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Research Report

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Comparative Curing and Thermal Properties of Demi Ultra LED Curing Light

Objective: To determine the beam divergence angle, depth of cure (DOC), tip temperature and human physiological response to the heat generated by several LED curing lights at various light intensity and exposure settings and separation between the light and the composite.

Methods:

Lights Tested:

Demi Ultra *(Kerr Corp.),* ***Elipar S10*** *(3M ESPE),* ***Valo Cordless*** *(Ultradent Products, Inc.),* ***Bluephase 20i*** and ***Bluephase Style*** *(Ivoclar Vivadent, Inc.),* ***SMARTLITE MAX*** *(DENTSPLY Caulk),* and ***Demi Plus*** *(Kerr Corp.)*(for Beam Divergence only)

Beam divergence:

The light tip diameter (Dt) and the diameter of the beam when projected onto white polar co-ordinate paper (Db) in a darkened room were measured. 70 mm was chosen to be the distance between the light tip and the projected beam circle as it amplified the divergence without diminishing the intensity so the beam circle diameter was easily measured. The beam divergence angle $\alpha = \tan^{-1}\left[\frac{(Db-Dt)/2}{70}\right]$.

Depth of Cure:

Depth of cure is defined as the depth along the axis of the curing light beam into the composite where the polymer is cured to a hardness of 80% or greater of the top surface of the composite. Barcol Hardness measurements of the top and bottom of a column (5 mm dia.) of composite [***SonicFill A2*** *(Kerr Corp.)*] were made after curing columns of composite with the protocol LED lights at several different intensities and times to determine the % similarity of hardness of the top and bottom faces of the column. The "% cure" at the specific test column length is: % similarity = % of full cure = hbot/htop x 100%. Specimens of various column lengths were prepared and the top and bottom hardness tested and the values of "% of full cure" plotted against the column length. The column length interpolated on the graph where this plot crossed the 80% cure condition was determined to be the depth of cure reported in the results section for each light setting of intensity and duration.

Curing Light Tip Temperature:

The maximum tip temperature was measured for the curing lights using a type "K" thermocouple and Omega HH306 Thermometer/Data Logger temperature recorder. Additionally, the time for the tip to cool back to 94°F was determined. Two distances between light tip and tissue (0 and 2 mm), and a variety of intensities and time periods were evaluated. Only data for the 0 mm distance are reported here. The thermocouple was placed in contact with a pre-warmed (to 94°F) raw chicken drumstick muscle and the curing light tip was placed on the thermocouple bead. At test initiation, the ambient temperature recording with respect to time was started and the curing light turned on for each specific test intensity and duration. The temperature recording captured the maximum temperature and the time for the tip temperature to return to the ambient starting point for each "light-on" time interval and intensity combination. A minimum of three replications were performed for each set of conditions. Average maximum temperatures and cool down times are reported.

Heat versus Pain:

This study was added to help understand the relationship between the light energy beaming from the LED light tip and the occurrence of pain and to help answer the question "Why does the LED tip touching the soft tissue seem so much hotter to the test subject than the temperature sensed by the thermocouple?" It was a qualitative analysis of the time point where pain was sensed by the same individual when each light was placed against their fingertip for three different exposure times. It demonstrated that the temperature measured by the thermocouple at the surface of the skin could be significantly less than the temperature sensed by nerve endings located below the epidermis.

Results:

