Comparison on polymerization of bulk-fill composite resins in different marginal thickness of tunnel restoration

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ABSTRACT

Bulk-fill composite resins (BCR) was introduced with the advantage of 4-5mm depth of cured, thus an applicable material for a tunnel restoration. The study aimed to assess the polymerization of BCR with different marginal ridge thickness in tunnel restoration technique. Fifteen extracted teeth categorized into; G1=conventional proximal restoration (n:5), G2=tunnel 1.5mm marginal ridge thickness (n:5) and G3=tunnel 3.0mm marginal ridge thickness (n:5). Samples received the designated cavity preparation design and restored with BCR, embedded in resin and sectioned into halves. Each sample was tested with Vickers micro-hardness at the top (TP), middle (MP) and bottom part (BP) to get the micro-hardness value (VH). Data were statistically analyzed with 1-way ANOVA to compare means between groups and repeated measured ANOVA to compare means between the different areas. The mean micro-hardness (VH) value for top part (TP) G1=79.1, G2=77.3 and G3=74.9.; middle part (MP) G1=79.0, G2=73.3 and G3=74.9 and bottom part (BP) G1=71.1, G2=64.4 and G3=62.7. A decrease pattern of VH noted TP>MP>BP. No significant difference (p>0.05) VH for all groups for TP. For MP, significant difference (p<0.05) noted among the 3 groups and for BP, significant differences (p<0.05) between G1 to G2 and G3 only. In the same group, no statistical mean differences (p>0.05) were

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noted in Group 1 for all three parts of the tested restoration (TP, MP and BP). However, for Group 2 and Group 3, statistical mean differences ($p<0.05$) were reported between TP and BP, and between MP and BP. The thickness of marginal ridge in tunnel technique did affect the polymerization of BCR within the recommended depth, however the VHR of >80% in all areas indicate the material did receive adequate polymerization from light irradiation and clinically acceptable to be used.

Keywords: *Micro-Hardness; Bulk-Fill Composite Resins; Tunnel Restoration Technique; Marginal Ridge.*

Introduction

Light-cured composite resins are nowadays the materials of choice for restoring damaged or decayed teeth due to their aesthetic values (tooth-coloured properties), minimal cavity preparation, good handling characteristics and improved physical and mechanical properties. Over 166 million dental composite resin restorations were placed by US private practitioners in 2005 [1] and in Malaysia, the Oral Health Division 2016 Annual Report stated that almost 1.4 million tooth-colored restorations were provided in the government sector dental health division, fully demonstrating their popularity among dentists and patients worldwide. Therefore, the ability to place light-cured composite resins restorations in a simple, predictable and less time consuming would be beneficial to not only the practice, but also for the patients [2]. The development of bulk-fill composite resins (BCR) has become an innovation for direct restorative dentistry where this material was believed to be helpful in reducing the working time, at the same time exhibiting the same physical properties as the conventional composite resins [3]. BCR was reported to have excellent adaptation without additional expensive dispensing devices, exhibit stress relief capability to enable up to 5 mm depth of cure with excellent handling and sculpt ability [4].

In line with minimal intervention dentistry concept, caries removal is limited to removal of the infected enamel and dentine, leaving the affected and remaining sound tooth structure [5]. Tunnel technique was introduced as a conservative alternative approach compared to the conventional Class II box or slot preparation in treating proximal carious lesion with the main benefit of increased tooth integrity by preserving the marginal ridges [6]. Due to the deep and enclosed cavity preparation of tunnel approach, glass ionomer cement (GIC) was the common material of choice with its chemically cured properties despite the low wear resistance and less aesthetics appearances. Nowadays, clinicians have started to use bulk-fill composite resins to restore deep undermined cavity due to its mechanical and physical properties that superseded GIC [6]. The bonding of composite resins to cavity walls will increases the fracture resistance and structural integrity of the restored tooth and provide better aesthetic appearances. Previously, the main limitation of composite resins material was the curing depth of 2-3mm that makes it unacceptable in a deep undermined or tunnel technique. However, with the bulk-fill composite resin that has been introduced and proven to be fully polymerized in a depth of 4-5 mm with sufficient light irradiation [4], it may become the material of choice in deep undermined or tunnel restoration. However, it is still a concern if the undermined restoration of 4-5mm thickness underneath the intact marginal ridge can receive enough exposure to light irradiation to fully cure the whole bulk of material.

Thus, the purpose of our study was to evaluate the polymerization of bulk-fill composite resins used in tunnel technique restoration upon light irradiation through different marginal ridges thickness. The null hypothesis was that different thickness of marginal ridge left in-situ has no significant influence on the polymerization of bulk-fill resin composite.

