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EFFECT OF LIGHT CURING UNIT CHARACTERISTICS ON LIGHT INTENSITY OUTPUT, DEPTH OF CURE AND SURFACE MICRO-HARDNESS OF DENTAL RESIN COMPOSITE
B. A. Kassim, BDS, MDS, Lecturer, B. K. Kisumbi, BDS, MPHIL, Senior Lecturer, W. R. Lesan, BDS, MSc, Assistant Professor, Department of Conservative and Prosthetic Dentistry and L. W. Gathece, BDS, MPH, PhD, Assistant Professor, Department of Periodontology, Community and Preventive Dentistry, College of Health Sciences, University of Nairobi, P. O. Box 19676-00202, Nairobi, Kenya

Request for reprints to: B. A. Kassim, Department of Conservative and Prosthetic Dentistry, College of Health Sciences, University of Nairobi, P. O. Box 19676-00202, Nairobi, Kenya.

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B. A KASSIM, B. K. KISUMBI, W. R. LESAN and L. W. GATHECE

ABSTRACT

Background: **Modern dental composite restorations are wholly dependent on the use of Visible Light Curing devices. The characteristics of these devices may influence the quality of composite resin restorations.**
Objective: **To determine the characteristics of light curing units (LCUs) in dental clinics in Nairobi and their effect on light intensity output, depth of cure (DOC) and surface micro-hardness (SMH) of dental resin composite.**
Design: **Laboratory based, cross-sectional analytical study**
Setting: **Public and private dental clinics in Nairobi, Kenya.**
Subjects: **Eighty three LCUs which were in use in private and public dental health facilities in Nairobi, Kenya and resin composite specimens.**
Results: **Of the 83 LCUs studied, 43(51.8%) were Light Emitting Diodes (LEDs) and 39(47.0%) were Quartz-Tungsten-Halogen (QTH) and 1 (1.2%) was Plasma Arc Curing (PAC) light. Mean light intensity for QTH and LED lights was 526.59mW/cm2 and 493.67mW/cm2 respectively (p=0.574), while the mean DOC for QTH lights was 1.71mm and LED was 1.67mm (p=0.690). Mean Vickers Hardness Number (VHN) for LED was 57.44 and for QTH was 44.14 (p=0.713). Mean light intensity for LCUs ≤ 5years was 596.03mW/cm2 and 363.17mW/cm2 for units > 5years old (p=0.024). The mean DOC for the two age groups was 1.74mm and 1.57mm respectively (p=0.073). For SMH, the ≤ 5years and >5years age groups gave a mean VHN of 58.81 and 51.46 respectively (p=0.1). On maintenance history, the frequency of routine inspection, duration since the last repair/replacement of a part or other maintenance activity and the nature of the last maintenance activity were determined and were not found to have influenced the light intensity, DOC and SMH.**
Conclusion: **The LCU age has a statistically significant influence on its light intensity (p=0.024) while the type and maintenance history have no significant influence on its light intensity and composite DOC and SMH (p=0.574, p=0.690, p=0.713 respectively).**

INTRODUCTION

The use of photo-activated direct restorative materials is dependent on a light curing unit (LCU) that emits light of a certain intensity and wavelength range. Currently, four different types of LCUs are available for use with these materials. These are the QTH, LEDs,PAC and the Argon-ion Laser lamps(ALLs).Of these, the most widely used are the QTH (1). These lamps are affordable, durable and time tested. Both conventional and newer high intensity types of QTH units are available (2). The conventional QTH lamps usually serve as a standard against which other lamps are tested (2, 3, 4). Moreover, due to their use for ages, their advantages and disadvantages have been largely understood (1, 3, 5, 6). Despite their popularity, QTH lamps have several drawbacks which may not only result in inadequate polymerisation of the composite resin but also affect their longevity and the integrity of dental tissues in which they are used. For example, only a small part of the light spectrum they emit is appropriate for activation of the commonly used photo-initiators (3). Their large bandwidth creates unnecessary heat which causes deterioration of the unit's components. They thus have to utilise a fan for cooling and a filter to help narrow down the spectrum to a useful and safe range (7). The filter, the bulb, reflector, light guide and the fanell deteriorate with use and unless correctly handled and maintained, result in gradual reduction in the energy output of the LCU (2, 3, 4). The high intensity QTH lamps share most of the properties of the conventional ones, but the high intensity has been associated with rapid polymerisation of the resin composites and attendant high polymerisation shrinkage stress (8).