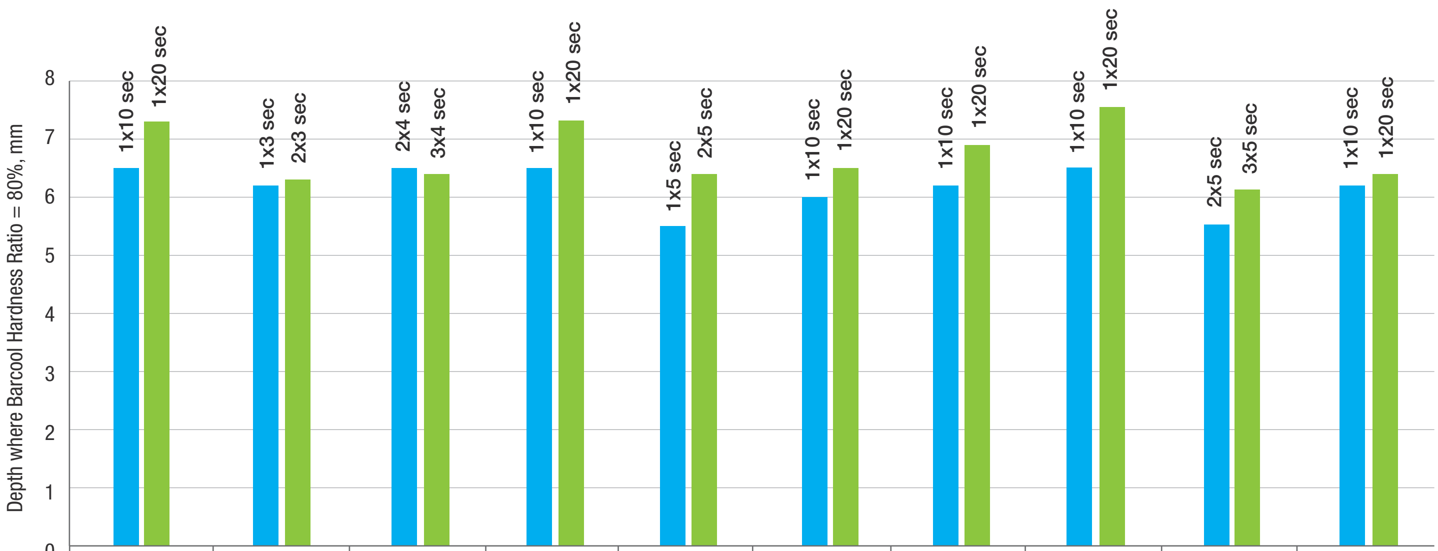
Table 1 displays the tip diameter (mm) and angle of divergence measured 70 mm from the tip for each curing light.

Table 1: Beam divergence angle (deg) and tip diameter (mm) for different curing lights.

Light	*Tip Diameter, mm*	*Angle, deg*
Demi Ultra	8.0	18
Valo Cordless	9.5	15
Bluephase 20i	7.4	36
Bluephase Style	9.5	31
3M ESPE Elipar S10	9.0	36
Smartlite Max	9.8	20
Demi Plus	7.5	18

Chart below displays depth of cure data collected for each output mode available per curing light for different time durations.

Depth of Cure for Short and Long Cure Times at 2mm Seperation Distance



Curing Light	DEMI ULTRA	VALO - Cordless	VALO - Cordless	VALO - Cordless	BLUEPHASE 20I	BLUEPHASE 20I	BLUEPHASE STYLE	ELIPAR S10	SMARTLTE MAX	SMARTLTE MAX
Output Mode	Standard	Xtra	High	Standard	Turbo	High	Standard	Standard	Boost	Continuous
Intensity $\frac{mW}{cm^2}$	1,100-1,330	3,200	1,400	1,000	2,000	1,200	1,100	1,200	1,400	1,200

Short Cure Time @ 2mm   Long Cure Time @ 2mm

Results:

The average maximum temperature obtained by each curing light is shown in Table 2, along with the average time it took the tip of the curing light to cool from the maximum temperature down to 94°F (cool down time). Data are reported at 0 mm separation distance for different output modes, exposure times and exposure amounts. Standard deviations are reported in parentheses.

Table 2: Average maximum temperature and average cool down time per curing light at 0mm separation distance for different output modes, exposure amounts, and exposure times.

