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https://www.usuhs.edu/pdc

THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: "A comparison of Curing Distances and Their Effects on the Photocurability of a Sonically Activated Bulk Fill Composite System""

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Master of Science Degree
June 15, 2018

THESIS/MANUSCRIPT APPROVED: DATE:

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A COMPARISON OF CURING DISTANCES AND THEIR EFFECTS ON THE PHOTOCURABILITY OF A SONICALLY ACTIVATED BULK FILL COMPOSITE SYSTEM

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April 2018

This manuscript was prepared to meet the submission guidelines of *General Dentistry*, a publication of the Academy of General Dentistry.

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Acknowledgements

The authors wish to acknowledge the 2-Year Advanced Education in General Dentistry, highlighting its director, LTC Charles Lambert and assistant director, MAJ Jason Bullock for continuous guidance and encouragement. In addition, the Womack Army Medical Center Department of Clinical Investigation is acknowledged for their support of this project. Finally, the lead author would like to thank his immediate family and particularly his wife, Mrs. Sara Browning, a Speech Language Pathologist, for all reviews, commentaries, and enthusiastic support over many years.

Disclosures and Affiliations

Neither I, nor any member of my family, have a financial arrangement or affiliation with any corporate organization offering financial support or grant monies for this research, nor do I have a financial interest in any commercial product(s) or service(s) I will discuss in the presentation or publication.

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ABSTRACT

Recent advancements in composite resin have facilitated the development of the sonically activated bulk-fill composite system, Sonicfill 2, which its manufacturer claims can be cured to a 5mm depth. The aim of this in vitro study was to test the adequacy of polymerization with the curing light at different tip distances from the SonicFill 2 composite resin, in a posterior class I occlusal restoration. The null hypothesis was that adequate polymerization will only occur at the 0mm tip distance, and the remaining tip distances will result in inadequate polymerization. Eighty samples of the SonicFill 2 bulk-fill composite resin were created using shade A3 at a 5mm depth. All samples were cured for 20 seconds using the Demi Plus curing light at a tip distance of 0mm, 2mm, 4mm, or 6mm. Each of the curing distance groups contained 20 samples. The hardness of the top and bottom sides were determined and compared to assess the polymerization of each group. None of the curing groups achieved the desired threshold of at least an 80% bottom/top KHN ratio. Data revealed a significant effect of curing distance on bottom side hardness, as well as significant differences between each of the curing distances, with the hardness significantly decreasing on the bottom side as the tip distance increased. The results of the investigation suggest that adequate polymerization of the Sonicfill 2 system does not occur at a depth of 5mm when the composite is cured from the occlusal surface only for 20 seconds.

INTRODUCTION

Recent advances in composite resin have propelled its use in dentistry over the last two decades. This growth is so significant that in some geographical markets they have replaced amalgam restorations.[1] These advances also created a noticeable shift in the wishes and needs of patients, from immediate treatment for pain in emergencies to longer-term necessities such as function and esthetics.[2-4] This shift in patient desires forced the profession, and thus, the industry to develop more esthetic restorative materials, with better physical and mechanical properties.[4-5]

The science behind modern composites reveals an organic matrix, an inorganic matrix filler, and a coupling agent. There are numerous functions for the filler, which include enhancing the radiopacity, the modulus of elasticity, and the coefficient of thermal expansion.[6] This basic structure, through several generations of advancements, has unleashed varying composite types into the market, including microfilled, hybrid, microhybrid, nanofilled, and low-shrinkage bulk fill composites. These variations are due to specific changes with each composite, such as the type of coupling agent, filler particle size, or activation process, all of which affect physical or chemical properties.[3,5]

A significant property change in the advancement of composites is the development from self-curing materials to those that cure by means of Ultraviolet (UV) and Visible Light Curing (VLC) methods. This advancement is based on the concept of photopolymerization of dimethylacrylate monomers, which yields a cross-linked polymerizable resin, filler, and the filler-resin interface.[6] This new capability increased working time, thus facilitating more ease of placement and accommodation while manipulating artistic shape and form.