Materials and methods

Sample preparation

The sample size in which standard deviation (SD) was estimated as 0.76 to detect the average micro-hardness of 2.00 between material with 95% power and alpha 0.05 indicate a minimum of 4 sample size per group [7-8]. Fifteen extracted molar teeth were cleaned from soft tissues and hard deposits attached to the surface using ultrasonic before categorized into three groups; group 1, G1=conventional proximal restoration (n:5), group 2, G2=tunnel 1.5mm marginal ridge thickness (n:5) and group 3, G3=tunnel 3.0mm marginal ridge thickness (n:5) and prepared with the designated cavity design (Table 1). Ethics approval to use extracted human teeth in the study was granted from Universiti Teknologi MARA Review Board [Reference: 600-IRMI (5/1/6)].

Table 1: Designated cavity preparation for each group

Group	Cavity Design	Variables
Group 1 (G1)	the slot proximal preparation	No intact marginal ridge
Group 2 (G2)	proximal tunnel preparation	1.5mm of marginal ridge left
Group 3 (G3)	proximal tunnel preparation	3.0mm of enamel and dentine thickness

In G1, a proximal box was prepared with a small elongated pear shaped bur held parallel to the long axis of the tooth crown. Figure 1(a) showed how the instrument was extended through the marginal ridge in a gingival direction [9]. Figure 1(b) and Figure 1(c) illustrated the tunnel cavity for group 2 and 3. It was prepared by first, initiating a small access cavity that was made through the occlusal fossa about 1.5 mm for G2 and 3.0 mm for G3, away from marginal ridge using the tapered diamond bur and angled axially. Once into dentin, an ovoid preparation (tunnel) was created until the proximal area below the contact point with the marginal ridge left in-situ [10].

Following the cavity preparation, the tooth surfaces were cleaned with pumice powder using a bristle brush. The cavities were etched with 37% phosphoric acid for 15 seconds and then rinsed for 15 seconds using a 2-way water syringe. The cavities were gently blotted dry with cotton pellet and light air-sprayed for 5 seconds to observe the chalky appearance of the enamel surface. Single bottle dentine bonding agent (DBA) (Adper Single Bond 2, 3M ESPE, USA) was applied on the prepared cavity with agitation for 15 seconds followed by gentle drying for 5 seconds with air to remove the remaining solvents prior light cured for 15 seconds with an Elipar™ S10 LED curing light (3M ESPE, St Paul, MN, USA) with an irradiance of 1200 mW/cm^2. After the placement of DBA, the cavity filled with bulk-fill composite resin (Filtek™ Bulk Fill, 3M ESPE, St Paul, MN, USA) in one increment and cured for 10s at each site; occlusally, bucally and lingually (Figure 2). The light cure protocol was based on the manufacturer recommendation.

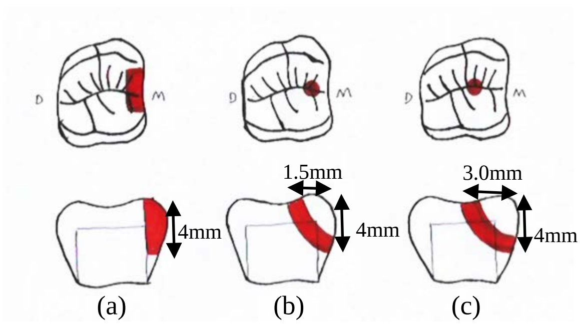


Figure 1: The designated cavity preparation; (a) slot cavity preparation, (b) tunnel cavity preparation with a 1.5 mm marginal ridge intact, (c) tunnel cavity preparation with a 3.0 mm marginal ridge intact.

Figure 2: Light irradiation of the bulk-fill composite resin to polymerize the material.

The bulk-fill composite resins restorations were then finished and polished according to the standardized protocol using a white stone bur and polishing burs. Each sample was marked at the mid-section prior placement in a centre of the mould hold by a tick tag. A mixture of resin (Quickmount) to hardener (Quickmount) ratio of 10:1 was poured into the mould embedding the whole sample in acrylic resin. The samples were then left for 24 hours for a complete polymerization of the acrylic resin (Figure 3a).