Manufacturer	Curing Light	Intensity	Exposure	Max Temp Avg. (SD), °F	Cool Down Time (SD), sec [from Max Temp to 94°F]	Total Exposure, sec
Ultradent Products, Inc.	Valo Cordless	3200	1 x 3	109.6 (2.9)	3.4 (0.5)	3
Kerr Corporation	Demi Ultra	1100-1330	1 x 5	100.4 (0.5)	2.6 (0.7)	5
Ivoclar Vivadent, Inc.	Bluephase 20i	1200	1 x 5	100.8 (0.9)	4.4 (0.7)	
Ultradent Products, Inc.	Valo Cordless	1000	1 x 5	101.2 (0.7)	2.5 (1.0)	
DENTSPLY Caulk	Smartlite Max	1200	1 x 5	103.2 (2.1)	3.0 (0.6)	
3M ESPE	Elipar S10	1200	1 x 5	104.4 (0.2)	2.5 (0.0)	
Ivoclar Vivadent, Inc.	Bluephase 20i	2000	1 x 5	107.4 (1.2)	5.5 (0.9)	
Ultradent Products, Inc.	Valo Cordless	3200	2 x 3*	118.5 (1.7)	5.3 (0.5)	6
Ultradent Products, Inc.	Valo Cordless	1400	2 x 4*	111.6 (2.1)	3.7 (1.2)	8
Ultradent Products, Inc.	Valo Cordless	3200	3 x 3*	123.6 (1.3)	5.0 (1.0)	9
Ivoclar Vivadent, Inc.	Bluephase Style	1100	1 x 10	102.7 (1.2)	2.4 (0.5)	10
Ivoclar Vivadent, Inc.	Bluephase 20i	1200	1 x 10	104.2 (0.7)	5.6 (0.2)	
Kerr Corporation	Demi Ultra	1100-1330	1 x 10	106.4 (1.7)	3.6 (1.0)	
3M ESPE	Elipar S10	1200	1 x 10	108.7 (2.4)	2.6 (0.5)	
Ultradent Products, Inc.	Valo Cordless	1000	1 x 10	109.9 (2.4)	3.2 (0.7)	
DENTSPLY Caulk	Smartlite Max	1200	1 x 10	111.8 (4.0)	5.5 (2.5)	
Ivoclar Vivadent, Inc.	Bluephase 20i	2000	2 x 5*	113.2 (2.3)	3.3 (1.1)	
DENTSPLY Caulk	Smartlite Max	1400	2 x 5*	113.3 (4.6)	28.3 (8.7)	
Ultradent Products, Inc.	Valo Cordless	1400	3 x 4*	114.5 (1.8)	5.2 (1.2)	12
Ivoclar Vivadent, Inc.	Bluephase Style	1100	1 x 15	105.9 (0.8)	2.5 (0.0)	15
Ivoclar Vivadent, Inc.	Bluephase 20i	2000	3 x 5*	114.8 (1.7)	2.9 (0.2)	15
DENTSPLY Caulk	Smartlite Max	1400	3 x 5*	119.8 (0.8)	170.0 (65.0)	15
Ultradent Products, Inc.	Valo Cordless	1400	4 x 4*	121.3 (1.3)	7.3 (1.4)	16
Kerr Corporation	Demi Ultra	1100-1330	1 x 20	109.1 (0.6)	10.3 (3.8)	20
Ivoclar Vivadent, Inc.	Bluephase Style	1100	1 x 20	111.3 (3.0)	4.5 (0.8)	
Ivoclar Vivadent, Inc.	Bluephase 20i	1200	1 x 20	111.6 (0.6)	5.8 (0.7)	
3M ESPE	Elipar S10	1200	1 x 20	112.0 (0.3)	9.0 (38)	
Ultradent Products, Inc.	Valo Cordless	1000	1 x 20	116.1 (1.8)	4.0 (2.4)	
DENTSPLY Caulk	Smartlite Max	1200	1 x 20	121.3 (3.0)	12.8 (3.5)	
DENTSPLY Caulk	Smartlite Max	1400	4 x 5*	121.4 (2.9)	143.0 (45.0)	

** Curing light OFF for 3 seconds between exposures* | Pain No Pain *(as indicated by results of Heat vs. Pain in Table 3)*

Table 3 displays the time at which pain (if any) was felt when holding the curing light tip to the finger tip. This test was repeated for each of the curing light's output modes and for different exposure amounts separated by three seconds.

Table 3: Recording of whether or not pain was felt per curing light for different output modes and amounts of exposure. Curing light tip was touching the finger, and multiple bursts were separated by 3 seconds.