The resulting outcome of this process depends on multiple factors, including the shade and thickness of material, the quality and intensity of the light's output and duration, the light's tip diameter and the distance from the resin sample. Changes in these factors result with varying effects on the reaction efficiency, thus affecting the polymerization process.[7-8] This, in turn, could affect physical and mechanical properties, such as the coefficient of thermal expansion, modulous of elasticity, and radiopacity.[7-10]

One variable with significant clinical application is the distance of the tip of the Light Curing Unit (LCU) to the surface of the composite material. This measurement is known as tip distance. The majority of studies use an in vitro standard of a 0mm tip distance, with the composite covered with a clear mylar strip.[11-12] Multiple studies have shown that by increasing tip distance, the light intensity is decreased up to 10% per 1mm of air.[8, 13-16] Other factors, along with tip distance, have a direct effect on energy dispersion to the composite, such as tip angulations, debris on the surface of the tip, and protective barriers.[17] Each of these factors can decrease the penetration depth of the light into the composite and in turn, will decrease its polymerization.

In addition to the tip distance, the exposure time and light intensity also affect the polymerization process. The degree of conversion will increase with a longer exposure time of the composite resin to the light.[7-8] The specific wavelength of the light, as well its irradiance and scatter properties within the restoration, also determine how deep the light can penetrate into a composite material.[18] The physical properties of the composite material can be reduced if the material does not polymerize completely.

In order to determine the level of polymerization, the terms Depth of Cure (DC) and Degree of Conversion(DoC) are used.[6, 9, 19-21] DC can be assessed indirectly by quantifying the hardness of the composite material at a certain depth, which has a direct correlation to the level of polymerization.[20] The DoC is the concentration of unreacted carbon double bonds in the resin when it is cured, which is important in obtaining good mechanical properties and biocompatibility.[6] DoC has a direct correlation with the total irradiance penetrating the material. This is dependent on the light curing unit (LCU) and the distance between the curing tip and the composite resin.[1] The top surface, which is closest to the light source, will have a higher DoC, but an acceptable DC is required to the planned depth for adequate polymerization. A low DoC may result in a faster degradation of composite, including marginal breakdown, fracture, and ultimately a shorter clinical life. Other possible effects of inadequate polymerization include marginal staining, recurrent decay, postoperative sensitivity, and pulpal irritation potentially resulting in necrosis.[7-9, 13, 22]

An unintended consequence of polymerization is volumetric shrinkage, which increases stress at the interface of tooth to resin.[15, 23] This shrinkage has become one of the most significant problems presented by composite materials because the resin pulls away from the tooth wall, creating gaps which allow saliva, food, and bacteria to enter. To reduce this effect, the technique of layering and curing composites in 2mm increments has been accepted as the standard technique for placing composite restorations.[24] This is beneficial because it allows adequate polymerization, improves marginal adaptation and physical properties, and it reduces the amount of overall volumetric shrinkage.[25]

Further advancements in dentistry have led to more cost-effective and efficient composite materials in the form of bulk-fill composites, which reduce the number of increments for direct composite restorations.[26] These manufacturers claim these composites provide the option to place and cure the material in increments of 4mm, without the degree of polymerization shrinkage or degree of conversion seen in conventional composites.[27-28] Depending on the type of bulk-fill composite, other advantageous characteristics include easier dispensing, more flowability to allow for better adaptation to the cavity preparation, minimal handling, and enhanced physical characteristics.[29] Some additional advantages that have been reported are reduced cup deflection in standardized class II cavities, and improved self-leveling ability for low-viscosity materials.[30-31] By allowing placement and curing in thicker increments, chairside work time decreases by reducing the number of steps to place a composite restoration. The overall result is a quicker and less stressful procedure for both the clinician and the patient.

One of the improvements in bulk-fill composite restorations was the introduction of SonicFill from the Kerr Corporation (Orange, CA). SonicFill’s advantage over traditional bulk-fill composites is its ability to provide an on-demand viscosity change for the provider. By simply pressing a dental rheostat, the SonicFill handpiece, with an attached unidose composite tip, can reduce the viscosity of the composite. This allows it to flow into a tooth preparation and adapt well against the preparation walls, reducing the need for a separate flowable composite liner.[32] In addition, the manufacturer claims a depth of cure up to 5mm in depth. The most recent edition of SonicFill was introduced as SonicFill 2 by the

Kerr Corporation. This newer version of SonicFill features a new filler system designed to enable excellent gloss, color-matching, wear resistance, and strength, according to the manufacturer.[33]

By allowing for more efficient placement and greater depth of cure, could this new sonically activated bulk-fill composite be the solution to replace amalgam? This answer depends on more research, especially in long-term studies. In the near-term, extensive research is needed to confirm the claims made by the Kerr Corporation, which manufactures both the SonicFill 2 system as well as the Demi Plus, a common, battery operated LED LCU.

