A COMPARISON OF THE CURING LIGHT AND COMPOSITE MANUFACTURES GUIDELINES TOWARDS ADEQUATE POLYMERIZATION OF A HIGH VISCOSTIY HYBRID COMPOSITE UTILIZING A VALO LED CURING SYSTEM

By
ANDREW J. CALLAHAN

A THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Oral Biology in the Uniformed Services University of Health Sciences
FORT BRAGG, NC

2017

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Protocol Title: A COMPARISON OF THE CURING LIGHT AND COMPOSITE MANUFACTURES GUIDELINES TOWARDS ADEQUATE POLYMERIZATION OF A HIGH VISCOSTIY HYBRID COMPOSITE UTILIZING A VALO LED CURING SYSTEM
Initial Date Submitted: 10 Jan 2016
Revision Date:

Request for Determination for Research Meeting the Criteria for Research Not Involving Human Subjects (RNIHS)

1.0 PROTOCOL TITLE: A COMPARISON OF THE CURING LIGHT AND COMPOSITE MANUFACTURES GUIDELINES TOWARDS ADEQUATE POLYMERIZATION OF A HIGH VISCOSTIY HYBRID COMPOSITE UTILIZING A VALO LED CURING SYSTEM

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3.0 RESEARCH NOT INVOLVING HUMAN SUBJECTS DETERMINATION Please double click on the box that applies to your research and mark the "check" box.

3.1. Is the activity a **systematic** investigation **designed** to develop or contribute to **generalizable** knowledge? 32 CFR 219.102(d) *Generalizable knowledge consists of theories, principles, or relationships (or the accumulation of data on which they may be based) that can be corroborated by accepted scientific observation and inference that is applicable to other related situations, populations, or devices outside of the tested situation.*

☒ No. Activity is not research and does not require Clinical Investigation Service oversight.

☐ Yes. Proceed to 3.2. Because you are making a request for Research Not Involving Human Subjects determination, this should be checked "yes."

3.2 Does the research involve obtaining information about living individuals? 32 CFR 219.102(f)

☒ No. Activity is Research Not Involving Human Subjects. *Cadaver studies or animal studies would fall into this category.*

☐ Yes. Proceed to 3.3. This would almost always be checked "yes."

3.3. Does the research involve **intervention** or **interaction** with the individuals? 32 CFR 219.102(f). Intervention or interaction is some form of contact with the study subject.

☐ Yes. Activity is Human Subjects Research. Please contact usarmy.bragg.medcom-wamc.list.wamc-irb-admin@mail.mil for further instructions. You will have to submit your proposal as an "exempt" protocol or standard protocol application.

☒ No. Proceed to 3.4.

3.4. Though you are not interacting or intervening with a living individual, you will be using their information. Is this information individually identifiable by the research team at any time?

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4.0 EXPECTED COMPLETION DATE FOR STUDY (INCLUDING DATA ANALYSIS):
DEC 2016

5.0 SUMMARY: To evaluate the effectiveness of curing duration using a VALO LED curing light at 3200 mW/cm^2 setting on 2 mm samples of TPH Spectra A3 hybrid composite

5.1 DATA COLLECTION METHODOLOGY AND STATE THE STUDY HYPOTHESIS OR RESEARCH QUESTION:

TPH Spectra composite was divided into 4 sample groups each containing 10 samples. The groups were differentiated by cure time (3,6,10, and 20 seconds). All samples were polymerized at the top end with the VALO LED light curing system at the highest setting of 3200mW/cm^2. The 2mm thick samples were then tested by subjecting each sample to a scrape test and then 4 top and 4 bottom surface points to gather microhardness measurements, collecting a total of 320 samples (80 per group).

5.2 DESCRIBE THE TYPE OF DATA OR SPECIMENS TO BE STUDIED:
Knoop hardness ratio data for TPH Spectra Composite

5.3 NUMBER OF PARTICIPANTS:
No participants will be utilized

5.4 DESCRIBE ANY CODING OF DATA OR SPECIMENS, INCLUDING INFORMATION ON WHO HOLDS THE KEY TO THE CODE:
No coding of data

5.5 MILITARY RELEVANCE:

The technology of curing lights has advanced to save the dentist as much time as possible. This has led to a conflict between what the composite manufacturer recommends for curing time and what the curing light purports to allow you to do. Many curing lights claim to adequately cure composites in less than ten seconds but most composite manufacturers recommend more time than that. If a composite is not properly and adequately polymerized then the restoration will fail at a higher and more rapid rate. This can lead to additional treatment including root canals, crowns and extractions. This study will encourage all clinicians to carefully read and follow the composite manufacturers' recommendations for adequate curing time of a common resin (TPH) even when using a rapid curing LED light (VALO), found in many military and civilian clinics. This may help to ensure the clinical survivability of TPH restorations in Army dental clinics

5.6 MEDICAL APPLICATION:

This study will assist clinicians in determining the curing time when using composite resins. If composites are cured properly then the physical and mechanical properties of the composite should be adequate which should lead to less post-operative complications.

6.0 PUBLICATION REQUIRMENTS: Proper WAMC publication clearance is required prior to all presentations, abstracts, and publications. The following require WAMC approval: reports involving WAMC subjects and/or patients, reports that cite WAMC in the title or byline, reports of WAMC approved clinical investigation or research, reports of research performed at WAMC, and reports of research conducted by WAMC assigned personnel.

The investigators will obtain proper OTSG publication clearance prior to all presentations, abstracts, and publications that involve traumatic brain injury, post-traumatic stress, poly-pharmacy, pain, or suicide.

The investigators must provide to the Department of Clinical Investigation a listing of presentations, abstracts, and publications arising from the study.

IRBNet Number:
PI:
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7.0 SIGNATURES: Signatures are not required for Associate Investigators and Collaborators.

I verify that the contents of this proposal are accurate and that I have read and agree to comply with the statements above which outline my responsibilities as a Principal Investigator.

ANDREW J. CALLAHAN DMD

Principal Investigator Signature
Name and Date: 10 JAN 2016

6.1 OTHER SIGNATURES FOR APPROVAL:

I concur with the submission of this proposal to the Department of Clinical Investigation for review and approval.

Manuel Peláez, DMD, MS
Periodontist 10 JAN 2016

Service Chief Signature
Name and Date:

Department Chief Signature
Name and Date: 10 Jan 16 Stacy L Larsen, COL, DC

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Regulatory Affairs Review

10JAN2016
Name and Date Kalen González, MAJ, DC

Scientific Review

10JAN2016
Name and Date Kalen González, MAJ, DC

Submitted by Andrew J. Callahan in partial fulfillment of the requirements for the degree of Master of Science in Oral Biology.

