Effect of convergent light-irradiation on microtensile bond strength of resin composite to dentin

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Purpose: This study investigated the effects of curing light convergence and irradiation distance on the microtensile bond strength of resin composite to dentin using three light emitted diode (LED) light-curing units.
Materials and Methods: Three light curing units were investigated in this study; Flash Lite (FL), Pencure (PN), and an experimental light-curing hand-piece developed for Dentaport ZX (DP), which was designed to emit convergent light. The light intensity of each unit was measured at irradiation distances up to 10 mm. For bond strength test, bonding area was demarcated on prepared dentin using black plastic rings, in which a self-etching adhesive and a resin composite (Clearfil Liner Bond IIΣ and Clearfil Photo Core) were light-cured at different distances (2, 4, 6, 8, and 10 mm). After 24 hours storage in 37ºC water, the specimens were sectioned into beams. Microtensile bond strength was then measured and failure modes were observed.
Results: The light intensity of all units significantly decreased with increasing irradiation distance. DP showed a smaller range of decrease, significantly higher intensity values at irradiation distances over 2 mm and significantly higher bond strengths at 8 and 10 mm compared to FL and PN ($p<0.05$). Percentage of cohesive failures in dentin decreased at 8 and 10 mm for FL and PN. Irradiation distance did not significantly affect light curing performance of DP.
Conclusion: Convergent light-irradiation was effective in maintaining adequate light intensity and bond strength as the irradiation distance increased. **(Int Chin J Dent 2009; 9: 45-53.)**
Key Words: irradiation distance, light intensity, microtensile bond strength.

Introduction

Advances in the light curing technology have revolutionized adhesive dentistry. Various light curing units (LCUs) have been developed using quartz-tungsten-halogen (QTH) bulbs, light emitted diodes (LEDs), argon-ion laser devices, and xenon plasma arc lamps as the light source.[1,2] Factors associated with the light and composite, affect the polymerization degree of resin composite. Light-related ones include irradiance, spectral distribution, exposure time, and light dispersion.[3] The required time for irradiation depends on the light intensity of the LCUs.[4] On the composite side, shade, translucency, photoinitiator system, matrix and filler characteristics affect depth and degree of cure.[5] Attenuation of light, deep in the composite, affects the degree of conversion of carbon double bonds (C=C), resulting in poor mechanical properties and also low bond strength to teeth.[6-8]

In order to increase depth of cure and decrease the irradiation time, manufacturers have made efforts including modification of the light-guide design or raising the power output from the light source.[9] However, it has been reported that regardless of the type of LCU used, light intensity decreases as the distance between the tip and irradiated surface increases, and as it passes through the material.[10-12] The design of the light-emitting tip and the light-guide can have a spectacular influence on the light beam characteristics, focusing effect, or dispersion of the emitted light.

This study aimed at evaluating the effect of an experimental LCU on the intensity of light and bond strength of resin to dentin at different irradiation distances. It was hypothesized that by altering the structure of the LCU to decrease light diffusions, it would be possible to maintain high light intensity and high dentin bond strength when the irradiation distance increased.

Materials and Methods

Light curing units

Three LED LCUs were used in this study (Table 1): Flash Lite 1001 (FL, Discus Dental, Culver City, CA, USA), Pencure (PN, J. Morita Mfg. Corp., Kyoto, Japan), and an experimental light-curing hand-piece developed for Dentaport ZX (DP), which was designed to emit convergent light (J. Morita Mfg. Corp.). Figure 1 presents a schematic of the light emitting tip for each of the LCUs. The wavelengths of all LCUs were measured using a spectrometer (USR-40V-01, Ushio, Japan). Light emission images were also obtained by projecting the light of each curing unit parallel across the surface of a flat black paper. Images were captured with a digital camera (Cyber-shot DSC-T70, Sony, Tokyo, Japan), at identical exposure and distance settings for each unit.[13]

Table 1. LED light curing units used in this study.

Light curing unit (Abbreviation)	Type	Tip diameter (mm)	Intensity (mW/cm^2)	Manufacturer
Flash Lite 1001 (FL)	Blue LED	8.0	600	Discus Dental, CA, USA
Pencure (PN)	Blue LED	9.0	600	J. Morita Mfg. Corp., Kyoto, Japan
Experimental Dentaport ZX (DP)	Blue LED	10.5	600	J. Morita Mfg. Corp.