The manufacturer instructions for Sonicfill 2 state that following a 10 second cure with the Demi Plus LCU (or any light with an output > $1000 mW/cm^2$), an additional 10 second cure is recommended on the buccal and lingual surfaces of posterior restorations.[34] These additional curing angles allow for better access to class II interproximal restorations following matrix removal. What if the restoration does not allow access on either the buccal or lingual surfaces, such as a large Class I occlusal restoration or an extensive, deep core buildup?

Regarding LCU tip distance, neither the manufacturer instructions for SonicFill 2 nor the Demi Plus LCU provide a maximum tip distance for the LCU from the composite surface.[34-35] Therefore, what is the maximum tip distance required to adequately cure SonicFill 2 composite? This is relevant because clinically, providers cannot routinely place the tip of the LCU directly on a posterior composite. Usually for posterior teeth, an obstacle exists which prevents an LCU tip from near direct contact with the composite. These obstacles are present in multiple forms, such as a cusp, marginal ridge, matrix band, tooth position, tooth orientation, tooth anatomy, or minimal opening. In addition, some class I preparations are deep, especially those requiring a core build-up. In these situations, some stand-off of the LCU tip from the surface of the composite is expected. Some studies recognize these clinical situations, so they incorporate a slightly greater tip distance of 1-2mm into their protocol to simulate interferences by cusp tips.[36-37]

Specifically for SonicFill, two studies have included greater tip distances. In one study, the claimed depth of cure of 5mm was not achieved with a tip distance of 7mm.[38] Another study, using a tip distance of 6mm, showed an increase in SonicFill monomer leaching with the increased tip distance.[39] This is consistent with previous studies concerning conventional resin-based composite.[40-42] This may imply that in order to achieve a clinically acceptable restoration, an additional curing time, a reduction of the composite increment depth, or a decrease of tip distance may be needed.

The aim of this in vitro study was to test the adequacy of polymerization with the curing light (Kerr Demi Plus) at different tip distances from the sonically activated bulk fill composite (Kerr SonicFill 2), in a posterior class I occlusal restoration. The null hypothesis was that adequate polymerization will only occur at the 0mm tip distance, and the remaining tip distances will result in inadequate polymerization. For the purpose of this investigation, only posterior class I restorations were simulated due to their limited occlusal access for curing, as compared with class II posterior restorations, which can be cured additionally from the buccal and lingual. This investigation assumed that more time was needed to cure occlusal restorations due to limited access; therefore, the recommended occlusal curing time for the Kerr Demi Plus LCU was doubled from 10 to 20 seconds.

MATERIALS AND METHODS

Eighty samples of Kerr's SonicFill 2 bulk-fill resin composite were broken down into four groups of 20 samples, with each group representing curing distances of 0mm, 2mm, 4mm, or 6mm. All samples were shade A3 and 5mm in bulk thickness. This was accomplished by making a 5mm high, stainless steel mold using 1mm stock washers glued together. The diameter of the mold was 5mm.

For each iteration, the composite was extruded into the stainless steel mold with the Sonicfill handpiece. A mylar strip was placed over the top and bottom of the composite sample. A standard mixing spatula was then pressed against the top mylar strip. Any excess was removed so the top and bottom surfaces of composite remained flush with the top of the mold to ensure a sample of 5mm thickness. To assess the adequacy of the manufacturer's guidelines, samples were cured using the Kerr Demi Plus curing light for 20 seconds at a tip distance of 0mm, 2mm, 4mm, or 6mm. These distances were kept constant using spacers fabricated from the same 1mm stock washers, glued together for the proper distance. The tip distance of 0mm did not require a spacer. The light tip was placed firmly against the open end of the spacer to ensure a 90^0 surface angle contact.

Prior to starting any cycle of curing, the Kerr Demi Plus curing light was fully charged per the manufacturer's recommendations. In addition, a radiometer (LED Radiometer, SDS/Kerr, Orange, CA) was used to measure the intensity and output of the LCU prior to every curing cycle. This was accomplished by placing the curing light tip over the photon reader and acquiring the number of photons per unit area over a unit of time.[43]

The Leco LM300 series microindentation hardness testing system was then used to assess each sample using the Knoop Hardness Test, which utilizes the Knoop Hardness Number (KHN). Eight KHNs (four from the top and four from the bottom) were obtained from each of the 80 samples yielding a total of 640 KHNs (160 per curing distance). Bottom/top KHN 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. Means and standard deviations are reported for continuous data. An analyses of variance (ANOVAs) were conducted to check for 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. Statistical significance for all statistical tests was declared at $P < 0.05$. Data were analyzed using SPSS 25 (IBM, Armonk, NY, USA).