Accepted on behalf of the Faculty of the Graduate School by the thesis committee:

Date	Manuel Pelaez, DMD Research Mentor
Date	Jason Bullock, DMD AEGD Assistant Director
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2-yr AEGD Program, Fort Bragg

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Date: 04/26/2017

ABSTRACT

The technology of curing lights has advanced to save the dentist as much time as possible. This has led to a conflict between what the composite manufacturer recommends for curing time and what the curing light purports to allow you to do. Many curing lights claim to adequately cure composites in less than ten seconds but most composite manufacturers recommend more time than that. If a composite is not properly and adequately polymerized then the restoration will fail at a higher and more rapid rate. The objective of this paper is to evaluate the effectiveness of curing duration using a VALO LED curing light at 3200 mW/cm^2 setting on 2 mm samples of TPH Spectra A3 hybrid composite. A statistically significant difference between the mean surface KHN of the top to bottom sides has a direct correlation to light duration. As the duration of the light increased, so did the hardness of the bottom layer. The only curing time that met the 0.80 bottom to top hardness ratio which shows adequate polymerization of a composite resin was the 20 sec light cure.

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LIST OF ABBREVIATIONS

B – Bottom surface hardness measurement

CQ- Camphoroquinone

DC – Degree of conversion

DoC – Depth of cure

HR - Hardness ratio (bottom/top)

ISO - International and Standards Organization

KHN – Knoop Hardness Number

LED –Light emitting diode

LCU – Light curing unit

mm – Millimeters

QTH - Quartz tungsten halogen lamps

SS – Stainless steel

T – Top surface hardness measurement

UV – Ultra-violet light

VK - Vickers Hardness Test

VLC – Visible light cured

Introduction

The use of light cured composites has grown and is now widely utilized in dentistry (1). This has been largely due to patient desires for more esthetic restorations (2,3,4). The use of appropriate techniques and curing lights are keys to proper polymerization of dental composites. Composite resins are more technique sensitive and generally take more time for a dental provider to properly place compared to other restorative materials (5). Because composites can require more time due to technique, a clinician is forced to search for ways to keep that time at a minimum while still providing the best possible care. Many clinicians have chosen to use curing lights that promise an adequate cure in as little as 3 seconds. The manufacturer of the composite generally recommends around twenty seconds for adequate cure. If a composite has not been adequately cured then the result will likely be a less than optimal outcome because the amount of polymerization or cure of a composite resin is directly related to its physical, mechanical, and biological characteristics (1,6,7,8,9).

Although dental composite resins have superior esthetic characteristics, there are disadvantages. Composites can be difficult to handle and require pristine isolation from saliva and moisture (10). Dental composites generally consist of an organic matrix, an inorganic matrix and a coupling agent. There are several types of composites including hybrid, microhybrid, microfilled, and nanofilled. Each of these composites has different materials which may affect the activation process and this may determine what the best curing light to use is. The most common photoinitiator in composite materials is camphorquinone (CG) (2,11). CG has peak absorption of around 468nm (12,13). Other materials are used as photoinitiators in composites which may have different peak wavelengths. The polymerization of a composite is dependent not only on the photoinitiator but several other factors including the shade, thickness of material, the type of light curing unit (LCU), and the distance of the tip of the LCU to the material. These aspects can affect the physical and mechanical properties of the composite (14,15,16,17). Inadequate polymerization of composite can diminish physical properties of a composite resin. Therefore, it is important to know what will affect the polymerization. The degree of conversion (DC) is vital in determining the mechanical performance of the composite. Strength, hardness and solubility have been shown to be directly related to the degree of monomer conversion (18). The DC is affected by numerous factors including the size of the increments placed and the curing time used. The light intensity and exposure time impact the depth of cure. In general, a composite is cured for 20 seconds in 2mm increments (19,41). When CQ is activated, it sets off the polymerization process of dimethylacrylate monomers into a polymerized cross-linked resin (11,14,17,20). An increase in the polymerization conversion of the composite will also lead to an increase in the strength of the physical properties. This will generally increase the probability of a clinically acceptable restoration (21). The increase in polymerization is not without consequence. As the degree of polymerization increases, the amount of volumetric shrinkage will in turn increase. This will lead to amplified stress at the margin of the composite and tooth structure. (11,22) There are techniques that a clinician can use to minimize the stress caused by volumetric shrinkage. The primary methods to combat the volumetric shrinkage is to place and curing no more than 2mm increments of composite and wedge the composite increments to decrease the amount of tooth surfaces being cured at one time (14,15,16,23).

There are numerous curing lights available to dental practitioners. The most common light curing unit is Quartz-Tungsten-Halogen devices (24). These have been considered the standard but they have limitations. These limitations include high temperature, short working period and extended working time (6,12,25). Many dentists have shifted to using light emitting diode (LED) curing lights to overcome the limitations of the QTH curing lights. LED curing lights have a longer effective working lifetime, less degradation, minimal decrease of power output and the light intensity is almost constant (24). In older generations of LED curing lights the light emitted has a narrower peak in its spectrum and is closer to CQ absorbing spectrum. These LED curing lights though may not adequately polymerize a composite with a photoinitiator that is not CG. Newer versions of LEDs have a wider output range and are better at covering this setback (6,13,25,27-30).

The VALO curing light is part of the newer generation of LED curing lights. VALO claims many aspects of its design lead to a proper cure of a composite resin in less time. The development of high powered LED chips allows VALO to claim to use the brightest and most efficient LED (23,31). Most clinicians use power density to compare curing light output, but doing so can be misleading, because although squeezing the same amount of power into a smaller area increases irradiance or density of light, it does not deliver more power, it just focuses power over a smaller area. VALO curing lights assert to offers the ‘right’ power density for every application (23) because VALO curing lights have three different power intensity modes (Figure1). VALO maintains intensity over a greater range of distances, allowing the clinician consistent, high quality results at any normal working distance (23). A curing light’s output should be uniform across the curing surface, but many lights vary more than 75% across the curing beam. Non-uniform output causes ‘hot’ or ‘cool’ spots, which result in inconsistent curing across the restoration, leading to composite that can be ‘softer’ in one area and ‘harder’ in another. VALO claims to solve this problem with specialized optics and LED technology, which produces consistent results regardless of the restoration type, size, or location. VALO states because of their technology beam uniformity is increased and is free of ‘hot’ and ‘cool’ spots, enabling it to deliver complete, uniform curing (23). If a curing light does not emit light over a broad spectrum, some dental materials will not polymerize completely (32). Quartz halogen bulbs produced the necessary ranges of blue and violet (spectral irradiance) to cure all dental materials. The advent of LED technology created a problem in that LEDs produce only a narrow spectrum of blue color, and may be unable to adequately cure the many dental products containing proprietary initiators (8,24). A true broad-spectrum curing light needs to produce light in the right color ranges, where the photoinitiators are most sensitive, to thoroughly cure dental materials. With its custom LED chipset, VALO produces light that provides uniform curing throughout the restoration, as well as three peak wavelengths or colors of blue and violet, allowing it to cure all dental materials effectively (23). VALO light curing unit recommendations are one 3second cure per 2mm of composite when placed on the highest power setting (23, Figure1).

