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A Comparison of Curing Distances and Their Effects on the Photocurability of 3M Filtek One Bulk Fill Restorative

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ABSTRACT

Objective: To compare the hardness of 5mm-depth samples of the bulk-filled composite resin, 3M Filtek One Bulk Fill, at different tip distances of 0mm, 2mm, 4mm and 6mm after curing for 20 seconds with an Acteon Mini LED curing light. The Knoop hardness test (KNH) was used to measure the hardness and ultimately evaluate the curability and polymerization of each sample.

Material and Methods: A 5mm deep x 5mm wide mold was used to create samples using 3M Filtek One Bulk Fill composite resin in shade. Twenty specimens were prepared for each group representing a 0-, 2-, 4-, and 6mm curing tip distance for a total of 80 samples. Samples were cured for 20 seconds with an Acteon Mini LED curing light system before being tested for hardness using the KNH. Each sample was measured at five locations (center, north, south, east, and west) on both the top and bottom surfaces, for a total of 800 hardness assessments using the Leco LM300 series microindentation hardness testing system. For each specimen, bottom/top KNH ratios were compared to the industry standard of 80% hardness to verify a clinically adequate depth of cure in relation to the manufacturer's recommended guidelines. Each sample was tested immediately after preparation.

Results: None of the groups achieved the desired threshold of at least an 80% bottom/top KHN ratio.

Conclusion: An acceptable hardness when using 3M Filltek One Bulk Fill composite resin in 5mm-depth samples was not achieved, regardless of tip distance, when cured for 20 seconds.

INTRODUCTION

In the history of dentistry, there have been various kinds of dental materials developed and used to restore carious or fractured teeth. Dentists have been using various amalgams in restorative cases for more than 150 years in the majority of world dental markets. One of the most popular materials in restorative dentistry, amalgams have a number of advantages such as strength, durability, ease of use, low cost and self-sealing properties.[1]

However, increasing number of patients have expressed their desires for more esthetic restorative dentistry, and clinicians have been looking for more time-saving and cost-effective materials as well. This propelled the global dental industries and markets to invent, develop, and introduce new type of advanced dental materials, which emphasize greater esthetic results with time- and cost- saving clinical procedures. This new material is composite resins, which meet patients' and dentists' recent needs for more esthetic, yet well-functioning restorative fillings. Therefore, for the last two decades, the changes in the demands/supplies of the advanced composite resins have influenced the international dental industry significantly. More patients have requested more esthetic restorative materials, and more dental professionals have sought and developed new types of composite resins.[2] As a result, recently composite resins have been replacing dental amalgams, especially in posterior teeth restoration cases.[3]

While composites have the above advantages, there are some disadvantages, such as handling difficulty and technique sensitivity. Compared to amalgam restoration, dental professionals need to pay more attention when applying the composite material, and they need more time to place it in the wide and deep cavity preparation.[4] This is because incremental composite application is necessary to reduce polymerization shrinkage and post-operative sensitivity. Additionally, more attention is required to remove any moisture or saliva from the surface so the material is not contaminated when applied.[5] Therefore, placing direct composite restorations in a reasonable time and with care becomes one of the most significant skills for successful restorative dentists.[6] In addition to the above disadvantages, polymerization conversion and shrinkage can be found occasionally in conventional composite restoration cases due to multiple increments of composite application.

In addition, several more disadvantages in light-cured composite restoration cases have been discovered and documented: inability to adequately cure the composite to depths greater than 2 mm,[7] and challenges related to preparation design on the C-factor, the ratio of bonded-to-unbonded restoration surfaces. Complications due to polymerization shrinkage and increased formation of gaps have been discovered as well.[8] Historically, when these types of new dental products/materials were developed, the main interests usually involve procedural and cost efficiency. However, the acknowledgement of possible complications/disadvantages is significant as well.

In the efforts to stabilize and advance this time-consuming and technique-sensitive dental material, bulk-fill composite resins have been introduced into the dental markets. These have made a single direct composite restoration possible instead of multiple increments of filling. With these advanced composite materials, it has become possible to provide an option to apply the increments of 4mm without polymerization conversion nor shrinkage. Therefore, the thicker increments at a single application have decreased chair work/waiting time by efficiently simplifying the procedural steps of composite restorations. This has resulted in less technique-sensitive, as well as time- and cost-saving dental procedures for both patients and operators. In addition, the more advanced composite materials in bulk-fill form have provided more results that are advantageous: ease of dispensing; enhanced physical aspects and improved fill depth of 4mm cure; more flexibility for cavity preparation; minimal dental handlings and steps; and reduced polymerization conversion or shrinkage. In some class II cavity cases, bulk-fill composite resins have shown strengths in cusp deflection in standardized class II cavities, and improved self-leveling ability for low-viscosity materials.[9] This advancement in the material has resulted in minimized complications as well.