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 53.4%; the 2mm group was 35.6%; the 4mm group was 28.1%; and the 6mm group was 7.8%. An ANOVA was performed to compare the mean surface KHN of the top and bottom sides of samples. The top side of samples was found to have a significantly higher KHN compared to the bottom side, $P < 0.001$. The mean surface KHN for the top side of samples was 43.1 (SD = 9.2) and the bottom side was 13.3 (SD = 8.0). 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, there was no significant main effect of curing distance ($P = 0.10$). The mean KHN for the top side varied between a minimum of 41.6 (SD=6.8) and a maximum of 45.0 (SD=7.0). Figure 1 shows the mean KHN values by distance.

In contrast, data revealed a significant effect of curing distance on bottom side hardness, $P < 0.001$. Post-hoc comparisons using Tukey's HSD reveal significant differences between each of the curing distances. The 0mm distance had the highest KHN with a mean of 22.1 (SD = 5.3). Each subsequent increase in distance (2mm, 4mm, and 6mm) yielded a significantly lower KHN (all $P < 0.001$). The 6mm curing distance produced the lowest mean KHN (M = 13.3, SD = 8.0). Figure 2 shows the mean KHN values by distance.

DISCUSSION

The variable for the study is the tip distance to the resin surface. This was decided upon due to the lack of any guideline provided by the Kerr Corporation for either SonicFill 2 or the SDS Demi Plus LCU. This factor is very important, because as previously discussed, every 1mm of air can decrease output by 10%.[8, 13-16] Because of the numerous variations in clinical dentistry, to include tooth orientation, cusp height, marginal ridges, matrix band placement, and overall access, a clinician will rarely have the ability to routinely place the tip of the LCU almost directly on the composite. Therefore, variation in tip distances is expected in restorative dentistry. This raises the concern of the ability of a common LED LCU to adequately polymerize a 5mm deep increment of Sonicfill 2 bulk-fill composite. If the LCU cannot adequately cure to the bottom of the composite increment, then the polymerization process will not thoroughly complete. This ultimately reduces the physical and mechanical properties, and lowers the bond strength to the tooth.[44-45]

In order to determine this degree of polymerization, this study used the Knoop Hardness Test, which created values for comparing the top vs. bottom sides of each resin composite sample using a ratio.

Adequate polymerization can only be achieved if a bottom/top ratio of >80% HR is produced.[9, 20-21] A minimum of 80% HR is required because anything less could result in a reduction of mechanical properties and an increase in clinical failures.

The results of the experiment did not support the null hypothesis that the 0mm tip distance would achieve adequate polymerization. Instead, none of the curing groups achieved the desired threshold of at least an 80% bottom/top KHN ratio, and it decreased significantly as the tip distance increased from the top surface of each sample. This indicates that the polymerization process overall was not adequate, even with a tip distance of 0mm. Despite doubling the recommended curing time on the occlusal surface, adequate polymerization still did not occur with any of the curing tip distances.

How do these results affect dental restorative techniques when using the Sonicfill 2 system? First, more near-term studies are needed to confirm the claims of the Kerr Corporation. These studies could address the minimal depth of Sonicfill 2 composite that can be adequately cured from the occlusal surface, or the recommended occlusal curing time to achieve adequate polymerization at a 5mm depth. At this point, if a clinician uses the Sonicfill system for a deep occlusal class I restoration, or for a deep core buildup following endodontic treatment, it is recommended to make increments less than 5mm, and even less if the clinician cannot place the LCU tip directly over the composite (near 0mm). Any increase in tip distance from the composite surface significantly affects the degree of polymerization.

CONCLUSION

The results of the current investigation suggest that adequate polymerization of the Sonicfill 2 bulk-fill composite system does not occur at a depth of 5mm when the composite is cured from the occlusal surface only for 20 seconds. Further testing to determine minimal composite depths and curing time are needed.