Light Emitting Diodes(LEDs)have an emission spectrum that is closely aligned with the absorption spectrum for camphoroquinone (CQ), the photo-initiator for most composites. They are thus ideally suited for polymerising composites that use CQ initiator but not for those that utilise other photo-initiators such as phenylpropanedione (9). LEDs have been reported to possess numerous advantages over QTH lamps. These include, less heat production, a consistent power output without degradation, better longevity, low power demand, portability and ease of use (7, 10). Despite these advantages, the early LEDs produced light of low intensity (2) which resulted in composites of inferior properties than QTH lamps (9, 11). Newer generations of LEDs try to address these deficits through higher intensities and being of dual spectrum. This allows them to be used with non-CQ composites (7). However, the high intensity has brought in the familiar problem of heat generation which has dogged the new generation of LEDs without exception.

Plasma Arc Curing lamps (PACLs) are characterised by a very high output (2000 mWcm-2) in a narrow range of wavelength around 470nm (2, 1) and their polymerisation characteristics are fairly close to those of high intensity QTH lamps (13, 14). However, several concerns surround their use and these include high polymerisation shrinkage, radiation heating, poor long-term colour stability and compromised physical and mechanical properties of the composite restoration (13, 15-19).

Argon-ion Laser lamps (ALLs) produce photons of a specific energy and concentrate them onto a tiny area. Their intensities are comparable to those of high intensity lamps (4) (HIHLs) and, although the small curing tip may reduce their efficiency, theyare reported to significantly reduce the curing time of photo-activated resin composites (7, 8). Nevertheless, both PAC and ALLs have not found a wide acceptance due to their high cost (7, 14, 20). Consequently, there is limited information on their longevity and efficiency with use.

Among the studies on in situ LCUs, none appear to probe the effect of LCU type on intensity, DOC or SMH. Numerous studies (21-25), on new LCUs, however, investigated the possible effect of LCU type but the reports did not provide a clear direction. Nevertheless, age has been reported to influence light intensity output but its effect on the cure properties of the composite is largely unknown (26). Hence the objective of this study which was to determine the effect of LCU characteristics on its light intensity output and the cure characteristics of the polymerised composite resin.

MATERIALS AND METHODS

The study was laboratory based, cross-sectional and analytical. Eighty three LCUs which were in use in private and public dental health facilities in Nairobi, Kenya, were studied. Data on type, age and maintenance history of the LCUs were collected from dentists who used them through a self-administered questionnaire.The intensity of the light emitted by the LCUs,DOC and SMH of composite specimens polymerised with the lights were then measured as subsequently described.

Light intensity: The LCU was switched on and allowed to run for about five seconds. The tip of the fibre-optic light guide was then made to contact a sensor on the light meter(CURE RITE, Caulk-Dentsply, USA), which then displayed the light intensity reading on a screen in mWcm-2. The measurement was repeated three times to ensure reliability.

Fabrication of specimens: A single batch of a commonly used resin based composite (AmelogenPlus, Ultradent, South Jordan, Utah, USA) was used to fabricate the specimens for DOC and SMH tests. The shade and composition of the material were controlled so as to exclude the influence of material factors on the variables being measured. LCUs in the sampled clinics were used to cure cylindrical composite specimens. The one for micro-hardness evaluation measured 8mm in diameter and 3mm in height while the other for depth of cure evaluation measured 4mm in diameter and 6mm deep. Split brass moulds made to these specifications were used to fabricate the specimens. The mould was positioned on a mylar strip supported underneath by a glass slab. The resin composite was then filled into the mould using a plastic instrument and a condenser. The filled mould was then covered with another mylar strip and finger-pressed with a microscope slide to give an even top surface. Any excess material that extruded during the pressing was removed before curing so as to give a constant depth for all the specimens.