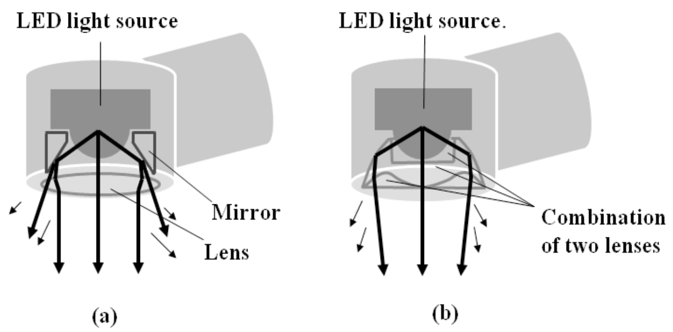


Fig. 1.

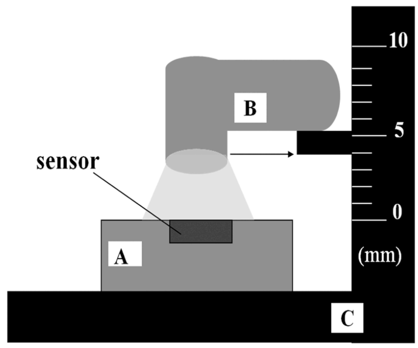


Fig. 2.

Fig. 1. Schematic structures of LCUs used in this study.
(a) Conventional LCU; Lenses and metal reflective mirrors at the tip, conduct the light towards the target.
(b) DP; The metal reflective mirrors have been eliminated from the structure, and a combination of two lenses composed of transparent polymer resin materials has been incorporated to concentrate the irradiation light.
Fig. 2. The setup for measuring the intensity of the three LCUs at irradiation distances up to 10 mm.
A, Hand-held radiometer; B, Light curing unit; C, Measured stand for the light curing unit.

Light intensity measurements at different distances

The light intensity of the three LCUs was measured using a spectroradiometer (Model 100 Optilux Radiometer; Sybron-Kerr, West Collins Orange, CA, USA). The distance of the light tip from the sensor of the radiometer was increased in 1 mm increments from 0 to 10 mm. The light intensity of each LCU was measured three times at each distance (Fig. 2).

Microtensile bond strength test

The procedure for microtensile bond test are schematically illustrated in Fig. 3. The restorative materials used in this study were a self-etching adhesive system (Clearfil Liner Bond IIΣ, Kuraray Medical, Tokyo, Japan) and a light-cured core buildup composite (Clearfil Photo Core, Kuraray Medical) (Table 2).