Using the Buehler Abrasimet 2 Abbrasive Cutter, the sample was fixed and securely mount on the handle (Figure 3b). The sample was positioned until the saw cutter located at the middle of the restoration (identified by the mid-section mark) and sectioned into halves in the middle of the restoration (mid-section) at the mesio-distal cross section (Figure 3c). The mesio-distal slice exhibited the cross-section of the sample including the proximal, middle and pulpal floor areas (Figure 3d). The samples were polished with silicon carbide sandpaper (320, 600, and 1200 grit) (Figure 3e) and the polished surfaces were observed using microscope x20 magnification to ensure smooth surfaces that would be ready for micro-indentation test [11].

Vicker Hardness Test

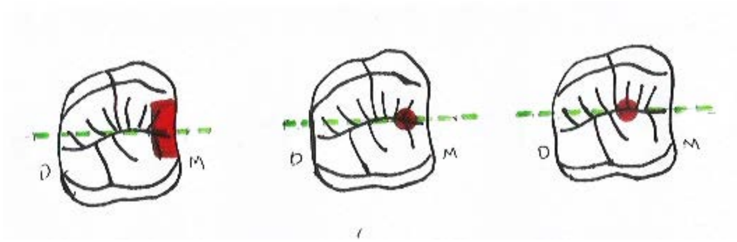
Micro-hardness of each sample from different groups were tested using the Vickers micro-hardness machine test (Mitutoyo HM-200 Series). Indentations were made on three different areas (Figure 4a-4c) on each sample; top part, middle part and bottom part. For each part, three indentations were made with 500g load and a dwell time of 15 seconds [9].

Measurements were done at the magnification x50 where the width and the height of the diamond notch will be recorded. These measurements will be translated to the micro-hardness value reported as Vicker Hardness (VH) for each sample.

All data obtained will be presented as mean and standard deviation (SD). One-way ANOVA was used to compare the mean VH values between each group samples at different part of the restoration (top, middle and bottom). Meanwhile, repeated measure ANOVA was used to compare the mean VH of different part (top, middle and bottom) within the same group. Statistical analysis was performed with IBM® SPSS® Statistics Version 23 for Windows.

Figure 3 (a): Embedment of sample in resin acrylic.

Figure 3(b): Sample positioned on the cutter for mesio-distal cross-section procedure.



(a) (b) (c)

Figure 3(c): The green dotted lines represent the section line of each sample (a) Group 1, (b) Group 2 and (c) Group 3.

Figure 3(d). The mesio-distal cross-section of the sample.

Figure 3(e). Sample positioning during polishing procedure.

Figure 3(a) – 3(e): Procedure steps of sample preparation prior Vicker Hardness Test

Results

Vickers Hardness Test:

The mean value of VH for each group at the different part of restoration displayed in Table 2. Generally, a pattern of decrease in VH were noted in top, middle and bottom part of the restorations TP > MP > BP in all groups (Figure 5). When comparisons were made among the three groups, the value of TP, MP and BP among the groups also exhibited a decrease pattern where the value of VH decrease from Group 1 > Group 2 > Group 3. Further analyses on the comparison of hardness between groups, the VH for the top part (TP) was not significantly difference among all 3 groups. However, in both the middle part (MP) and bottom part (BP), significant differences were noted between the groups for the VH value. Post-hoc Tukey test revealed that for BP, significant differences were only reported between Group 1 to Group 2 and Group 3 ($p<0.05$), but not between Group 2 and Group 3 ($p>0.05$).

Upon observation in the same group, no statistical mean differences ($p>0.05$) were noted in Group 1 for all three parts of the tested restoration (TP, MP and BP). However, for Group 2 and Group 3, statistical mean differences ($p<0.05$) were reported between TP and BP, and between MP and BP. No significant differences between TP and MP (Table 3).

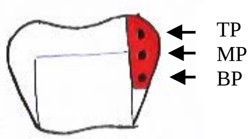


Figure 4a: The black dot represents the different part of tested area in Group 1; top part (TP), middle part (MP) and bottom part (BP).

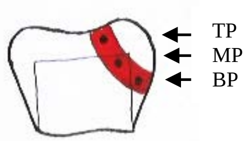


Figure 4b: The black dot represents the different part of tested area in Group 2; top part (TP), middle part (MP) and bottom part (BP).

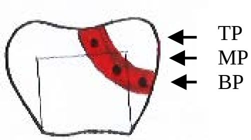


Figure 4c: The black dot represents the different part of tested area in Group 3; top part (TP), middle part (MP) and bottom part (BP).