This type of bulk-fill composite restoration uses Ultraviolet (UV) and Visible Light Curing (VLC) methods to harden the fillers. This light-cured bulk-fill advancement is based on the concept of photo-polymerization of dimethylacrylate monomers, which yields a cross-linked polymerizable resin, filler and the filler-resin interface.[10]

With this light-activated bulk-fill composite restoration process, there are multiple factors influencing the outcomes. The acceptable and sufficient polymerization depends on the adequate light output, appropriate wavelength ranges of the light, quality and intensity of the light's strength and duration, and the light's tip diameter and the distance from the light source and exposure time. Other factors affecting the adequate polymerization are the resin composite type, shade, thickness of material, and translucency of material for the light to penetrate.[11] Changes in these multiple factors will result in different effects on the efficiency of the reaction when cured with the light. Thus, these factors will affect to what degree the hardness of the bulk-fill has affected the light-treated teeth.[12] Therefore, it is crucial for clinicians to consider these factors in order to prevent undesirable changes in mechanical properties. The above factors could negatively affect the modulus of elasticity, radiopacity and the coefficient of thermal expansion.[13]

In dentistry, the terms Depth of Cure (DC) and Degree of Conversion (DoC) are used to determine the level of polymerization.[14] The DC is measured by quantifying the hardness of the composite material at a certain depth, which has a direct correlation to the level of polymerization. The DoC refers to the concentration of unreacted carbon double bonds in the resin when being cured, and this is very significant when obtaining good mechanical properties and biocompatibility. Among these two, DoC has a direct relation with the total irradiance penetrating the material, and is determined by the light curing unit (LCU) and the distance between the composite resin and the curing tip. The top surface, the closest to the source of the light, will have the higher DoC, but DC must be acceptable all through the planned depth to call it "adequate polymerization". When low DoC and DC are appearing, this may result in a faster degradation of the composite, which includes fracture, marginal breakdown, and shorter clinical life of the composite material. In addition, recurrent decay, postoperative sensitivity, edge staining and pulp irritation can happen as well. Therefore, the significance of adequate polymerization with acceptable DC and DoC is emphasized to prevent the above undesirable clinical outcomes.

Among many light-activated bulk-fill composites recently developed by many manufacturers 3M Corporation commercialized a new type of bulk-fill composite resin, Filtek One Bulk Fill Restorative ("Filtek One") into the worldwide dental markets in 2017. According to product general information, the manufacturer introduced Filtek One as a more advanced bulk-fill system.[15] According to the product's manual, the manufacturer insists that, as a visible-light activated restorative composite material, Filtek One is optimized to create fast and easy restorations, and provides excellent strength and low wear for durability and improved esthetics as results. In addition, the manufacturer insists that clinicians can apply 5mm depth bulk-fill composites with the single increment of the filling. The company recommends the curing light's tip distance to be as close as possible to the surface of the Filtek One. This Filtek One composite incorporates a highly-filled proprietary resin with special modifiers that react to curing light. When the light is applied, the modifier purportedly causes the viscosity to drop up to 87%, an increase in the flowability of the composite, and quick and precise adaptation to the cavity walls up to 5mm in depth. The restored teeth are then cured with the LCU for 20 seconds for the final polymerization procedure.

The manufacturer, 3M Corporation, recommends the curing light's tip distance to be as close as possible to the surface of the bulk-fill composite resin. Even with the "single" increment of the filling, the bulk-fill application requires the applicator's careful manual techniques and attention to the procedure. However, this study was prompted by the question of what will occur if the applicator demonstrates different techniques and degrees of care or attention when applying the material to teeth. Moreover, this led to the hypothetical question of what results if the applicator places the tip of the curing light at different distances.

Therefore, the purpose of this *in vitro* study is to evaluate the hardness of 5mm depth-filled bulk fill composite resins at different tip distances from the curing light. The different tip distance groups are 0mm, 2mm, 4mm and 6mm.

MATERIALS AND METHODS

The resin composite used in this study was 3M Filtek One Bulk Fill Composite Resin (3M company, Maplewood/Minnesota) in the shade of A2. The samples were prepared in a mold at a depth of 5mm and a diameter of 5mm. Filtek One Bulk Fill was dispensed to fill the mold, in accordance with the manufacturer's instructions, and any excess material was removed. Twenty samples for each distance group of 0mm, 2mm, 4mm and 6mm, a total of 80 specimens, were created and tested.