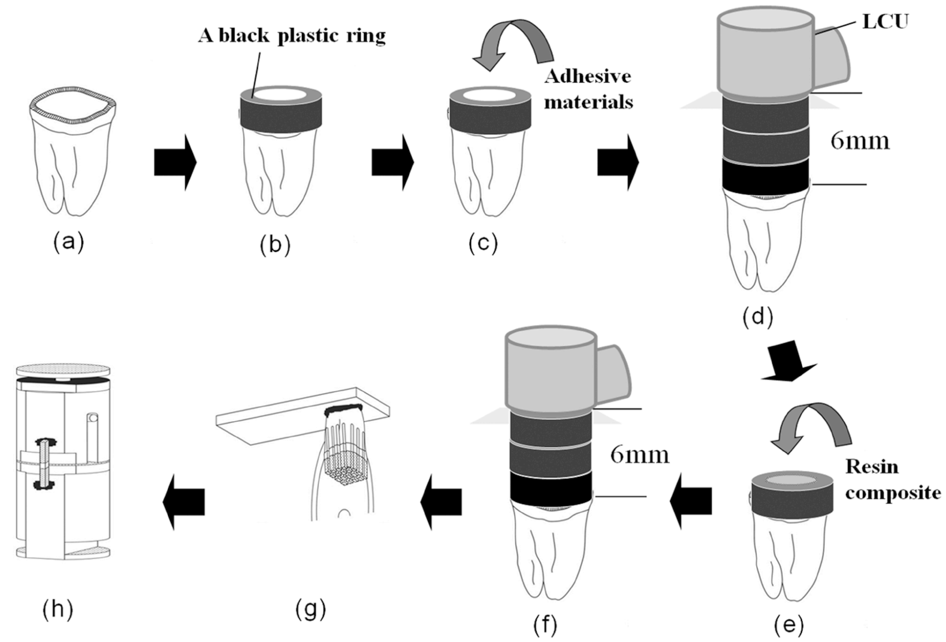


Fig. 3. Schematic showing the case of microtensile sample preparation for 6 mm irradiation distance subgroup. (a) Flat dentin surface were prepared on human third molars. (b) A plastic ring 2 mm in height and 8 mm in diameter was placed on the dentin surface. (c) The surface was treated with the adhesive. (d) Two plastic rings were added and the surface was irradiated for 20 s with the light curing unit. Irradiation distance was 6 mm. (e) The two rings on top were removed and composite was placed on the bonding resin by means of a bulk filling technique. The thickness of the resin composite was approximately 2 mm. (f) Two plastic rings were added again and the surface irradiated for 40 s. Irradiation distance was 6 mm. (g) All the plastic rings were removed and the specimen was cut into beams with bonded surface area of 7 mm x7 mm. (h) Microtensile bond test at a crosshead speed of 1 mm/min.

Table 2. Materials used in this study.

Material	Composition	Batch No.	Manufacturer
Bonding system			
Clearfil Liner Bond IIΣ	Primer A: MDP, HEMA, water, photoinitiator	00141B	Kuraray Medical, Tokyo, Japan
	Primer B: HEMA, water, photoinitiator	00139B	
	Bond A: MDP, dimethacrylates, microfiller, photoinitiator	00230A	
Light-cured resin composite			
Clearfil Photo Core	Bis-GMA, TEGDMA, fillers, dl-camphoroquinone	02070A	Kuraray Medical

MDP, 10-methacryloyloxydecyl di-hydrogen phosphate; HEMA, 2-hydroxyethyl methacrylate;
Bis-GMA, bisphenol A diglycidyl ether dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

Forty-five non-carious extracted human third molars were used in this study, the individuals' informed consent was obtained under a protocol approved by the Institutional Review Board of Tokyo Medical and Dental University (TMDU). The teeth were randomly distributed into three groups, based on the LCUs. After the occlusal third of each tooth was removed using a low-speed diamond saw (Isomet, Buhler, Lake Bluff, IL, USA), the dentin was ground using 600-grit Si-C papers to expose a flat dentin surface. The bonding area was demarcated on the prepared dentin surface of each tooth using a black opaque plastic ring, 2 mm in height and 8 mm in bore diameter. The dentin surface was conditioned with the primer agent for 30 s and thoroughly air dried. Then the bonding agent (Bond A) was applied to the primed dentin and air spread. In each group, there were five subgroups according to the irradiation distances of 2, 4, 6, 8, or 10 mm. During irradiation of the adhesive, the tip of the LCU was held at the desired distance from dentin surface by adding plastic rings on the top of the first ring (e.g. no additional ring for 2 mm and two additional rings for 6 mm irradiation distance subgroups). The adhesive was irradiated for 20 s using the corresponding LCU for each sample.

After polymerization of adhesive, plastic rings on top of the first one were removed and the composite was placed on the bonding resin by means of a bulk filling technique, pressed flat using a plastic matrix strip and a glass slide and light-cured for 40 s. The thickness of the composite was approximately 2 mm, regardless of the irradiation distance. Using the plastic rings again, LCU tip was held at the same distance for resin composite as that for the adhesive in each subgroup. After all the rings were removed, the specimens were stored in water at 37ºC for 24 hours, and then vertically cross-sectioned perpendicular to the bonded surface to obtain beams with bonded area dimensions of approximately 0.7 mm ×0.7 mm, using the diamond saw, under water cooling.

The beams were fixed by their ends to the microtensile testing jig of a universal testing machine (EZ test, Shimadzu Co., Kyoto, Japan) with a cyanoacrylate adhesive (Model Repair II Blue, Sankin Industry Co., Tokyo, Japan) and tested at a crosshead speed of 1 mm/min.

Failure mode analysis

After the bond test, the fractured surfaces were observed using a confocal laser scanning electron microscope (CLSM, 1LM21, Lasertec Corp., Tokyo, Japan). According to the observation, fracture modes were classified into four categories as follow: cohesive failure in dentin (CD), adhesive failure at the interface between resin and dentin (A), cohesive failure in resin (CR), and a mixed failure (M).

Statistical analysis

The experimental data were analyzed using SPSS statistical software package (ver. 11, SPSS Inc., Chicago, IL, USA). The light-intensity data and bond strength data were separately analyzed by two-way analysis of variance (ANOVA). The two factors analyzed were irradiation distance and LCU. Afterwards, pair-wise comparisons were performed using Bonferroni tests for subgroups within each group and among similar subgroups (at each irradiation distance) between groups (significance level $p<0.05$).