Table 2: The mean VH values at the different part of the restoration and in different groups.

		n	Mean	Std. Deviation
Top part (TP)	Group 1	5	79.10	2.08
	Group 2	5	77.30	4.47
	Group 3	5	74.94	3.31
Middle part (MP)	Group 1	5	79.00	0.62
	Group 2	5	73.30	2.03
	Group 3	5	69.74	2.23
Bottom part (BP)	Group 1	5	71.16	3.51
	Group 2	5	64.44	0.71
	Group 3	5	62.74	1.05

Table 3: Comparison of VH in relation to different groups and different parts

	H Means (SD)		
	G1	**VG2**	**G3**
Top	79.10 (2.08)	77.30 (4.47)^{a}	74.94 (3.31)^{a}
Middle	79.00 (0.62)^{A}	73.30 (2.03)^{Ab}	69.74 (2.23)^{Ab}
Bottom	71.16 (3.51)^{B}	64.44(0.71)^{Bab}	62.74 (1.05)^{Bab}

^{A} and ^{B} indicate statistical difference in same part of different group (row).
^{a} and ^{b} indicate statistical difference in different part of the same group (column).

Vickers Hardness Ration (VHR):

In order to get Vicker Hardness Ration (VHR) value for each sample, the VH value of bottom part (BP) was divided by VH value of top part (TP) x 100 for the percentage. The bottom-top-ratio of above 80% is the criteria applied as a minimum acceptable degree of polymerization for any light-cured investigated material [12]. The VHR for Group 1 was 89.96, Group 2 was 83.36% and Group 3 was 83.72%. Figure 6 clearly exhibited that all groups have achieved >80% of VHR.

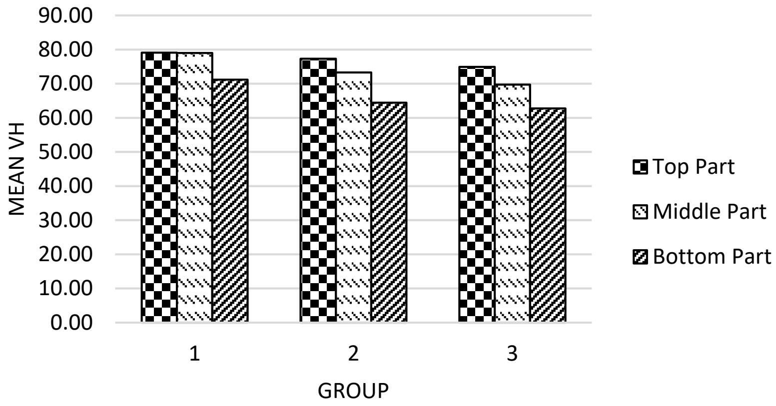


Figure 5. The mean VH values at the different part of the restoration and different groups.

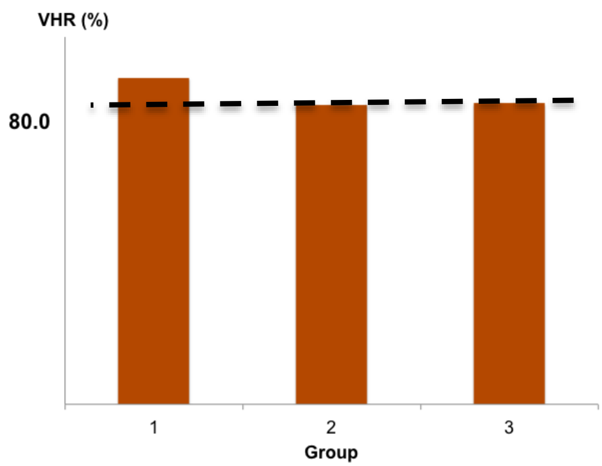


Figure 6. The Vicker Hardness Ratio (VHR) value for each tested group.

Discussion

Tunnel preparation fits into the modern concept of minimally invasive dentistry, which aimed at maximum preservation of healthy dental tissue [13]. Despite being recommended for management of proximal carious lesion, one of the downsides of the tunnel cavity preparation is the technique sensitivity and the undermined nature of the cavity design, which arise to two main concerns; caries free cavity, and the full penetration of light irradiance to polymerize light-cured material used [6].

Polymerization of composite resin material can be measured by different technique; degree of conversion [14], Vickers micro-hardness test [12)], Knoop micro-hardness test [4], assessment of the interfacial integrity by scanning electro-microscope (SEM) [15] or by microleakage test using silver nitrate combine with micro-computed tomography [16] or using dye penetration with stereo-microscope [17].