After the composite is cured the depth of cure (DoC) needs to be assessed. The external surface can be evaluated quite easily by any clinician on any patient but the DoC of the internal area of the composite is of equal importance and is much more difficult to gauge. Clinicians need to perform a test prior to utilizing the composite in order to verify that their technique and equipment will adequately cure the entire resin. The hardness of the external surface of the composite is not an indicator of the internal polymerization (33). A clinician can test the hardness of a cured composite directly or indirectly.

The International and Standards (ISO) Standard No. 4049 is used as an indirect technique to assess the DoC. This test is a scraping technique. The composite is put in a tube shaped mold, cured from one end, and then pushed out the other end. The uncured composite is then scraped away. The length of the remaining composite is then divided in half. The rationale behind this is that not the entire remaining cured composite has clinically acceptable hardness. This test is simple to perform but will frequently overestimate the depth of polymerization (34).

Another indirect technique to calculate DoC is the Knoop Hardness test. This is a microhardness test for mechanical hardness used particularly for very brittle materials or thin sheets, where only a small indentation may be made for testing purposes. A pyramidal diamond point is pressed into the polished surface of the test material with a known (often 100g) load, for a specified dwell time, and the resulting indentation is measured using a microscope (33). The indentation varies with the tested material's mechanical properties and is then measured through a microscope and applied to a formula to get the specific values (14,35-39). The advantages of the test are that only a very small sample of material is required, and that it is valid for a wide range of test forces. The main disadvantages are the difficulty of using a microscope to measure the indentation (with an accuracy of 0.5 micrometer), and the time needed to prepare the sample and apply the indenter. Variables such as load, temperature, and environment, may affect this procedure, which have been examined in detail. The top and bottom surface values that are obtained can be compared. In order to attain adequate polymerization a value of greater than 0.8 bottom to top surface needs to be achieved (14,36,37). So, a composites bottom surface should be at least eighty percent as hard as the top surface to achieve proper mechanical properties. These values are then compared between bottom to top surfaces to get a hardness ratio (HR). To achieve adequate polymerization, a ratio of >80% HR should be used (14,36,37). When the 80% bottom to top HR is not met then a clinician can expect an increase in clinical failures due to a decrease in mechanical properties (18,33,40).

Purpose

The purpose of this study is to evaluate the effectiveness of curing duration using a VALO LED curing light at 3200mW/cm^2 setting on 2 mm samples of TPH Spectra A3 hybrid composite. Dentsply recommends a minimum twenty second cure per 2mm on TPH Spectra hybrid composite (41), while VALO recommends a three second for a 2mm increment of composite (23). A bottom to top HR of 0.80 using a Knoop Hardness Test will be the standard used to determine if a sample has been adequately cured.

Materials and methods

The experiment was conducted in a room with no windows, and the overhead lighting was controlled by placing red filters (Lee Filters, 027 Medium Red) over the florescent bulbs to minimize the lights' effect. The LCU was charged per manufacturers' recommendations and tested with the LED radiometer (Demetron, SDS/Kerr, Orange, CA) prior to every sample cure to verify light intensity.

All stainless steel (SS) molds (Phoenix Specialty Manufacturing, Bamberg, SC) were measured using a digital caliper (General UltraTech, Model 1433) to confirm and exclude any variations in mold size. All molds were confirmed to be 2 mm high x 8 mm wide and a "T" was placed with permanent marker on one side of the metal mold for top and "B" on the other side for bottom. The uncured resin samples were extruded into the SS molds and a mylar strip (DuPont Mylar 0.002 gauge/60mm thick) was placed over both the top and bottom of the samples. The mold/sample was placed into the stainless steel (SS) master mold canister (Phoenix Specialty Manufacturing, Bamberg, SC), with the T-side facing up, and a clear glass slide (Globe Scientific Glass Microscope Slide, 25mm X 75mm) was pressed over the top of the mylar strip to extrude any excess composite to ensure a 2 mm thick sample. Then the glass slide and top mylar strip were removed. The 5 mm SS spacer (Phoenix Specialty Manufacturing, Bamberg, SC) was placed over the radiometer to test the light output consistency for 5 seconds which was done prior to every sample. The 5 mm spacer (Phoenix Specialty Manufacturing, Bamberg, SC) was then placed into the master mold on top of sample mold. The LCU tip was then positioned over the 5 mm spacer and into the master mold. There was a 2 mm lip from the top of the master mold to the 5 mm spacer. This 2 mm lip allowed positive and repeatable placement of the LCU tip to engage the 5 mm spacer at an average 90 degree interface, which was much more repeatable than clinically possible while chairside.

TPH Spectra composite was divided into 4 sample groups each containing 10 samples. The groups were differentiated by cure time (3,6,10, and 20 seconds). All samples were polymerized at the top end with the VALO LED light curing system at the highest setting of 3200mW/cm^2. The 2mm thick samples were then tested by subjecting each sample to a scrape test and then 4 top and 4 bottom surface points to gather microhardness measurements, collecting a total of 320 samples (80 per group).

This data was collected utilizing the Knoop hardness tester (Leco, LM 300 AT, St Joseph, MI) under a load of 0.1 kilograms for 15 seconds. For each sample, a Knoop hardness number (KHN) was obtained by dividing the applied load (kg) by the projected area of the impression (mm^2). Additionally, a bottom to top Knoop hardness surface ratio was obtained. Ratio values of at least 80% were utilized as they represent an acceptable value in order to achieve a clinically adequate depth of cure.

Statistical Analysis

Exploratory data analyses were conducted on the KHNs and the Shapiro-Wilk test was used to assess the normality of the data distribution. Post-hoc power analysis showed that the data was sufficient for an ANOVA to show a medium effect size (f = 0.19) at a significance level P = 0.05 and 80% power. Measures of central tendency (means) and dispersion (standard deviations) are provided for continuous data. A twoway ANOVA was performed to compare the mean surface KHN between the four groups. Post-hoc comparisons were accomplished using Tukey's HSD. Confidence intervals (95% CI) are based on 1000 bootstrap samples. Data were analyzed using SPSS 20 (IBM, Armonk, NY, USA). Statistical significance for all statistical tests was declared at $p < 0.05$. An Institutional Review Board waiver was obtained in accordance with policies regarding research not involving human subjects.