The specimens were cured only from the top with the light guide angulated at 90^{o} to the resin surface. Irradiation times of 40 seconds for LEDs and QTH and ten seconds for PAC lamps were applied. Throughout the curing period, the tip of the light guide was in contact with the mylar strip covering the top surface of the specimen. Thus the light source-restoration distance was constant and equivalent to the thickness of the mylar strip (100μm). After curing, the specimen was retrieved from the mould, inspected and the procedure repeated if it was found to have been defective. Each specimen was then placed in a serialised envelope and immediately stored in a light-proof cooler box at room temperature to await conduction of the tests.

Evaluation of surface micro-hardness and depth of cure: Surface micro-hardness evaluation was done after 24 hours in a laboratory using a Vickers's micro-hardness tester (V-tester 2, Amsler Otto Wolpert-Werkke, GMBH) with a load of 200g and a dwell time of 15 seconds. Three indentations were made on the top surface of each specimen by a diamond indenter and the hardness determined by measuring the diagonals of each indentation with a measuring light microscope (x200 magnification). The measurements were then converted into Vickers Hardness Numbers (VHNs) using conversion tables. The average of the three measurements was taken as the Vickers Hardness Number of the specimen and recorded.

The depth of cure was measured, within six to seven hours of specimen fabrication. The uncured material at the bottom of the specimen was removed by shaking it in 99% acetone for 15 seconds using a capsule and a mixing device (Ultramat 2, SDI, Australia). The acetone removed all the uncured material and left a macroscopically even surface. The remaining length of the composite cylinder was measured using a digital Vanier Calliper (Shengya Machine & Tools Co., Ltd. China). Half of the remaining length of the cylinder was taken as the DOC.

RESULTS

Table 1
Effect of a LCU's type on light intensity output and DOC and SMH of composite

Variable	Type of Light Curing Unit	n	Mean	SD	p value	t
Light Intensity	QTH(Halogen)	39	526.59	406.34		
(mWcm-2) (n= 82)					0.713	0.369
	LED	43	493.67	399.93		
DOC (mm) (n= 82)	QTH(Halogen)	39	1.71	.48	0.683	0.410
	LED	43	1.67	.29		
Surface micro-	QTH(Halogen)	28	55.14	21.20	0.574	0.566
hardness (n= 58)	LED	30	57.44	6.59		

Light intensity and DOC were measured for all the 83 LCUs. The mean light intensity for QTH lights was 526.59 ±406.34SD while that of the LED lights was 493.67±399.93SD. Mean DOC for QTH was 1.71mm±0.48SD and that of LED was 1.67±0.29SD.The VHN was measured for 58 (70.0%) of the LCUs. The lowest and highest VHN values were zero and 80.30 respectively. The mean VHN for the LED lights was 57.44±6.59SD and that of the QTH was 44.14± 21.20SD. An independent samples t-test was used to compare the two means for each dependent variable and no significant difference between the means was found. The PAC light was excluded from the analysis since it was only one (thus n= 82).

Table 2
Effect of a light curing unit's age on light intensity output, DOC and SMH

Variable	Age of the LCU (years)	n	Mean	SD	p value	t
Light Intensity (mWcm-2)	≤ 5					2.302
(n= 81)*		58	596.03	437.87		
	> 5				0.024	
		23	363.17	329.58		

Depth of cure (mm)	≤ 5					1.819
		58	1.74	0.38		
(n= 81)*	> 5				0.073	
		23	1.57	0.41		
Surface micro-hardness	≤ 5					1.676
(n= 56)**						
		38	58.81	12.27		
					0.100	
	> 5	18	51.46	20.47		

*units with unknown ages were excluded from this analysis

The mean light intensity for LCU ≤ 5 years old was 596.03 ±437.87SD while that of units older than 5 years was 363.17 ±329.58SD. The mean DOC for the two age groups was 1.74 mm± 0.38SD and 1.57 mm±0.41SD respectively(Table 2). For SMH, the two age groups gave mean hardness of 58.81±12.27SD and 51.46±20.47SD respectively. Independent samples t-tests were conducted to compare the means between the two age groups. The group that was ≤ 5 years old had a higher mean for all the three parameters (intensity, DOC and SMH) than the group that was older than 5 years but the difference was found to have been significant only in relation to the light intensity (p=0.024).