In this particular study, micro-hardness test Vickers Hardness was used to assess the polymerization of the bulk-fill composite resin in tunnel technique restoration. Vickers indents were chosen as it was easier to measure by image analysis than Knoop indents due to the lower contrast at the tips of the Knoop indents. The diamond indenter used in the procedure did not deform over time and reportedly suitable for measuring the hardness of fragile brittle materials. However, considerations need to be taken when doing the hardness testing as there are numerous factors that may contribute to the quality of micro indentation test results (Table 4) [18].

Table 4. Factors affecting precision and bias in micro-indentation hardness test [18]

Instrument Factor	**Measurement Factor**	**Material Factor**
Accuracy of the applied load	Calibration of the measurement system	Heterogeneity of the specimen
Inertia effects, speed of loading	Numerical aperture of the objective	Strength of crystallographic texture, if present.
Lateral movement of the indenter or specimen	Magnification	Quality of specimen preparation
Indenter sharp deviations	Uniformity of illumination	Creep during indentation
Damage to the indenter	Distortion in optics	Fracture during indentation
Inadequate spacing between indents or form edges	Operator’s visual acuity	Oil, grease or dirt on indenter or specimen
Angle of indentation	Focusing of the image	

A composite resin is considered fully set and clinically acceptable to be use as a dental restoration when the hardness at any part of the restoration is >80% from the mean occlusal part of the restoration (Vickers hardness ratio). The mean HV value for TP were G1=79.10, G2=77.30 and G3=74.94 and these value were used as the standard maximum value due to the assumption of full polymerization in a depth of 0.5mm with full light irradiation access. This study found that the lowest HV value of 62.7 at the bottom part of a 3.0mm thickness of marginal left in-situ (G3) still exhibited VHR >80%, indicating that the material did achieve adequate polymerization from sufficient light irradiation.

The main advancements of bulk-fill composite resin material that allow the increase in depth of cure and low polymerization shrinkage stress were from the modifications in the material filler content and/or organic matrix [19]. The translucency of the material was increased by reducing the filler contents opacity, increasing the filler size and the incorporation of additional photo-initiator [(20-21].

In this study, the decrease pattern in VH value were noted for all group samples. However, no significant difference was reported for G1 in their decrease pattern, which was due to the cavity design that has no marginal ridge intact allowing maximum light irradiation during the polymerization process. As for the other two groups, presence of intact marginal ridge (1.5mm and 3.0mm thickness) did compromise the light cure penetration to fully polymerize the undermined restoration resulting in a significant difference for VH value in G2 and G3 at the middle and bottom part. However, despite of the decrease pattern in VH for all groups on every tested part, the mean VHR % value was more than 80% in all areas (top, middle and bottom) which indicate adequate polymerization. This achievement was obtained due to the proper curing protocol that was proposed by the manufacturer where curing was done from three different angulations; (i) 10 seconds from the occlusal surface, followed by (ii) 10 seconds from the buccal directions and, (iii) 10 seconds from the lingual directions after removal of the matrix band. The light curing intensity unit was calibrated to an intensity of $1000mWcm^{-2}$ or greater to ensure the optimum efficiency of the light-curing unit. This protocol was supported by a study that proved multi-sited curing technique was effective in achieving the threshold of 80% maximum hardness in proximal cavity restorations [4].

Photo-polymerization of composite resin is fundamentally important for optimization of the physical and mechanical properties and clinical results of the material. Inadequate polymerization of composite can deteriorate the margin of the restoration causing leakage, reduced hardness and lead to greater cytotoxicity. Therefore, it is crucial for a dentist to regularly calibrate their light curing unit (LCU) to ensure delivery of adequate and sufficient energy to optimize composite polymerization. Different light intensity has proven to affect the degree of conversion of the monomer to polymer and depth of cure [22]. One of the factor that affect the degree of polymerization of resin-based composites (RBC) is the thickness of the composite restoration. Increasing the composite resins restoration thickness results in more curing light absorption and scattering and less light penetration within the layers of the cured material. Therefore, overall curing light energy is reduced with increasing composite resins thickness. Although 2 mm incremental thickness is the regular standard for conventional composite resins increment placement, bulk-fill allows placement of the material in one increments (up to 5 mm thickness) while maintaining an adequate degree of conversion [23-24] which was also reported in this study.

Conclusion

In conclusion, VH value of bulk-fill composite resins was statistically reduced in relation to the different marginal ridge left in-situ at the middle and bottom areas. However, the mean VHR value that was more than 80% in all areas (top, middle and bottom) indicating that bulk-fill material used in tunnel technique restorations did receive enough light intensity for an adequate polymerization and can be clinically suggested as a method in restoring proximal caries.

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