The Acteon Mini LED curing light (Acteon North America, Mt Laurel Township/New Jersey) was used in this study. Before each cure, the intensity of the LCU was measured using a radiometer (Demetron LED Radiometer, Kerr, Brea/California). The light source was placed on the top surface of each sample at the different tip distances groups of 0mm, 2mm, 4mm and 6mm, utilizing a clamp to stabilize the curing unit. The light was emitted for 20 seconds. Only the top surface of each sample was irradiated for 20 seconds, while keeping the curing unit centered in the restoration. Then the samples were removed from the molds, and tested immediately for microhardness to avoid further exposure to ambient light after initial polymerization.

Each sample was tested for hardness in five locations (center, north, south, east, and west) on both the top and bottom sides. Thus a total of 800 hardness assessments were accomplished. The Leco LM300 series microindentation hardness testing system was used to assess each sample. Bottom/top Knoop hardness test (KNH) ratios were compared to the industry standard of 80% hardness to verify a clinically adequate depth of cure in relation to manufacturer's recommended guidelines.

Exploratory data analyses were conducted on the KHNs and the Shapiro-Wilk test was used to assess the normality of the data distribution. For continuous data, measures of central tendency are presented as means with associated standard deviations. Analyses of variance (ANOVAs) were conducted to check for overall differences in mean surface KHN between the top and bottom sides of samples, as well as to examine the effect of curing distance on mean surface KHN. Eta squared (η^2) statistics are presented as measures of effect size for significant ANOVA results.[16] A factorial ANOVA was conducted to compare the main effects of distance, position, and the interaction effect between the two on surface KHN. Statistical significance for all statistical tests was declared at $P < 0.05$. Data were analyzed using SPSS 25.0 (IBM).

RESULTS

None of the curing groups achieved the desired threshold of at least an 80% bottom/top KHN ratio. The bottom/top KHN ratio for the 0mm group was 36.9%; the 2mm group was 37.6%; the 4mm group was 31.6%; and the 6mm group was 9.0%. An ANOVA was performed to compare the mean surface KHN of the top and bottom sides. The top side of samples was found to have a significantly higher KHN compared to the bottom side, $P < 0.001$. The effect size for this difference was $\eta^2 = 0.68$, indicating a large difference between the top and bottom side hardness. The mean surface KHN for the top side of samples was 46.1 (SD = 19.7) and the bottom side was 13.6 (SD = 8.1). Due to the difference in hardness, ANOVAs were conducted to assess the effect of curing distance on each side separately.

Table 1 shows the mean KHN values by curing distance and side. Among the top side of samples, an analysis of variance showed a major effect of curing distance on surface hardness ($P < 0.001$, $\eta^2 = 0.42$). Post-hoc analysis using Tukey's HSD indicated that the mean surface KHN was lowest for the 4mm group (all $P < 0.01$) and highest for the 0mm group (all $P < 0.001$). Interestingly, the 2mm and 6mm groups did not differ with respect to mean surface KHN, $P = 0.74$. Overall, the mean KHN for the top side varied between a minimum of 15.3 in the 6mm group and a maximum of 111.1 in the 0mm group.

Similarly, data revealed a major effect of curing distance on bottom side hardness ($P < 0.001$, $\eta^2 = 0.69$). Post-hoc comparisons using Tukey's HSD revealed significant differences between each of the curing distances (all $P < 0.001$). The 0mm distance had the highest KHN with a mean of 22.4 (SD = 7.7). Each subsequent increase in distance (2mm, 4mm, and 6mm) yielded a significantly lower KHNs at 16.3 (SD = 3.8), 11.9 (SD = 2.7), and 3.8 (SD = 1.0) respectively. This monotonic decrease, although not linear, stands in contrast to the apparent leveling off of the top side hardness. Figure 1 shows the mean surface KHN values by distance for both the top and bottom sides.

A factorial ANOVA was also conducted to compare the main effects of curing light tip distance, and sample location (center, north, south, east, and west). On the top side of the samples, no significant effect was found with regard to sample location ($P = 0.77$), indicating a uniform curing of the top side regardless of distance. Additionally no interaction between sample location and distance was noted, $P = 0.08$. Similarly, on the bottom side of the samples, no major effect was found for sample location ($P = 0.92$), nor was there an interaction between location and distance, $P = 0.99$. Figure 2 shows the mean surface KHN by curing distance and position.