Table 3

Effect of maintenance history of a LCU on SMH of composite

Maintenance history		Surface micro-hardness (VHN)				
		n	M	SD	F	P value
Routine inspection (n=58)	Weekly	1	68.30	-	0.319	0.728
	Others*	48	55.29	14.08		
	Never	9	55.22	22.37		
Time from the last maintenance activity (n=58)	≤ 6 months	22	55.19	20.23	0.754	0.475
	1 year	6	50.43	24.90		
	Other**	30	58.35	6.75		
Type of last maintenance activity (n=57)****	Replacement of bulb	12	51.89	25.70	0.851	0.500
	Replacement of light guide	2	58.65	8.70		
	Cleaning of light filter	2	62.90	7.64		
	Routine check	16	61.24	8.37		
	Others***	25	54.28	13.12		

* Less frequent than weekly
** Any period more than a year earlier.
*** Repair/replacement of power cable, not known etc.
**** Missing value was excluded

The aspects of the maintenance history that were studied included: the frequency of routine inspection, time from the last maintenance activity and the type of the last maintenance activity.

Of the 58 LCUs whose hardness was tested, only one (1.7%) had weekly routine inspection while nine (15.5%) were never routinely inspected. The majority (82.8%) were inspected less frequently and were grouped together here as others. The mean VHN for those LCUs routinely inspected weekly was higher than that of units never inspected or inspected less frequently than weekly. The mean VHNs for the three groups were 68.30, 55.22±22.37SD, and 55.29±14.08SD respectively(Table 3). However, one way ANOVA test did not find the difference between the three means to have been statistically significant (p= 0.728).

Regarding the time from the last maintenance activity, it was ≤ 6 months for 22 (37.9%) LCUs, 1 year for 6 (10.3%) LCUs and more than that for the rest (51.7%). The respective mean VHNs for the three groups was 55.19±20.23SD, 50.43±24.90SD and 58.35±6.75SD. One way ANOVA showed no significant difference amongthese three means (p= 0.475).

On the type of the last maintenance activity, the mean VHN for bulb replacement was 51.89± 25.70SD, light guide replacement was 58.65±8.70SD, cleaning of light filter was 62.90±7.64SD and routine inspection was 61.24±8.37SD. The mean VHN for other maintenance activity was 54.28±13.12SD. One way ANOVA showed no significant difference between the 4 means, hence the type of the last maintenance activity had no statistically significant influence on the surface VHN of the specimen of composite (p= 0.5).

Table 4
Effect of LCU maintenance history on light intensity output

Maintenance history		Light intensity (mW/cm2)				
		n	M	SD	F	P value
Routine inspection (n=82)	Weekly	2	562.50	531.50	0.250	0.779
	Others*	71	541.01	430.71		
	Never	9	436.67	257.24		
Time from the last maintenance activity (n=82)	≤ 6 months	27	529.78	433.05	0.767	
	1 year	9	436.33	366.21		
	Other**	46	548.61	424.93		
Type of last maintenance activity (n=80)****	Replacement of bulb	17	455.24	322.90	2.053	0.096
	Replacement of light guide	6	629.17	617.39		
	Cleaning of filter	2	218.00	90.51		
	Routine check	20	739.30	435.99		
	Other***	35	564.11	396.45		

* Less frequent than weekly
** Any period more than a year earlier.
*** repair/replacement of power cable, not known etc.
**** Missing values were excluded