Results

Mean surface KHNs by group and side are shown in Table 1. Overall the 3sec group (n=80) had a mean KHN of 30.35 (SD 12.84); the 5sec group (n=80) had a mean KHN of 34.76 (SD 10.78); the 10sec group (n=80) had a mean KHN of 36.93 (SD 6.89); and the 20sec (n=80) group had a mean KHN of 40.40 (SD 7.00). There was a significant main effect of curing time on the surface KHN of the samples, $F(3,312) = 21.64$, $p < 0.001$, $\eta_p^2 = 0.17$. Additionally, a larger main effect of side (top or bottom) on surface KHN was found, $F(1,312) = 124.36$, $p < 0.001$, $\eta_p^2 = 0.29$. The interaction between side and the length of curing time on the KHN was significant as well, $F(3,312) = 6.62$, $p < 0.001$. However, the effect size of the interaction ($\eta_p^2 = 0.06$) was much weaker than either of the two main effects. Post-hoc comparisons revealed the 3 second group to have the lowest KHN of all the groups, $p < 0.01$. The 5 and 10 second groups were not significantly different from one another on hardness, $p = 0.33$. However, both had larger KHNs than the 3 second group, both $p < 0.001$ and smaller KHNs than the 20 second group, both $p < 0.001$. Figure 1 shows the hardness of the groups by time with 95% CIs.

Discussion

The first observation that was noted was using all 40 samples were subjected to the Scrape Test and that not one sample had any composite that was scraped away. The next observation can be discerned from table 4. In general, the hardness of the top and bottom increased with an increase in curing time as would be expected. The slope of the bottom was much steeper though. Also of note is that the variance of the hardness of the top surface is much less than the variance of the bottom surface hardness. This shows that the bottom surface is much more affected by an increase in time. This would be expected as the top will receive ample curing light irrespective of the curing time but the bottom will take more time to penetrate (15,19,24). This is one of the issues that a clinician faces; the fact that the only area that we can access clinically, the top, takes very little time to harden. This may lead a false confidence that a composite has been cured properly. As has been discussed previously a bottom to top hardness ratio of 0.8 is key for the polymerization of composites for proper mechanical properties and long term clinical results so the hardness of the bottom of the composite is arguably more important than the top. Examining table 2 shows a clear pattern that as curing time is increased then the number of samples that obtain a 0.8 bottom to top hardness ratio increases. The data for the three second curing group shows that 1/10 samples met the 80% standard. The average bottom to top hardness was 63.27%. The data for the six second curing group shows that 0/10 groups met the 80% standard. The average bottom to top hardness was 68.48%. The data for the ten second curing group shows that 5/10 groups met the 80% standard. The average bottom to top hardness was 82.08%. The data for the six second curing group shows that 10/10 groups met the 80% standard. The average bottom to top hardness was 88.90%.

Conclusion

The study has shown that the time spent curing has a significant effect on the bottom and top hardness and the resulting ratio of bottom to top hardness ratio. Based on the data and statistical analysis, the curing times of 3 seconds, 6 seconds, and 10 seconds were not sufficient in curing 2mm of composite. This would lead to under polymerized composite which will have the effect of reduced mechanical properties and high clinical failures. A clinician should think about how long it will take to appropriately polymerize the bottom of the composite resin and not the top. The 20 second group consistently cured 2mm composite increments to the 0.8 bottom to top hardness ratio and would produce clinically acceptable composite restorations. Based off this research the minimum curing time should be twenty seconds even with a LED curing light. A clinician must know the materials that are being used and what the manufacturer's recommendations are. A scrape test can be used to verify if the protocol being used to cure composites is satisfactory. As a general rule a practitioner should over cure versus under cure. One of the potential complications of over curing is damaging the pulp because of overheating and volumetric shrinkage. This risk of overheating can be mitigated by pausing between cures and having the assistant blow air on the tooth being worked on. This should keep heat from building up on the tooth. As discussed previously the most frequently used technique to alleviate the stress caused by volumetric shrinkage is to place and cure composite in two mm increments (14,15,16,23).

TABLE 1: KHN RESULTS

*All samples are 2mm thick

* Temp = 22^{0}C, Humidity = 62%

*All tip distance is 5mm from sample as per manufacturers' maximum guidelines

TPH Shade/Light Duration	Sample-Test Point- Top or Bottom	DC mm	KHN	Surface Mean	T/B KHN Ratio
A3.0 3 SEC	SA1-1-T	2	50.4		
	SA1-2-T	2	55.3		
	SA1-3-T	2	46.0		
	SA1-4-T	2	48.3	SA1T =50	SA1=58.55%
	SA1-1-B	2	27.2		
	SA1-2-B	2	29.8		
	SA1-3-B	2	29.4		
	SA1-4-B	2	30.7	SA1B=29.275	
	SA2-1-T	2	32.6		
	SA2-2-T	2	27.3		
	SA2-3-T	2	25.0		
	SA2-4-T	2	26.3	SA2T =27.8	SA2 =62.05%
	SA2-1-B	2	15.0		
	SA2-2B	2	19.5		
	SA2-3-B	2	16.7		
	SA2-4-B	2	17.8	SA2B =17.25	
	SA3-1-T	2	51.7		
	SA3-2-T	2	49.3		
	SA3-3-T	2	48.7		
	SA3-4-T	2	56.2	SA3T =51.475	SA3 =45.41%
	SA3-1-B	2	24.4		
	SA3-2-B	2	22.1		
	SA3-3-B	2	23.2		
	SA3-4-B	2	23.8	SA3B = 23.375	
	SA4-1-T	2	23.6		
	SA4-2-T	2	27.3		
	SA4-3-T	2	29.3		
	SA4-4-T	2	24.6	SA4T = 26.2	SA4= 59.35 %
	SA4-1-B	2	13.2		
	SA4-2-B	2	17.8		

SA4-3-B	2	15.4		
SA4-4-B	2	15.8	SA4B =15.55	
SA5-1-T	2	32.8		
SA5-2-T	2	28.9		
SA5-3-T	2	31.4		
SA5-4-T	2	27.6	SA5T =30.175	SA5=78.79%
SA5-1-B	2	24.6		
SA5-2-B	2	23.0		
SA5-3-B	2	24.8		
SA5-4-B	2	22.7	SA5B = 23.775	
SA6-1-T	2	36.4		
SA6-2-T	2	39.0		
SA6-3-T	2	45.4		
SA6-4-T	2	37.6	SA6T = 39.6	SA6= 65.09%
SA6-1-B	2	26.8		
SA6-2-B	2	26.1		
SA6-3-B	2	24.8		
SA6-4-B	2	25.4	SA6B= 25.775	
SA7-1-T	2	31.7		
SA7-2-T	2	23.2		
SA7-3-T	2	29.0		
SA7-4-T	2	32.5	SA7T= 29.1	SA7= 62.80%
SA7-1-B	2	13.1		
SA7-2-B	2	17.4		
SA7-3-B	2	23.1		
SA7-4-B	2	19.5	SA7B= 18.275	
SA8-1-T	2	23.2		
SA8-2-T	2	19.6		
SA8-3-T	2	13.4		
SA8-4-T	2	24.7	SA8T =20.225	SA8= 71.32%
SA8-1-B	2	9.5		
SA8-2-B	2	15.5		
SA8-3-B	2	18.9		
SA8-4-B	2	13.8	SA8B=14.425	
SA9-1-T	2	43.7		
SA9-2-T	2	38.6		
SA9-3-T	2	35.2		
SA9-4-T	2	44.1	SA9T= 40.4	SA9= 86.32%
SA9-1-B	2	35.3		
SA9-2-B	2	31.8		
SA9-3-B	2	37.3		