Table 1.Mean Surface KHN

Side	Distance (mm)	N	M	SD
Top	0	80	41.6	6.8
	2	80	45.0	7.0
	4	80	43.3	10.1
	6	80	42.4	11.6
	Total	320	43.1	9.2
Bottom	0	80	22.1	5.3
	2	80	15.9	4.7
	4	80	11.9	3.9
	6	80	3.4	1.8
	Total	320	13.3	8.0

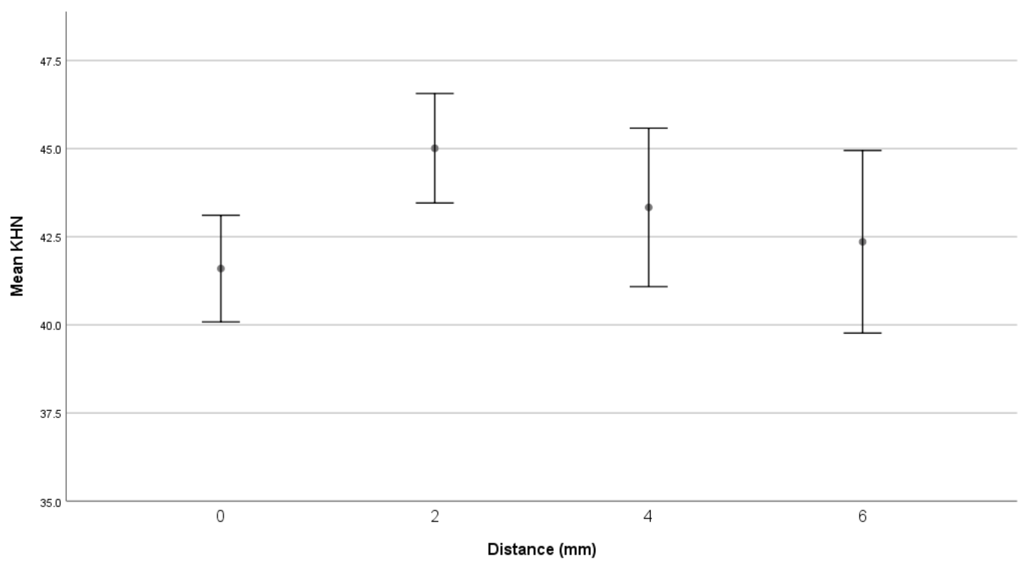

Figure 1: Top Side Mean KHN by Curing Distance

Error bars represent 95% Confidence Intervals

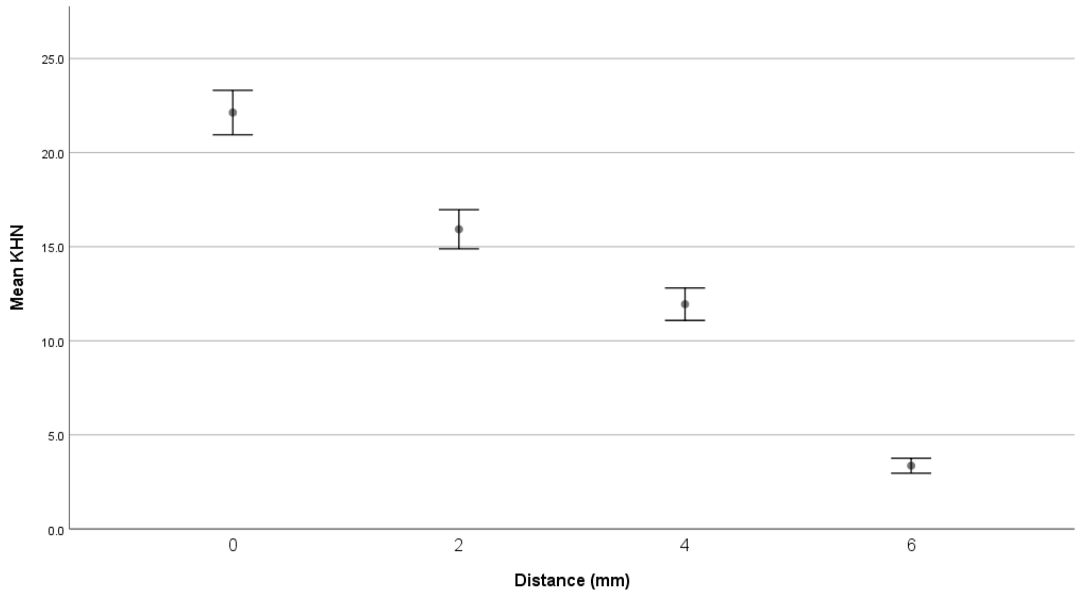

Figure 2: Bottom Side Mean KHN by Curing Distance

Error bars represent 95% Confidence Intervals

Figure 3: SonicFill handpiece with SonicFill 2 composite

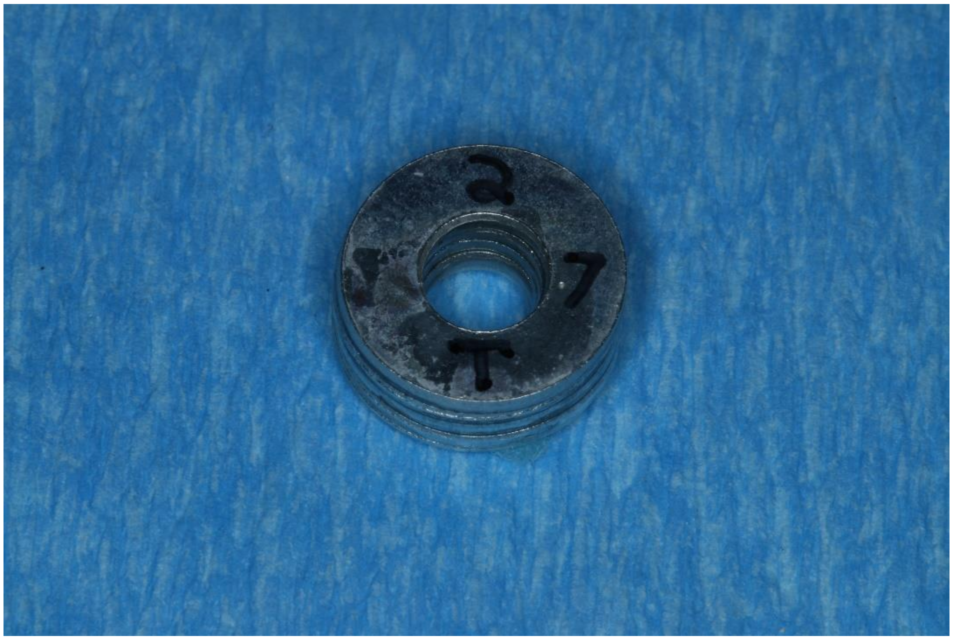