On the frequency of routine inspection, the two (2.4%) LCUs that were inspected weekly had a mean light intensity of 562.50 mW/cm^2 while the 9 (11.0%) that were never inspected had a mean intensity of 436.67 mW/cm^2. The others (71 or 86.6%) had a mean light intensity of 541.01mWcm-2(Table 4). The difference between the three means was not statistically significant (p=0.779, one way ANOVA). On the time of the last maintenance activity,LCUs that were maintained within the previous 6 months (32.9%) had a mean light intensity of 529.78mWcm-2 while those that were maintained a year earlier (11.0%) had a mean light intensity of 436.33mWcm^{-2}. The rest (56.1%) had a mean of 548.61mWcm^{-2}. This aspect of the maintenance history had no significant influence on the light intensity of the LCUs (p=0.767, one way ANOVA).

Regarding the type of the last maintenance activity, bulb replacement had a mean of 455.24mWcm-2; light guide replacement 629.17 mWcm-2 and cleaning of the filter 218.00mW/cm^2. Routine inspection was 739.30mWcm^{-2} while the others had a mean light intensity of 564.11mW/cm^2. Again, this component of the maintenance history had no significant influence on the mean light intensity (p=0.096, one way ANOVA).

Table 5
Effect of LCU maintenance history on the DOC of composite

Maintenance history		Depth of cure (mm)				
		n	M	SD	F	p value
Routine inspection (n= 82)	Weekly	2	1.53	0.760	0.212	0.809
	Others *	71	1.70	0.38		
	Never	9	1.72	0.24		
Time from the last maintenance activity (n= 82)	≤ 6 months	27	1.66	0.40	0.263	0.769
	1 year	9	1.72	0.36		
	Others**	46	1.72	0.37		
Type of last maintenance activity (n= 80)****	Replacement of bulb	17	1.63	0.43	1.298	0.279
	Replacement of light guide	6	1.59	0.25	1.298	0.279
	Cleaning of filter	2	1.55	0.00		
	Routine check	20	1.86	0.36		
	Others***	35	1.69	0.37		

* Less frequent than weekly
** Any period more than a year earlier.
*** Repair/replacement of power cable, not known etc.
**** Missing values were excluded

The units that were supposedly inspected weekly had a lower mean DOC (1.53mm) than those that were never inspected (1.72mm) (Table 5). The rest had a mean DOC of 1.70mm. The three means were, however, not significantly different (p=0.809, one way ANOVA).Light curing units that were reportedly maintained within the previous 6 months had a lower DOC (1.66mm) than those that were maintained one year earlier (1.72mm) or before (1.72mm). The three means were, however, not statistically different (p=0.769, one way ANOVA). Units that had a bulb replacement as the last maintenance activity had a mean DOC of 1.63mm, while those that had light guide replacement had 1.59mm. Cleaning of the filter, routine inspection and others had a mean DOC of 1.55mm, 1.86mm and 1.69mm respectively. The type of the last maintenance activity had no significant influence on the mean DOC (p=0.279, one way ANOVA).

DISCUSSION

Various types of dental LCUs have been developed since the advent of photo-activated resin based composites in the 1970s (14). Currently, QTH, LED, PAC and ALLs are in use. This study found that there are marginally more clinics using LED (51.8%)type of LCU than QTH (47.0%). This is in contrast with previous reports which indicate that the QTH lights are the most widely used devices in clinical practice. This study also reaffirms that the popularity of PAC and laser lights is still low, as only 1(1.2%) PAC light and no Laser lights were encountered in the study. The latter may be due to reportedly high cost of PAC and Laser lights (7), or simply due to lack of awareness among dentists occasioned by inadequate marketing. More still, the dental practitioners may be content with the units that are currently in use and hence there may be lack of a felt need for more sophisticated equipment. Most similar studies (26, 27,28), on in situ LCUs do not report the type of machine but one is known to have evaluated only QTH lights (29). Halogen lights have been popular presumably because of their affordability, durability and long history of use (1,21). However, dentists in Nairobi appear to have also embraced the newer LED lights perhaps due to the reported advantages of the early LEDs (7,10,21). In addition, it was observed during the current study that many LED lights come attached to the dental chair, a factor that is thought tohave attracted dentists who want to avoid the "extra" cost of buying a separate LCU.