DISCUSSION

The variable for this in vitro study is the LCU's tip distance to the composite resin surface. Because every clinician has different techniques when applying the bulk-fill composite resin in dental restoration cases, a question emerged: what if the distance from the tip of the LCU to the resin surface is different because of clinicians' differing techniques? This variable of this study is very significant because a clinician will scarcely have the ability to position the tip of the LCU almost directly on the composite due to other numerous variations such as tooth orientation, cusp height, marginal ridges, matrix band placement, and overall access to the targeted tooth. Therefore, variation in tip distances between the LCU's tip to the surface of the treated tooth is often expected in restorative dentistry.

As we can see, the result shows none of the different tip distance groups achieved the sufficient percentages of KHN (to test the hardness of the resin) to consider it as an "adequate polymerization". The result shows that the KHN ratio was not accordingly consistent even with the increase of the tip distances. This raises the concern of the ability of a common LED LCU to adequately polymerize a 5mm deep increment of Filtek One bulk-fill composite. If the LCU cannot properly cure the bulk-fill-treated tooth, the polymerization process will not be thoroughly completed. Ultimately, this may reduce the composite's physical and mechanical effectiveness, and lower the bond strength to the tooth[17].

In addition to the LCU's ability to harden the restored tooth, in other words, adequate polymerization, use of the 5mm increment may be in question as well. The manufacturer advertises that Filtek One makes it possible to have the 5mm bulk-filling at a single time, and acceptable hardening of 5mm depth composite filling will occur as a result. However, when we refer to the result of this study, even the ideal 0mm tip distance shows a low percentage of KHN and, thus, low curability. Therefore, using a 5mm bulk-fill composite of Filtek One with potential low curability and inadequate polymerization contradicts the manufacturer's advertisement.

CONCLUSIONS

The results of this study present that sufficient hardness of the Filtek One bulk-fill composite system does not consistently occur at a bulk-fill depth of 5mm when the composite is cured from the occlusal surface for 20 seconds. Future studies could evaluate if acceptable hardness can be achieved by using a longer curing time, a shallower sample depth, or a combination thereof.

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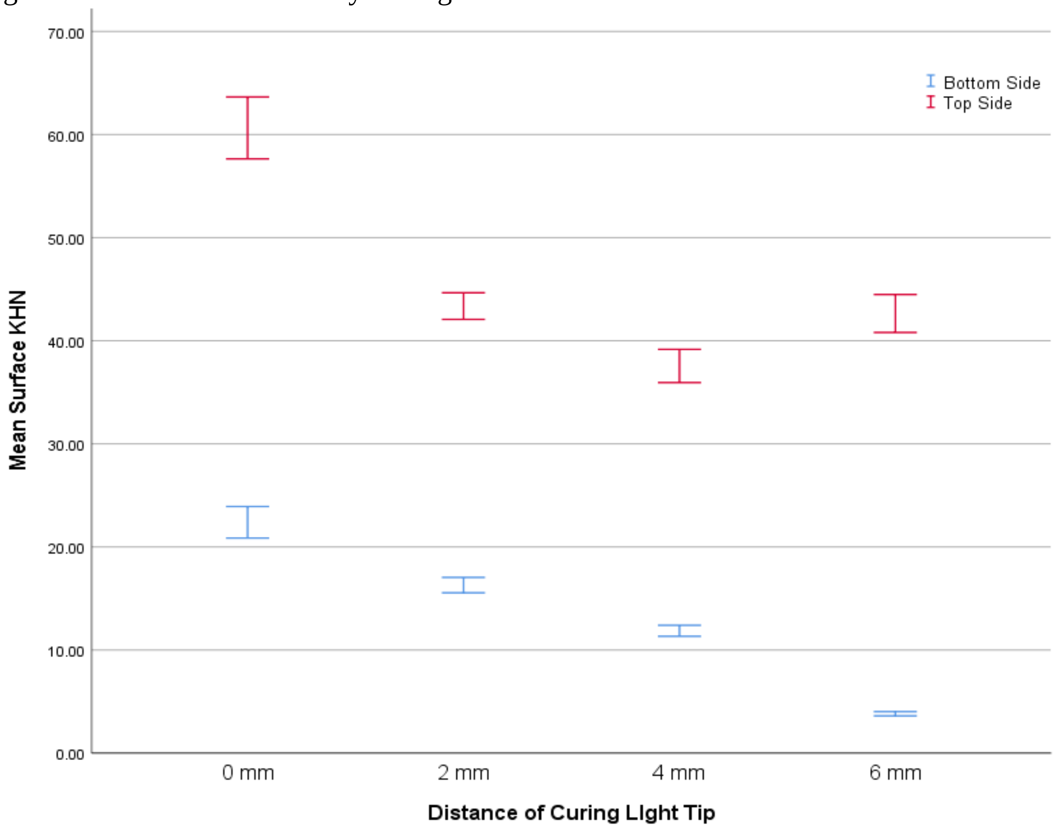
Appendix