Figure 4: 5mm deep well consisting of 1mm stock washers glued together. The number 2 at the 12 o'clock position indicates a sample with a 2mm tip distance. The number 7 at the 3 o'clock position indicates it is the 7th sample of the group. The letter T at the 6 o'clock position indicates the top side of the sample, which is closest to the curing light.

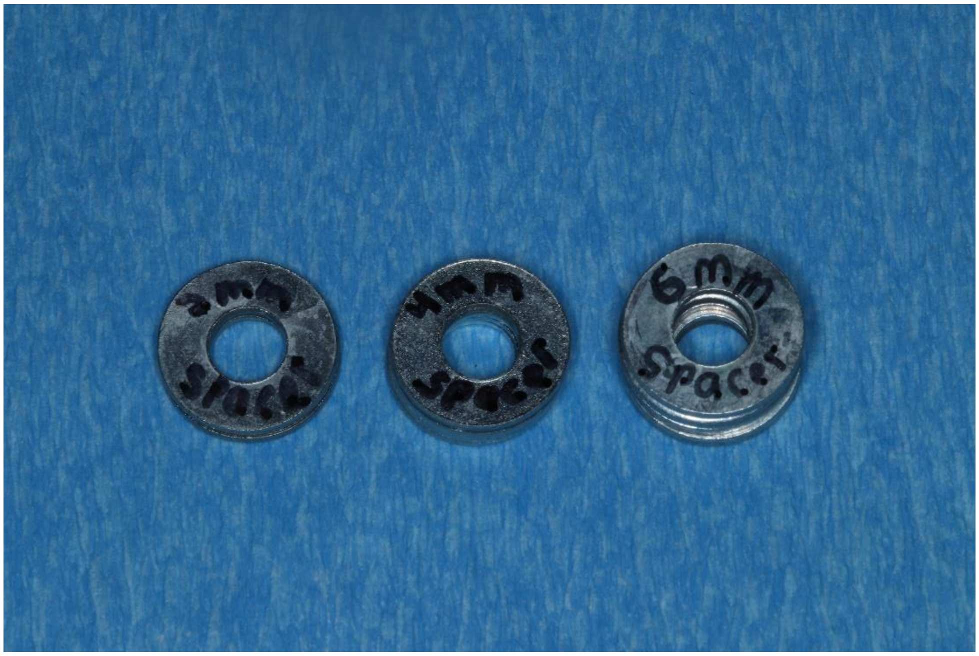

Figure 5: Spacers used to keep the curing light tip distance constant for each group. Starting from left to right, 2mm spacer, 4mm spacer, and 6mm spacer. The 0mm group did not require a spacer.