	SA9-4-B	2	35.1	SA9B= 34.875	
	SA10-1-T	2	61.4		
	SA10-2-T	2	67.7		
	SA10-3-T	2	63.6		
	SA10-4-T	2	57.3	SA10T= 62.5	SA10=43.00 %
	SA10-1-B	2	31.8		
	SA10-2-B	2	23.4		
	SA10-3-B	2	23.8		
	SA10-4-B	2	28.5	SA10B= 26.875	
A3.0 5 SEC	SA11-1-T	2	39.5		
	SA11-2-T	2	33.9		
	SA11-3-T	2	47.9		
	SA11-4-T	2	42.5	SA11T =40.95	SA11=67.46%
	SA11-1-B	2	29.8		
	SA11-2-B	2	26.8		
	SA11-3-B	2	23.4		
	SA11-4-B	2	30.5	SA11B=27.625	
	SA12-1-T	2	32.3		
	SA12-2-T	2	40.0		
	SA12-3-T	2	35.3		
	SA12-4-T	2	42.4	SA12T =37.5	SA12 =70.07%
	SA12-1-B	2	25.7		
	SA12-2B	2	21.8		
	SA12-3-B	2	33.0		
	SA12-4-B	2	24.6	SA12B =26.275	
	SA13-1-T	2	39.8		
	SA13-2-T	2	58.6		
	SA13-3-T	2	48.3		
	SA13-4-T	2	53.8	SA13T =50.125	SA13 =72.17%
	SA13-1-B	2	40.7		
	SA13-2-B	2	34.7		
	SA13-3-B	2	33.9		
	SA13-4-B	2	35.4	SA13B = 36.175	
	SA14-1-T	2	49.7		
	SA14-2-T	2	40.6		
	SA14-3-T	2	44.2		
	SA14-4-T	2	42.6	SA14T = 44.275	SA14= 54.66%
	SA14-1-B	2	26.2		
	SA14-2-B	2	20.5		
	SA14-3-B	2	23.3		

SA14-4-B	*2*	*26.8*	***SA14B =24.2***	
SA15-1-T	*2*	*33.4*		
SA15-2-T	*2*	*26.4*		
SA15-3-T	*2*	*43.6*		
SA15-4-T	*2*	*35.1*	***SA15T =34.625***	***SA15=69.89%***
SA15-1-B	*2*	*24.7*		
SA15-2-B	*2*	*22.7*		
SA15-3-B	*2*	*23.8*		
SA15-4-B	*2*	*25.6*	***SA15B = 24.2***	
SA16-1-T	*2*	*39.6*		
SA16-2-T	*2*	*55.7*		
SA16-3-T	*2*	*47.6*		
SA16-4-T	*2*	*44.2*	***SA16T = 46.775***	***SA16= 64.99%***
SA16-1-B	*2*	*31.3*		
SA16-2-B	*2*	*29.0*		
SA16-3-B	*2*	*26.6*		
SA16-4-B	*2*	*34.7*	***SA16B= 30.4***	
SA17-1-T	*2*	*64.9*		
SA17-2-T	*2*	*55.9*		
SA17-3-T	*2*	*43.5*		
SA17-4-T	*2*	*62.5*	***SA17T= 56.7***	***SA17= 71.56%***
SA17-1-B	*2*	*45.8*		
SA17-2-B	*2*	*36.0*		
SA17-3-B	*2*	*32.9*		
SA17-4-B	*2*	*47.6*	***SA17B= 40.575***	
SA18-1-T	*2*	*44.6*		
SA18-2-T	*2*	*37.2*		
SA18-3-T	*2*	*33.1*		
SA18-4-T	*2*	*45.6*	***SA18T =40.125***	***SA18= 60.68%***
SA18-1-B	*2*	*26.7*		
SA18-2-B	*2*	*26.4*		
SA18-3-B	*2*	*27.0*		
SA18-4-B	*2*	*17.3*	***SA18B=24.32***	
SA19-1-T	*2*	*38.8*		
SA19-2-T	*2*	*42.9*		
SA19-3-T	*2*	*27.0*		
SA19-4-T	*2*	*25.7*	***SA19T= 33.6***	***SA19= 74.78%***
SA19-1-B	*2*	*25.4*		
SA19-2-B	*2*	*23.3*		
SA19-3-B	*2*	*27.2*		
SA19-4-B	*2*	*24.6*	***SA19B= 25.125***	
SA20-1-T	*2*	*26.2*		

	SA20-2-T	*2*	*33.1*		
	SA20-3-T	*2*	*25.6*		
	SA20-4-T	*2*	*29.2*	**SA20T= 28.525**	***SA20= 78.53%***
	SA20-1-B	*2*	*19.2*		
	SA20-2-B	*2*	*24.5*		
	SA20-3-B	*2*	*23.2*		
	SA20-4-B	*2*	*22.7*	**SA20B= 22.4**	
A3.0 10 SEC	***SA21-1-T***	*2*	*34.9*		
	SA21-2-T	*2*	*37.6*		
	SA21-3-T	*2*	*40.0*		
	SA21-4-T	*2*	*37.6*	**SA21T=37.525**	***SA21= 78.48%***
	SA21-1-B	*2*	*32.9*		
	SA21-2-B	*2*	*25.8*		
	SA21-3-B	*2*	*30.8*		
	SA21-4-B	*2*	*28.3*	**SA21B=29.45**	
	SA22-1-T	*2*	*45.7*		
	SA22-2-T	*2*	*48.0*		
	SA22-3-T	*2*	*39.8*		
	SA22-4-T	*2*	*46.3*	**SA22T=44.95**	***SA22=93.77%***
	SA22-1-B	*2*	*37.8*		
	SA22-2-B	*2*	*37.5*		
	SA22-3-B	*2*	*46.6*		
	SA22-4-B	*2*	*46.7*	**SA22B=42.15**	
	SA23-1-T	*2*	*55.6*		
	SA23-2-T	*2*	*39.4*		
	SA23-3-T	*2*	*49.6*		
	SA23-4-T	*2*	*44.8*	**SA23T=47.35**	***SA23=77.30%***
	SA23-1-B	*2*	*40.8*		
	SA23-2-B	*2*	*37.1*		
	SA13-3-B	*2*	*33.6*		
	SA23-4-B	*2*	*34.9*	**SA23B=36.6**	
	SA24-1-T	*2*	*46.3*		
	SA24-2-T	*2*	*45.8*		
	SA24-3-T	*2*	*29.7*		
	SA24-4-T	*2*	*51.5*	**SA24T=43.325**	***SA24= 70.57%***
	SA24-1-B	*2*	*28.3*		
	SA24-2-B	*2*	*31.4*		
	SA24-3-B	*2*	*30.8*		
	SA24-4-B	*2*	*31.8*	**SA24B=30.575**	
	SA25-1-T	*2*	*49.2*		
	SA25-2-T	*2*	*37.0*		