Although both QTH and LED machines are capable of producing adequately cured composites, the narrow emission spectrum of the latter makes them unsuitable for use with noncamphoroquinone composites (9). Nevertheless, although the photoinitiator type in the material for the current study was not disclosed by the manufacturer and contrary to expectations, this study found that there were no statistically significant differences in light intensity, and the DOC and the SMH of composites for the different types of lights. Among the studies on in situ LCUs, none appear to probe the effect of LCU type on intensity, DOC or SMH. Numerous studies (21, 22, 23, 24, 25), on new LCUs, however, investigated the possible effect of LCU type but the reports did not provide a clear direction. Diverse results obtained when different generations of LED lights are compared with QTH lights could partly account for the mixed picture. Nevertheless, this study did not categorise the LED lights into generations but placed them together as one type of LCU which, undoubtedly, included both new and older generations of the LED lights.

De Araujo *et al* (21) reported that the LCU type has no significant effect on the SMH of composites but the same also found that LCU type has a significant influence on the SMH of dark shades. Although the current study did not compare the cure efficiency of different shades, the findings appear to be similar to De Araujo's findings that, for light shades, such as the A2 that was used here, the LCU type does not significantly influence the SMH of composites.

Ceballos *et al* (22) showed in their study that at a 40-seconds exposure time, LED and QTH showed similar DOC and hardness performances, but the LED gave a significantly higher micro-hardness than the QTH when both were exposed for 20 seconds. The studyconcluded that DOC and micro-hardness are not affected by the LCU type, a fact corroborated by the findings of this study. However, it may be inferred from their results that LEDs give a better SMH at shorter exposure times. This finding is noteworthy particularly when viewed with another report (28) which states that over 40% of dental practitioners may be exposing their composites only for 20 seconds, which may imply that the LCU type is important if one has to use the shorter, but inappropriate, exposure time of 20 seconds. The current study did not investigate this aspect as a 40 second exposure time was applied to both the LEDs and QTH lights. Correr *et al* (23) also found no significant SMH difference among composites cured with LED and QTH lights but found specimens cured with PAC lights to have a lower hardness than those with QTH and LED. The difference has been attributed to the low energy density of PAC lights occasioned by the short exposure time. This study did not include the composite surface hardness associated with the one PAC light that was found. Campregher *et al* (24), while evaluating the effectiveness of second generation LED lights found that SMH for LEDs and QTH were not significantly different. They also found that the DOC between the LED and QTH were not statistically different. They concluded that the LCU type has no influence on the DOC and the surface hardness. According to Tsai *et al* (25) QTH give a significantly greater DOC than LED but the surface hardness was not statistically different between the two types of lights.

The consensus from these reports appears to be in agreement with the findings of the current study that LCU type has no significant effect on the DOC and SMH of composite resins. However, it is noteworthy that the high standard deviations encountered throughout this study may have raised the threshold for statistical significance. Thus, lack of statistical significance may not preclude clinical significance for some of the results.

This study found that age has a significant negative influence on the light intensity of LCUs with the mean light intensity for those that are ≤ 5years being 596.05mW/cm^2 and those older than five years being 363.17mW/cm^2 ($p<0.024$). Age, however, did not have a statistically significant influence on the DOC (p=0.073) and the SMH (p= 0.1). This finding supports that of previous studies (26, 28,29). For example, Mitton and Wilson (26) studied light curing units in use and found a significant difference between the light intensity of old (>6years) and new (<5years) units (p=0.025). However, their study did not include DOC and SMH of composite specimens. El-Mowafy *et al* (29) also studied LCUs in private clinics and found that light intensity significantly decreased as age increased. Notably, El-Mowafy *et al* (29) attributed only 26% of the variation in light intensity to light unit age and the remaining 74% was unexplained. Martin (28) also found a negative correlation between the age of the light curing unit and the intensity recorded.