Figure 6: LED Radiometer (Demetron, SDS/Kerr, Orange, CA)

Figure 7: Leco 300AT Knoop Hardness Tester

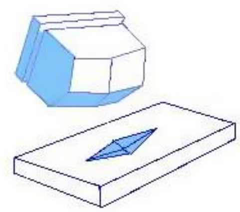

Figure 8: Knoop Hardness Tip Utilizing 100 gram load for 15 sec

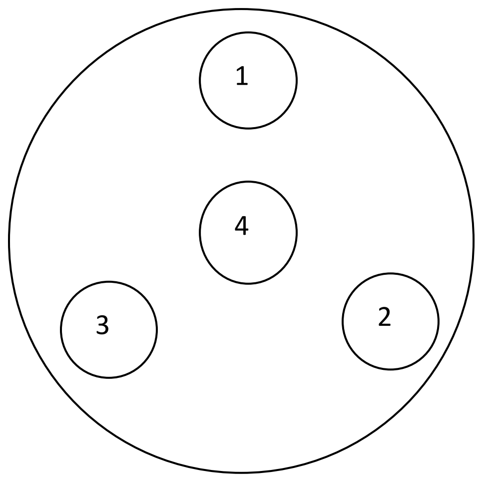

Figure 9: Sequence of Sample Collection Top/Bottom

REFERENCES

1. Lindberg A, Peutzfeldt A, van Dijken JW. Curing depths of a universal hybrid and flowable resin composite cured with quartz tungsten halogen and light emitting diode units. Acata Odontol Scand 2004; 62:97-101.

2. Schulein, TM. The history of operative dentistry. Jour of Hist of Dent 2005; 53:63-72.

3. Milnar, FJ. The evolution of direct composites. AEGIS 2011; 32:1-3.

4. Bowen, RL. Beginnings of the dental composite revolution. JADA 2013; 144:880-884.

5. Chan, KHS, Mai Y, Kim H. Review: Resin composite filling. Materials 2010; 3:1228-1243.

6. Moore, BK, Platt JA., Depth of cure of dental resin composites: ISO 4049 depth and microhardness of types of materials and shades. 2008; 33-4:408-412.

7. David Jose R., Gomes, OsnaraM., Effect of exposure time on curing efficiency of polymerizing units equipped with light-emitting diodes. Journal of Oral Sciences 2007; 49(1):19-24.

8. Aguiar, FHB., Lazzari, CA., Effect of light curing tip distance and resin shade on microhardness of a hybrid resin composite. Brazilian Oral Research 2005; 19(4).

9. Rueggeberg, Fredrick A., Cole, Megan A., Comparison of Manufacturer Recommended Exposure Durations with Those Determined Using Biaxial Flexure Strength and Scraped Composite Thickness Among a Variety of Light-Curing Units. Journal Compilation 2009; 21: 43-61.

10. Ferreira, APB., Soraes, PC., Wavelength of experimental LEDS: Hardness, elastic modules, degree of conversion and temperature rise of a microhybrid composite. Materials Research 2015; 18:1-9.

11. Czasch P, Ilie N. In vitro comparison of mechanical properties and degree of cure of bulk fill composites. Clinical Oral Investigations 2013; 17:227-35.

12. Ibarra ET, Lien W, Casey J, Dixon SA, Vandewalle KS. Physical properties of a new sonically placed composite resin restorative material. General Dentistry 2015; May/June: 51-56.

13. Cacciafesta, V., Sfondrini, MF., Effect of Light-tip Distance on the Shear Bond Strengths of Composite Resin; Angle Orthodontist 2005; 75(3):386-391.

14. Caldas, DBM., Almeida JB., Influence of curing tip distance on resin composite Knoop hardness number, using three different light curing units; Operative Dentistry 2003; 28(3):315-320.

15. Kramer, N., Lohabauer, U., Light curing of resin based composites in the LED era. American Journal of Dentistry 2008; 21:135-142.

16. Vandewalle, K., Roberts, H., Effects of light dispersion of LED curing lights on resin composite polymerization. Journal of Esthetic and Restorative Dentistry 2005; 17-4:244-255.