SA25-3-T	*2*	*37.3*		
SA25-4-T	*2*	*34.7*	***SA25T=39.55***	***SA25= 94.63%***
SA25-1-B	*2*	*41.2*		
SA25-2-B	*2*	*38.1*		
SA25-3-B	*2*	*37.8*		
SA25-4-B	*2*	*32.6*	***SA25B=37.425***	
SA26-1-T	*2*	*41.5*		
SA26-2-T	*2*	*37.5*		
SA26-3-T	*2*	*37.8*		
SA26-4-T	*2*	*41.6*	***SA26T=39.6***	***SA26=73.11 %***
SA26-1-B	*2*	*25.7*		
SA26-2-B	*2*	*34.5*		
SA26-3-B	*2*	*32.4*		
SA26-4-B	*2*	*23.2*	***SA26B=28.95***	
SA27-1-T	*2*	*31.1*		
SA27-2-T	*2*	*30.8*		
SA27-3-T	*2*	*40.2*		
SA27-4-T	*2*	*38.7*	***SA27T=35.2***	***SA27=83.81%***
SA27-1-B	*2*	*29.3*		
SA27-2-B	*2*	*31.4*		
SA27-3-B	*2*	*26.4*		
SA27-4-B	*2*	*30.9*	***SA27B=29.5***	
SA28-1-T	*2*	*33.1*		
SA28-2-T	*2*	*42.4*		
SA28-3-T	*2*	*37.3*		
SA28-4-T	*2*	*36.4*	***SA28T= 37.3***	***SA28=87.13%***
SA28-1-B	*2*	*27.6*		
SA28-2-B	*2*	*35.8*		
SA28-3-B	*2*	*31.9*		
SA28-4-B	*2*	*34.7*	***SA28B=32.5***	
SA29-1-T	*2*	*38.9*		
SA29-2-T	*2*	*46.7*		
SA29-3-T	*2*	*45.9*		
SA29-4-T	*2*	*33.0*	***SA29T=41.125***	***SA29=70.70%***
SA29-1-B	*2*	*31.4*		
SA29-2-B	*2*	*27.0*		
SA29-3-B	*2*	*28.8*		
SA29-4-B	*2*	*29.1*	***SA29B=29.075***	
SA30-1-T	*2*	*32.4*		
SA30-2-T	*2*	*40.1*		
SA30-3-T	*2*	*41.6*		
SA30-4-T	*2*	*42.8*	***SA30T=39.225***	***SA30= 91.27%***

	SA30-1-B	2	39.6		
	SA30-2-B	2	34.9		
	SA30-3-B	2	41.0		
	SA30-4-B	2	27.7	SA30B=35.8	
A3.0 20 SEC	SA31-1-T	2	31.6		
	SA31-2-T	2	39.7		
	SA31-3-T	2	32.0		
	SA31-4-T	2	33.8	SB1T =34.275	SB1=91.17%
	SA31-1-B	2	35.2		
	SA31-2-B	2	28.3		
	SA31-3-B	2	29.2		
	SA31-4-B	2	32.3	SB1B=31.25	
	SA32-1-T	2	39.0		
	SA32-2-T	2	41.8		
	SA32-3-T	2	40.5		
	SA32-4-T	2	35.4	SB2T =39.175	SB2=95.53%
	SA32-1-B	2	34.4		
	SA32-2B	2	40.9		
	SA32-3-B	2	39.7		
	SA32-4-B	2	34.7	SA2B =37.425	
	SA33-1-T	2	43.7		
	SA33-2-T	2	42.5		
	SA33-3-T	2	42.3		
	SA33-4-T	2	45.8	SA3T =43.575	SB3=86.63%
	SA33-1-B	2	43.1		
	SA33-2-B	2	34.7		
	SA33-3-B	2	33.4		
	SA33-4-B	2	39.8	SA3B = 37.75	
	SA34-1-T	2	49.4		
	SA34-2-T	2	50.1		
	SA34-3-T	2	49.7		
	SA34-4-T	2	52.6	SA4T =50.45	SB4=96.43%
	SA34-1-B	2	52.3		
	SA34-2-B	2	48.7		
	SA34-3-B	2	45.8		
	SA34-4-B	2	47.8	SA4B =48.65	
	SA35-1-T	2	50.8		
	SA35-2-T	2	37.9		
	SA35-3-T	2	54.5		
	SA35-4-T	2	44.0	SA5T =46.8	SB5=88.41%

SA35-1-B	2	41.8		
SA35-2-B	2	41.3		
SA35-3-B	2	39.8		
SA35-4-B	2	42.6	SA5B = 41.375	
SA36-1-T	2	46.9		
SA36-2-T	2	50.7		
SA36-3-T	2	47.7		
SA36-4-T	2	40.6	SA6T = 43.475	SA6=91.32%
SA36-1-B	2	34.9		
SA36-2-B	2	43.3		
SA36-3-B	2	38.7		
SA36-4-B	2	41.9	SA6B= 39.7	
SA37-1-T	2	47.1		
SA37-2-T	2	38.7		
SA37-3-T	2	55.5		
SA37-4-T	2	46.0	SA7T= 46.825	SA7=89.05%
SA37-1-B	2	43.0		
SA37-2-B	2	38.1		
SA37-3-B	2	43.9		
SA37-4-B	2	41.8	SA7B= 41.7	
SA38-1-T	2	51.2		
SA38-2-T	2	34.6		
SA38-3-T	2	47.6		
SA38-4-T	2	45.8	SA8T =44.8	SA8=83.93%
SA38-1-B	2	31.1		
SA38-2-B	2	34.6		
SA38-3-B	2	40.7		
SA38-4-B	2	44.0	SA8B=37.6	
SA39-1-T	2	36.2		
SA39-2-T	2	37.2		
SA39-3-T	2	44.6		
SA39-4-T	2	32.2	SA9T= 37.55	SA9=81.67%
SA39-1-B	2	38.3		
SA39-2-B	2	28.2		
SA39-3-B	2	27.5		
SA39-4-B	2	28.5	SA9B= 30.625	
SA40-1-T	2	47.3		
SA40-2-T	2	41.3		
SA40-3-T	2	37.0		
SA40-4-T	2	28.7	SA10T= 38.575	SA10=84.90%
SA40-1-B	2	31.7		
SA40-2-B	2	33.4		