Impact of service history on the performance of a LCU is not widely reported, but it is believed that recent service history positively influences performance. El-Mowafy *et al* (29) reports that the mean light intensity of units serviced in the preceding 12 months was significantly higher than that of units serviced 12-72 months previously. Reports (26, 27,30) also recommend that LCUs be inspected weekly or monthly using a radiometer so as to test if they are optimally functional and to take remedial action if necessary. These and other studies (28) also show that between 49% and 67% of dentists never routinely inspect the adequacy of the intensity of their LCUs and yet 44% of them cured their composites for only 20-seconds.

In this study, wehave reported that only two (2.4%) of the LCUs fulfilled this requirement of weekly inspection while nine (11%) were reported never to have received a routine inspection. However, although the mean light intensity and SMH was higher for those inspected weekly than those never inspected, statistical tests did not find history of routine inspection, or lack of it, to affect the light intensity, DOC or SMH(p>0.05). The reasons for this are not explicit but it is was observed duringthe data collection that most of the clinics did not have written records on maintenance history of the units and the dentists appeared to have relied mainly on recall, potentially resulting in inaccurate reporting. In addition, the inclusion of LED lights in this study, which have different maintenance requirements, may also partly account for the difference. These aside, the unexpected findings serve as strong justification for a larger study with a bigger sample size.

CONCLUSION

An LCU age has a statistically significant influence on its light intensity (p = 0.024) while the type and maintenance history have no significant influence on light intensity, and composite DOC and SMH (p = 0.574, p = 0.690, p = 0.713 respectively).

