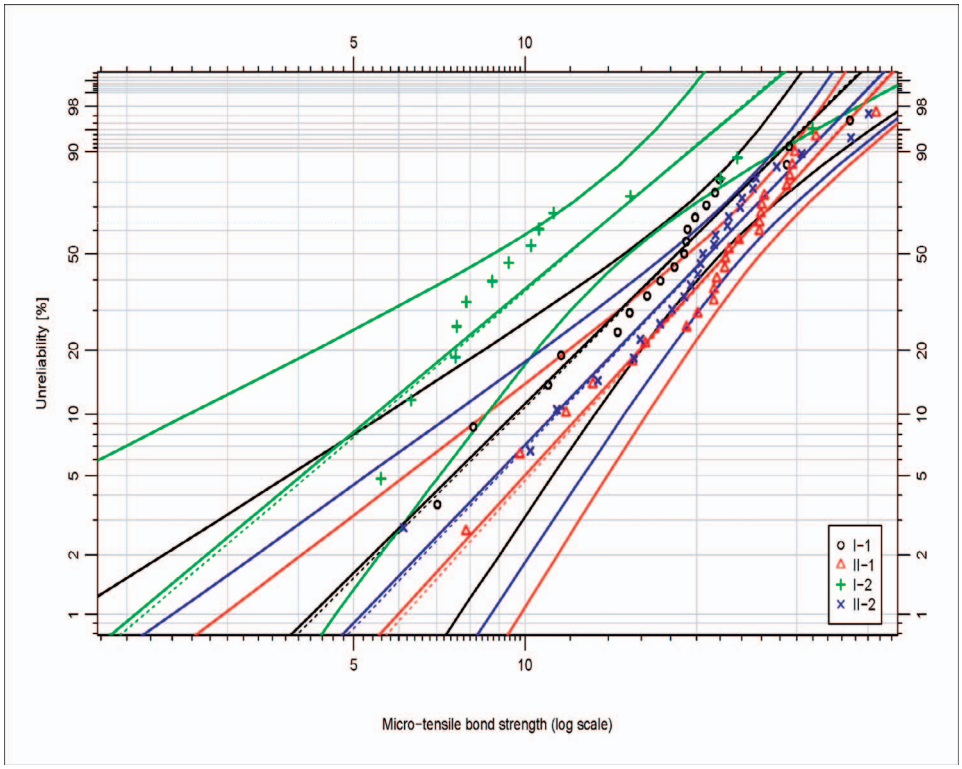

Figure 4. *Weibull plot of μ-TBS values for groups I-1, I-2, II-1, and II-2. Solid/dotted lines represent the Weibull line and the pure solid lines represent the 95% confidence bounds, as calculated from Monte Carlo simulations.*

cavities (Table 2). Polymerization stress can vary depending on cavity configuration.[33,34] The low bond strength in group I may be due to the high polymerization stress in high C-factor cavities.[15] Feilzer and others demonstrated with their *in vitro* model that restorations involving cavities with a C-factor of less than one are more likely to survive polymerization shrinkage stress.[33] Watts and others reported that polymerization stress can be greatly affected by the volume of composite.[35] The effect of the C-factor should be investigated with specimens of the same volume. In addition to the cavity configuration, the volume was also identical to ensure valid comparison in this experiment.

We also investigated the effect of cavity wall compliance in this experiment. The magnitude of the stress developed at the restoration's interface is related to the compliance of the surrounding structures.[13] The bond strength of two groups (II and III) showed no difference and as a result, the third hypothesis was accepted. Thus, there is little influence of the compliance on μ-TBS in low-C-factor cavities. A possible explanation could be that low C-factor cavities provide enough free surfaces such that the flexible walls of group III may not have any influence. For Class I cavities, however, it was not possible to measure the compliance of the wall using the device employed in this experiment. Rodrigues and others calculated the compliance for tooth preparation in Class I cavities using the finite element method.[36] They demonstrated different cavity compliances depending on the shape and dimension of Class I cavities. Whether the compliance of high C-factor cavity walls can affect the bond strength remains to be seen. Further studies should be conducted in high C-factor cavities to determine the relationship between bond strength and compliance.