Curing Light	Output Mode	Intensity, mW/cm2	Exposure A, sec	Exposure B, sec	Exposure C, sec
Demi Ultra	Standard	1100-1330	1 x 5	1 x 10	1 x 20
		pain →	no	no	yes @ 14 sec
Valo Cordless	Xtra	3200	1 x 3	2 x 3	3 x 3
		pain →	yes @ 3 sec	yes @ 3 sec	yes @ 3 sec
	High	1400	2 x 4	3 x 4	4 x 4
		pain →	yes @ 4 sec	yes @ 4 sec	yes @ 4 sec
	Standard	1000	1 x 5	1 x 10	1 x 20
		pain →	no	no	yes @ 14-15 sec
Bluephase 20i	Turbo	2000	1 x 5	2 x 5	3 x 5
		pain →	no	end of 2nd 5 sec	end of 2nd 5 sec
	High	1200	1 x 5	1 x 10	1 x 20
		pain →	no	no	yes @ 15 sec
Bluephase Style	Standard	1100	1 x 10	1 x 15	1 x 20
		pain →	yes @ 5 sec	yes @ 5 sec	yes @ 5 sec
Elipar S10	Standard	1200	1 x 5	1 x 10	1 x 20
		pain →	no	yes @ 8 sec	yes @ 8 sec
Smartlite Max	Boost	1400	2 x 5	3 x 5	4 x 5
		pain →	yes @ 4-5 sec	yes @ 4-5 sec	yes @ 4-5 sec
	Continuous	1200	1 x 5	1 x 10	1 x 20
		pain →	no	yes @ 7 sec	yes @ 7-8 sec

Exposure code: 2x5 = 2 bursts for 5 seconds each

Discussion:

Pain is the sensation the body uses to warn that an insult, in this case, heat, may be high enough to be creating some physiological damage. The soft tissue temperature increase caused by the curing light is potentially greater than that measured by the thermocouple and recording system used in this experiment because the heat sensed by the nerves is generated by the absorption of light energy by the various tissues (skin, blood, fat, and nerve) which surround the heat sensing nerves. The thermocouple, therefore, only measures the temperature increase caused by the curing light tip and the increase in temperature of the surface of the tissue at the point of contact. Curing lights that utilize the fiber optic light pipe technology can generate significant heating of the tissue just from the light energy alone and not demonstrate an increase in the temperature of the tip resulting from conduction of heat generated by the light source's (LEDs) electrical resistance. The pain versus temperature experiment was performed to correlate the approximate point of physiological pain (sensed at the level of the pain sensing nerves) for the single subject in the test with the time period the light was on and the number of individual bursts of light when multiple bursts were tested. The thermocouple data are of value because they allow a relative comparison of the surface temperature of the tissue for different curing lights and different burst periods and repetitions. The pain data in Table 3 provide information on when each light and condition may be starting to cause tissue damage.

Conclusions:

The beam divergence angle of the ***Demi Ultra*** was less and, therefore, more collimated than the majority of lights tested. The depth-of-cure of the ***Demi Ultra*** compared favorably with the other tested lights. The maximum temperature of the tissue at the tip of ***Demi Ultra*** was the lowest of the lights tested at the 5- and 20-second durations and one of the three lowest maximum temperatures for the 10- second duration. Bluephase Style had the best 5-second burst duration cool down time at 2.4 seconds with ***Demi Ultra*** at 2.6 seconds. Both the ***Demi Ultra*** and Valo Cordless resulted in no pain when used in their standard settings for 5 and 10 seconds. Similarly, the Bluephase 20i, when used in its lowest intensity setting, produced no pain for 5 and 10 seconds durations. Pain was produced when all lights were used for their long-duration settings when in *boost, high, xtra* and t*urbo settings*, except for the Bluephase 20i in *high* for 5 and 10 seconds and in *turbo* for 5 seconds. The thermocouple method of measuring temperature is a reasonable method for measuring relative temperatures achieved at the tips of each curing light; however, it is not a definitive method of determining whether a particular curing light will, at certain settings, cause pain and possible tissue damage.