Table 1. Mean Surface KHN by Side

Distance, mm	Bottom / Top Ratio, %	Top		Bottom		P[1]	η^2
		N	M (SD)	N	M (SD)		
0	36.9	100	60.6 (15.1)	100	22.4 (7.7)	<0.001	0.72
2	37.6	100	43.4 (6.5)	100	16.3 (3.8)	<0.001	0.87
4	31.6	100	37.6 (8.1)	100	11.9 (2.7)	<0.001	0.82
6	9.0	100	42.6 (9.3)	100	3.8 (1.0)	<0.001	0.90
Total	29.5	400	46.1 (19.7)	400	13.6 (8.1)	<0.001	0.68

1.Significance based on ANOVA

Figure 1. Mean Surface KHN by Curing Distance



*Error bars represent 95% Confidence Intervals

Figure 2. Mean Surface KHN by Curing Distance and Position

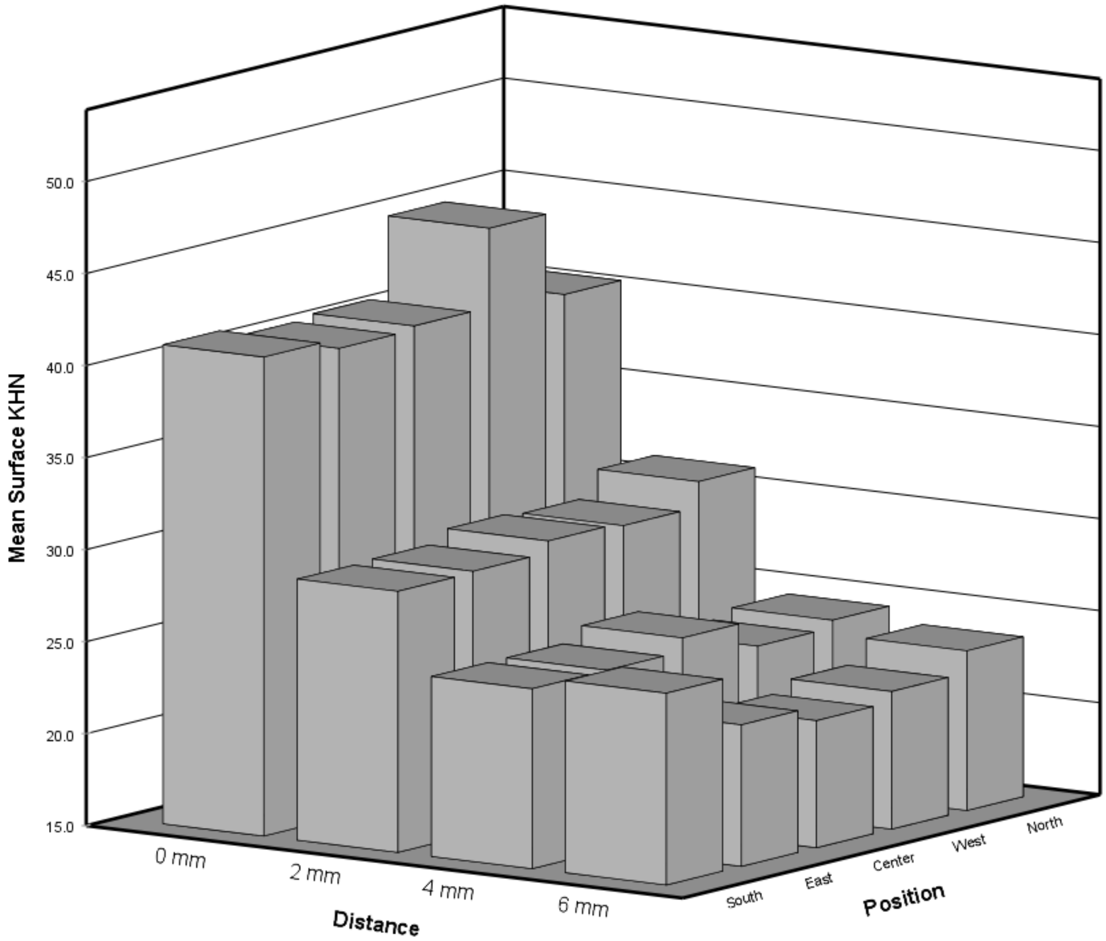


Figure 3. Acteon Mini LED

Figure 4. LED Radiometer (Demetron, SDS/Kerr, Orange, CA)

Figure 5. Leco 300AT Knoop Hardness Tester

Figure 6. Spacers used to keep constant distance from the samples to the light tip