Because different results were found in previous research involving large and small cavities, large cavities were chosen in this experiment to compare the two techniques.[1] A large cavity is an unfavorable condition for bonding composite to tooth material. It was previously asserted that use of the incremental technique can be effective in large cavities.[1] In contrast, research with small cavities has shown no difference between the two techniques.[5] Other studies have verified that the volume of the shrinking composite influenced the polymerization stress value.[13,37] In small cavities, the reduction of polymerization stress obtained by incremental filling may not be sufficient to allow a significant difference to be observed between the two techniques.[38]

There was no difference in μ-TBS between subgroups 1 and 3 or between 2 and 4 in each group, which allowed the last hypothesis to be accepted. TB

showed lower polymerization stress than did VB. However, no statistical difference was found between the μ-TBS values of TB and VB. In studies concerning the degree of conversion, TB showed a significantly lower degree of conversion than did VB.[20,39] The degree of conversion of TB was 54.5% and that of VB was 71.9%, as determined by Fourier transform infrared spectrometry.[39] For TB and VB, a recent study investigated the bottom/top surface hardness ratios. According to this study, the TB and VB ratios were 0.82 and 0.91, respectively, which indicated higher polymerization of the VB composite on the floor side.[40] A lower degree of composite conversion was reported to be associated with a lower bond strength.[41,42] VB is also known to have a significantly lower elastic modulus than TB, which may help to relieve the stress.[17,20] In other studies, TB and VB demonstrated different physical properties.[17,20] Not only the polymerization stress of the material but also other factors, such as the degree of conversion and elastic modulus, might have affected the bond strength to the floor.

Research has demonstrated that μ-TBS to dentin exhibits wide variability, which can mean that the bond strength of a composite to tooth material may vary in magnitude along the interface.[43-46] Several studies excluded specimens that failed during the procedure, which Nikolaenko and others had claimed to be inadequate.[2] Failed specimens may have two explanations: procedural error or too weak bonding. Therefore, the validity of including failed specimens for statistical analysis has been questioned. As an answer to this question, reporting the number of PTFs has been suggested,[47] as they can be an indicator of a specimen's ability to estimate bonding quality. The PTF was highest in groups I-2 and I-4, which could indicate that more of the cavity floor was detached or bonded weakly. In this experiment, four beams per tooth were obtained for a μ-TBS test at the identical position of each tooth. The cavity bottom dentin in all the specimens was midcoronal and at the central pit position to make sure that the effects of regional variability would be minimal.

Another approach to compensate for the shortcomings of the μ-TBS would be the Weibull analysis. The main difference is that the distribution of the failures is not determined from actual measurements, but is estimated from the data. Each Weibull analysis is characterized by two parameters: β (modulus) and η (scale) parameters. If the modulus is higher, it can mean that the bonding procedure is more reliable. Inokoshi and others have proposed that if the scale is higher, the bonding effectiveness will actually be better.[48] The modulus and scale parameters were found to be higher in incremental filling groups than in bulk-fill groups (Table 3). This difference was more evident in group I than in groups II or III.

CONCLUSIONS

In high C-factor cavities, the incremental technique showed higher bond strength than did the bulk-fill technique on the cavity floor. In the low C-factor cavities, there was no difference in bond strength between the two techniques. The bond strength in the high C-factor cavities was significantly lower than that in the low C-factor cavities. In the latter, the bond strength was not dependent on the compliance of the cavity walls. Two composite resins of different polymerization stresses did not show a significant difference in bond strength.

Acknowledgements

We would like to thank Prof Jan De Munck and his colleagues at the Catholic University of Leuven, Belgium, for their contribution to our Weibull analysis as well as for the support of the R-code and their helpful advice.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of St Vincent Hospital, Catholic University of Korea. The approval code for this study is VC15EISI0163.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service and/or company presented in this article.

(Accepted 8 December 2017)

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