SA40-3-B	*2*	*28.1*	
SA40-4-B	*2*	*37.8*	***SA10B= 32.75***

Table2: Bottom to Top HR vs. Curing Time

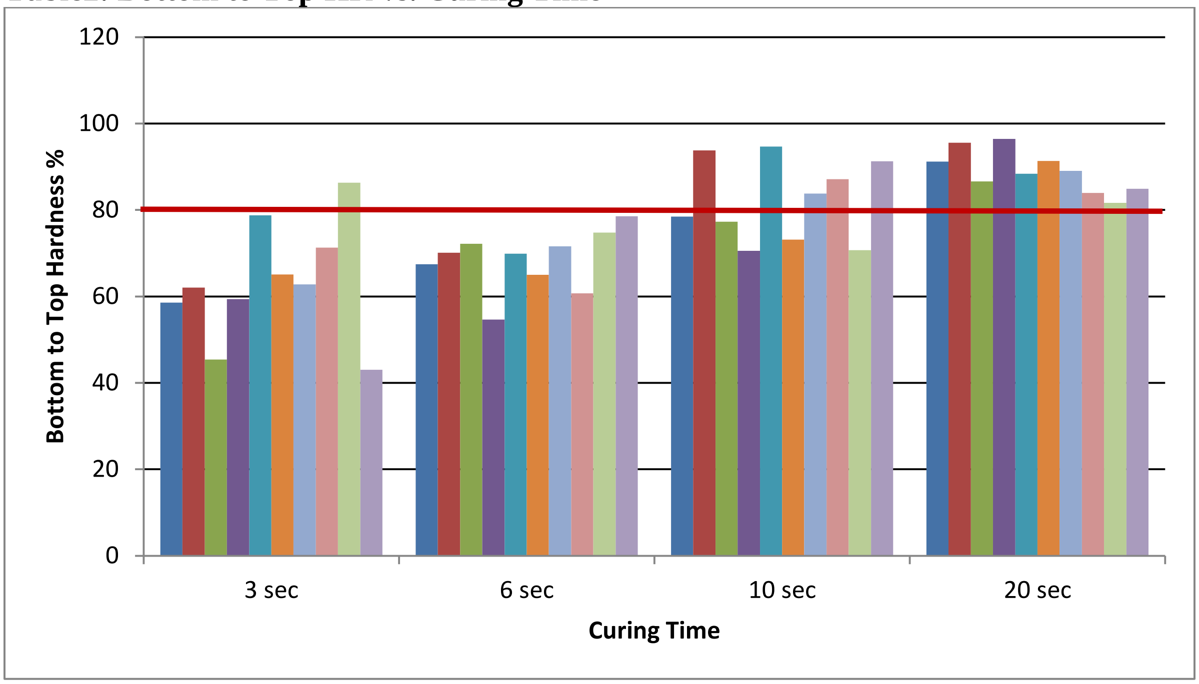


Table3: Top and Bottom Mean Surface KHN

Light Duration (sec)	Top Side		Bottom Side	
	Mean Surface KHN	Std. Deviation	Mean Surface KHN	Std. Deviation
3	37.73	13.36	22.97	6.63
6	41.38	10.04	28.15	6.70
10	40.60	6.09	33.25	5.61
20	42.90	6.83	37.90	6.31
Total	40.65	9.62	30.57	8.40

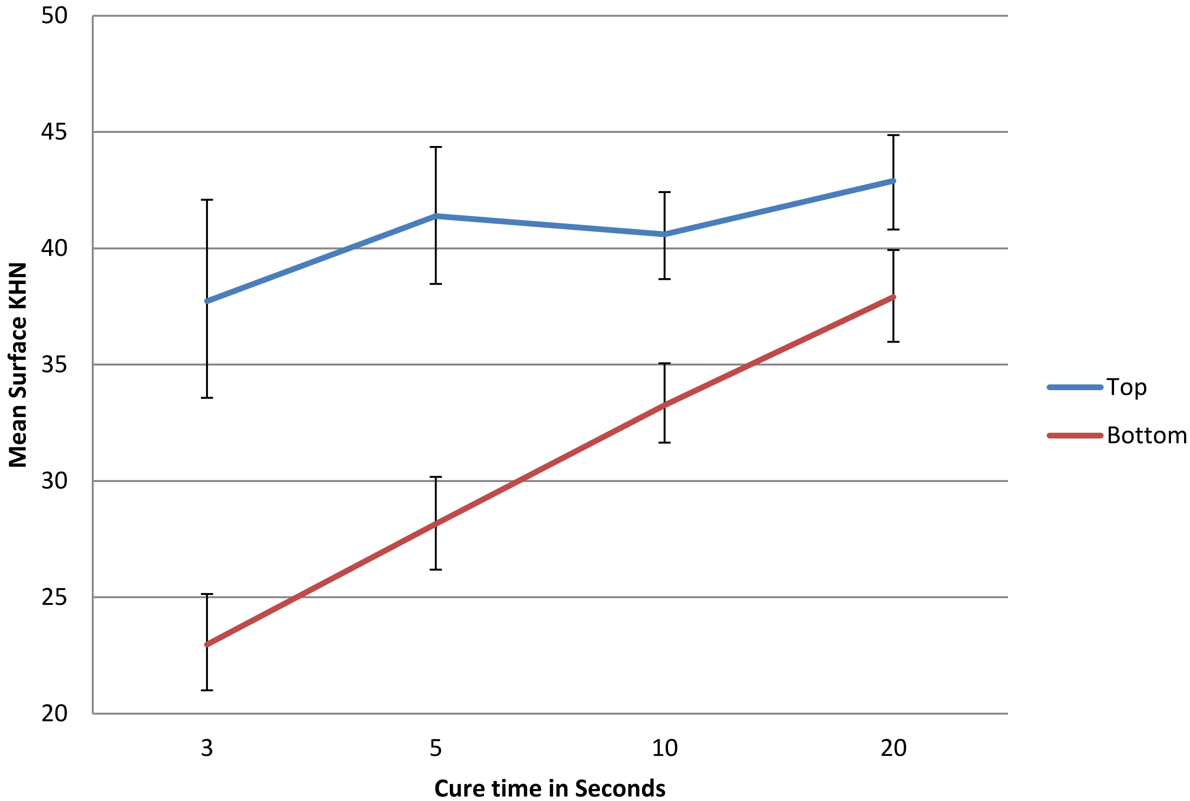
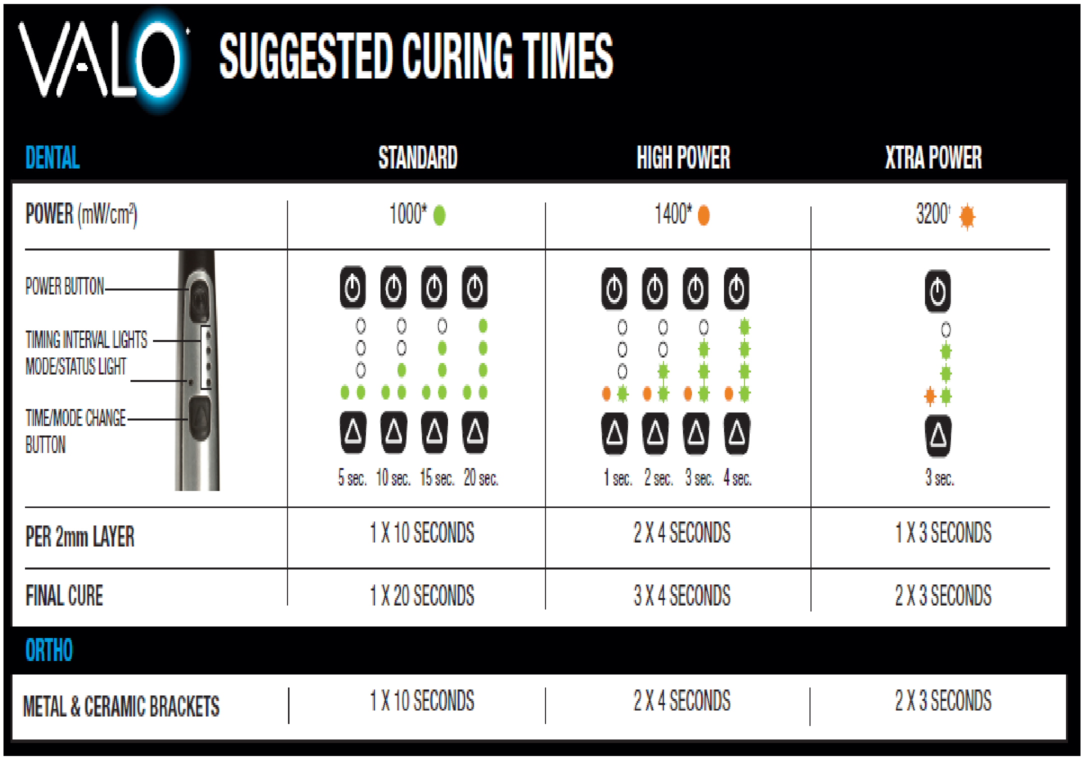