17. Strassier, HE., Successful light curing-not as easy as it looks. Oral Health Group 2013;1-15.

18. Powers JM, Sakaguchi RL. Craig's Restorative Dental Materials, Twelfth Edition. Elsevier, Inc. 2011.

19. Leprince, JG., Leveque, P., New insight into the "depth of cure" of dimethacrylate-based dental composites. Dental Materials 2012; 28:512-520.

20. Dewald, JP., Ferracane, JL., A comparison of four modes of evaluating depth of cure of light activated composites. Journal of Dental Research 1987; 66:727-730.

21. Bouschlicher, M., Berning, K., Describing adequacy of cure with maximum hardness ratios and non-linear regression. Operative Dentistry 2008; 33-3:312-320.

22. Van Ende, A., De Munck, J., Bulk-filling of high C-factor posterior cavities: Effect on adhesion to cavity-bottom dentin. Dental Material 2013; 29:269-277.

23. Nomoto, R., Effect of light wavelength on polymerization f light cured resins. Dental Material Journal 1997; 16:60-73.

24. Sakaguchi RL, Douglas WH, Peters MC. Curing light performance and polymerization of composite restorative materials. J Dent 1992; 20:183-8.

25. Lutz F, Krejci I, Barbakow F. Quality and durability of marginal adaptation in bonded composite restorations. Dental Materials 1991; 7:107-13.

26. Abbas G, Fleming GJP, Harrington E, Shortall ACC, Burke FJT. Cuspal movement and microleakage in premolar teeth restored with a packable composite cured in bulk or in increments. J Dent 2003; 31:437-44.

27. VOCO America, Inc. www.vocoamerica.com

28. Fleming GJ, Awan M, Cooper PR, Sloan A. The potential of a resin-composite to be cured to a 4mm depth. Dental Materials 2008; 24:522-529.

29. Roggendorf MJ, Kramer N, Appelt A, Naumann M, Frankenberger R. Marginal quality of flowable 4-mm base vs. conventionally layered resin composite. Journal of Dentistry 2011; 39:643-647.

30. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. Journal of Dentistry 2012; 40:500-505.

31. Petrovic LM, Zorica DM, Stojanac I, Krstonosic VS, Hadnadjev MS, Atanackovic TM. A model of the viscoelastic behavior of flowable resin composites prior to setting. Dental Materials 2013; 29:929-934.

32. Lowe RA. SonicFill: the next step in the evolution of direct composite placement. Australian Dental Practice 2012; Jan/Feb:160-66.

33. Kerr Corporation. SonicFill 2. www.kerrdental.eu/FillingMaterials/Composites/.../SonicFill

34. Kerr Corporation, Orange, CA. SonicFill 2: SingleFill Composite System, Directions For Use. December 2014.

35. DemiPlus LED light Curing System, www.Kerrdental.com.

36. Bouillaguet S, Caillot G, Forchelet J, Cattani-Lorente M, Wataha JC, Krejci I. Thermal risks from LED and high-intensity QTH-curing units during polymerizatio of dental resins. Journal of Biomedical Materials Researh Part B: Applied Biomaterials 2005; 72B:260-7.

37. Furness A, Tadros MY, Looney SW, Reuggeberg FA. Effect of bulk/incremental fill on internal gap formation of bulk-fill composites. Journal of Dentistry 2014; 42:439-449.

38. Ilie N, Stark K. Curing behaviour of high-viscosity bulk-fill composites. Journal of Dentistry 2014; 42:977-985.

39. Kopperud HM, Kleven IS, Knarvang T, Wellendorf H. Leaching of monomers from bulk-fill composites. Dental Materials 2014; 30 S1:e46.

40. Kopperud, HM., Kleven, IS., Leaching of monomers from bulk fill composites. Dental Materials 2014; 305:e130.

41. Aldossary, M., Santini, A., Effect of curing time on Vickers microhardness of bulk-fill materials. Dental Materials 2014; 305: e180.

42. Leonard, DL., Charlton, DG., Determination of the minimum irradiance required for adequate polymerization of a hybrid and a microfill composite. Operative Dentistry 2001; 26: 176-180.

43. Malhotra, N., Mala, K., Light curing considerations for resin based composite materials: A Review. Part 1. Compendium 2010; 31:498-505.

44. Ikeda I, Otsuki M, Sadr A, Nomura T, Kishikawa R, and Tagmi J. Effects of filler content of flowable composite on resi-cavity interface. Dental Materials 2009; 28:679-85.

45. Lee IB, Cho BH, Son HH, Um CM. A new method to measure the polymerization shrinkage kinetics of light cured composites. J Oral Rehabil 2005; 32:304-14.