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REFERENCES

1. Ralph Rawls H, Esquivel-Upshaw J. Restorative resins, in; Anusavice K J, editor, Philips' Science of Dental materials 11thedn. Elsevier Science (USA) St. Louis, Missouri 2003. pp 399-441.
2. Rahiotis C, Kakaboura A, Loukidis M Vougioukiakis G. Curing efficiency of various light curing units. *Eur J oral Sci.* 2004; **112**:89-94.
3. Hofmann N, Hugo B, Klaiber B. Effect of Irradiation type (LED or QTH) on photoactivated composite shrinkage strain kinetics, temperature rise and hardness. *Eur J Oral Sci* 2002; **110**:471- 479.
4. Ushio inc. Halogen lamps Technical specifications. Bulletin 1000 SA. Tokyo: Ushio inc, 92-12.
5. Kleverlaan CJ, de Gee AJ. Curing efficiency and heat generation of various resin composites cured with high- intensity halogen lights. *Eur J oral Sci* 2004; **112**:84 – 88.
6. Ferracane JL. Correlation between hardness and degree of conversion during the setting reaction of unfilled dental restoration resins. *Dent mater* 1985; **1**:11- 14.
7. Vandewalle KS, Roberts HW, Miniotis N. Critical Appraisal: Quartz-Tungsten-Halogen and Light-Emitting Diode curing units. Journal of Esthetic *Dentistry* 2006; **18**:161-167.
8. Rueggeberg FA, Ergle JW, Mettenburg DJ. Polymerisation depths of contemporary light curing units using microhardness. *J Esther Dent* 2000; **12**:340-349.
9. Jandt KD, Mills RW, Blackwell GB, Ashworth SH. Depth of cure and compressive strength of dental composites cured with blue light emitting diodes (LEDS). *Dental Materials* 2000; **16**:41-47.
10. Leonard DL, Swift Jr EJ. Critical Appraisal: Light Emitting Diodes curing units, Parts II. *Journal of Esthetic and Restorative Dentistry* 2003; **15**:251-252.
11. Kurachi C, TuboAM, Magalhoes DV, Bagnato VS. Hardness evaluation of a dental composite polymerized with experimental LED-based devices. *Dental Materials* 2001; **17**:309-315.
12. Deb S, Mallet R, Millar B. The effect of curing with plasma light on the shrinkage of dental restoration materials. *J. of Oral Rehabilitation* 2003; **30**:723-728.
13. Knezevic A, Tarle Z, Meniga A, Sutalo J, Pichler G. Photopolymerisation of composite resins with plasma light. *J. of Oral Rehabilitation* 2002; **29**:782-786.
14. Peutzfeldt A, Sahafi A, Asmussen E. Characterization of resin composites polymerized with plasma arc curing units. *Dental Materials* 2000; **16**:330-336.
15. Feilzer AJ, Doreen LH, de Geee AJ, Davidson CL, Influence of light intensity on polymerisation shrinkage and integrity of restoration-cavity interface. *Eur J oral Sci* 1995; **103**:322-326.
16. Hofmann N, Hugo B, Schubert K, Klaiber B. Comparison between plasma arc light source and conventional halogen curing units regarding flexural strength, modulus and hardness of photoactivated resin composites. *Clin Oral Invest* 2000; **4**:140-147.
17. Janda R, Roulet J-F, Latta M, Steffin G, Ruttermann S. Color stability of resin-based filling materials after aging when cured with plasma or halogen light. *Eur J Oral Sci* 2005; **113**:251-257.
18. Curtis JW, Rueggeberg FA, Lee AJ. Curing efficiency of the turbo tip. *Gen Dent* 1995; **43**:428-433.
19. Campbell JM. Introduction to synthetic polymers. Science publications, Oxford, 1994.
20. Moon H-J, Lee Y-K, Lim B-S, Kim C-W. Effect of various light curing methods on the leachability of uncured substances and hardness of a composite resin *J. of Oral Rehabilitation* 2004; **31**:258-264.
21. De Araujo CS, Schein MT, Zanchi CH, Rodrigues SA Jr, Damarco FF. Composite resin microhardness: The influence of light curing method, composite shade, and depth of cure. *J Contemp Dent Pract* 2008;**4**: 43-50.
22. Ceballos L, Fuentes MV, Tafalla H, Martinez A, Flores J, Rodriguez J. Curing effectiveness of resin composites at different exposure times using LED and halogen units. *Med Oral Patol Cir Bucal,* 2009;**14**:51-56
23. Correr AB, Sinhoreti MAC, Sobrinho LC, Tango RN, Schneider LFJ, Consani S. Effect of the increase of energy density on Knoop hardness of Dental composites light cured by QTH, LED and Xeno Plasma Arc. *Braz Dent J,* 2005; **16**:218-224.
24. Campregher UB, Samuel SMW, Fortes CBB, Medina ADC, Collares FMC, Ogliari FA. Effectiveness of second generation Light-Emitting Diode(LED) light curing units. *J Conmp Dent Pract* 2007; **8**:035-042.
25. Tsai PCL, Meyers IA, Walsch LJ. Depth of cure and

surface micro-hardness of composite resin cure with blue LED curing units. *Dental Materials* 2004;**20**: 364-369.
26. Mitton BA, Wilson NHF. A Survey on the use, care and maintenance of light activating units. *British Dental Journal* 2001; **191**: 82 – 86.
27. Pilo R, Oelgiesser D, Cardash HS. A Survey of output intensity and potential for depth of cure among light-curing units in clinical use. *J. of Dentistry* 1999; **27**:235 – 241.
28. Martin FE. A survey of the efficiency of visible light curing units. *J. of Dentistry* 1998; **26**:239 – 243.
29. El-Mowafy O, El-Badrawy W, Lewis D W, Shokati B, Kermali J, Soliman O, Encioiu A, Zawi R, Rajwani F. Light intensity of quartze-tungsten-halogen light-curing units used in private practice in Toronto. *J AM Dent Assoc* , 2005;**136**:766-773.
30. Caughman WF, Rueggeberg FA, Curtis JW. Clinical guidelines for photocuring restorative resins. *J. of American Dental Association*.1995; **126**:1280- 1286.