Table4: Mean Surface KHN vs. Cure Time



VALO SUGGESTED CURING TIMES

DENTAL	STANDARD	HIGH POWER	XTRA POWER
POWER (mW/cm²)	1000*	1400*	3200'
POWER BUTTON TIMING INTERVAL LIGHTS MODE/STATUS LIGHT TIME/MODE CHANGE BUTTON	5 sec. 10 sec. 15 sec. 20 sec.	1 sec. 2 sec. 3 sec. 4 sec.	3 sec.
PER 2mm LAYER	1 X 10 SECONDS	2 X 4 SECONDS	1 X 3 SECONDS
FINAL CURE	1 X 20 SECONDS	3 X 4 SECONDS	2 X 3 SECONDS
ORTHO			
METAL & CERAMIC BRACKETS	1 X 10 SECONDS	2 X 4 SECONDS	2 X 3 SECONDS

Figure1: VALO curing light power settings and suggested curing times

Figure2: VALO LED Curing Unit

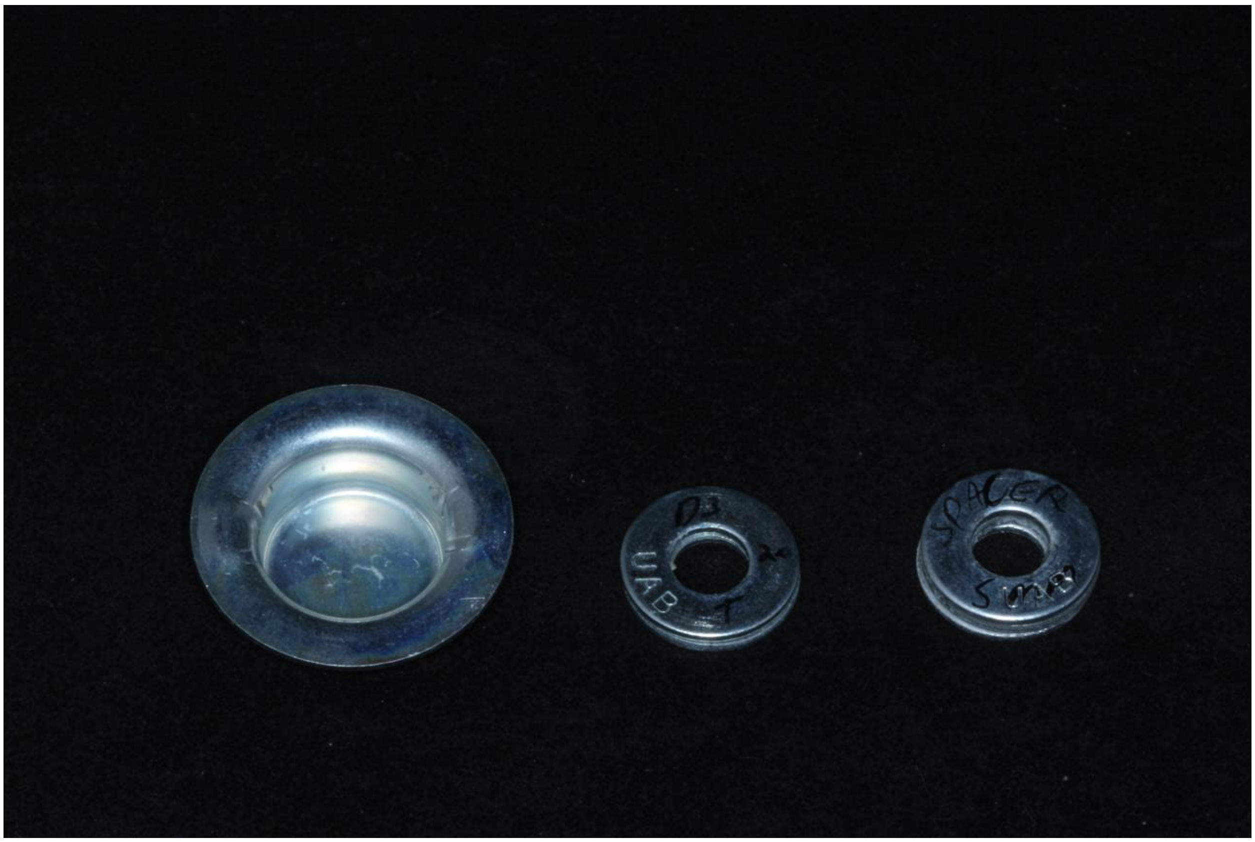


Figure3: Stainless Steel Molds (Phoenix Specialty Manufacturing, Bamberg, SC)

Sample Collection Mold: Left to Right

8mm X 18mm stainless steel master mold cylinder

2mm X 8mm X 18mm stainless steel sample mold receptacle

5mm X 8mm X18mm distance spacer

Figure4: LED Radiometer (Demetron, SDS/Kerr, Orange, CA)

Figure5: Leco 300AT Knoop Hardness Tester

Figure6: Leco 300AT Calibrating Disc

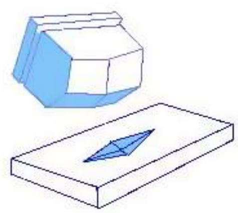


Figure7: Knoop Hardness Tip Utilizing 100 gram load for 15 seconds

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