Results

Light characteristics

Figure 4 presents results of the spectrometry. All the LCUs showed similar emission spectra ranging from 420 to 520 nm, with the intensity peak around 470 nm. The digital camera images of the lateral projection patterns are shown in Fig. 5 and the light intensity values measured at each irradiation distance (Table 3) are graphically presented in Fig. 6. Two-way ANOVA revealed a significant interaction between the two factors of distance and LCU type. All the units showed a similar light intensity of 600 mW/cm^2 at the light curing tip (irradiation distance: 0). However, pair-wise comparisons showed that at other irradiation distances, there were significant differences between groups, with the experimental unit DP consistently showing the highest values. In general, the light intensity within each group decreased with increased irradiation distance. DP maintained the base light intensity for up to 3 mm, and showed the smallest range of changes in light intensity.

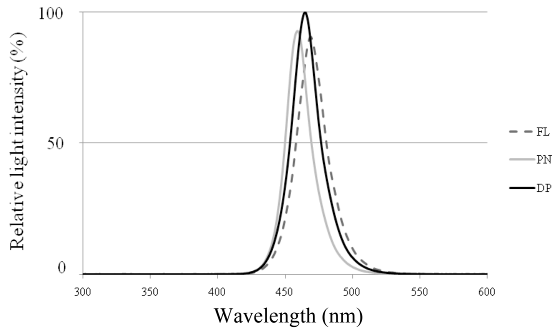


Fig. 4.

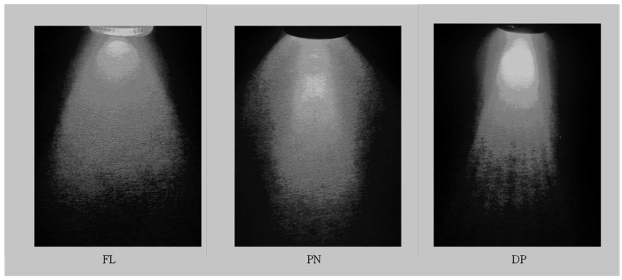


Fig. 5.

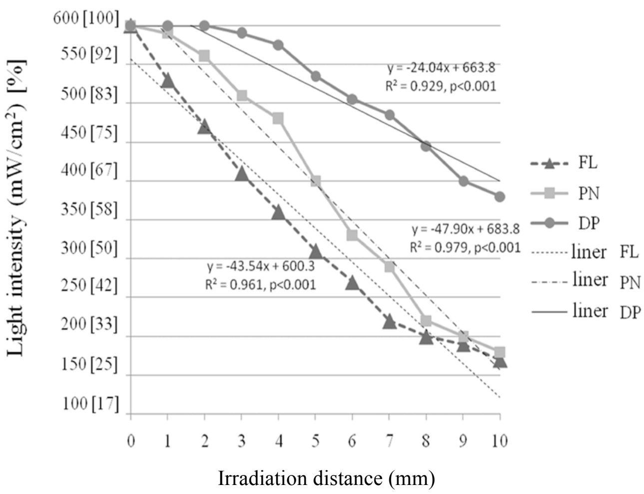
Fig. 4. Wavelength distribution of the LCU. The spectra were similar for all the three units.

Fig. 5. Light dispersion images obtained by the digital camera. Compared to FL and PN, DP assembly appeared to maintain a uniform irradiation and lower divergence angles of the outgoing light.

Table 3. The relationships between intensity of LCUs and irradiation distance intensity in mW/cm^2.

Irradiation distance (mm)	FL	PN	DP
0	600 (0) [A]	600 (0) [A, b]	600 (0) [A, c]
1	530 (10)	590 (0) [B, b]	600 (0) [B, c]
2	470 (0)	560 (10)	600 (0) [c]
3	410 (5)	510 (0)	590 (0) [c, d]
4	360 (0)	480 (10)	575 (5) [d]
5	310 (0)	400 (0)	535 (5)
6	270 (0)	330 (10)	505 (5)
7	220 (10)	290 (10)	485 (5)
8	200 (0) [a]	220 (0)	445 (15)
9	190 (10) [C, a]	200 (0) [C]	400 (0)
10	170 (5) [D]	180 (0) [D]	380 (0)

The numbers in parenthesis show standard deviations (SD). n=3. All values show mean (SD). Within the same row, means with the same capital superscript letter are not significantly different ($p>0.05$). All the other combinations of means are significantly different ($p<0.05$). Within the same column, means with the same lowercase superscript letter are not significantly different ($p>0.05$). All the other combinations of means are significantly different ($p<0.05$).



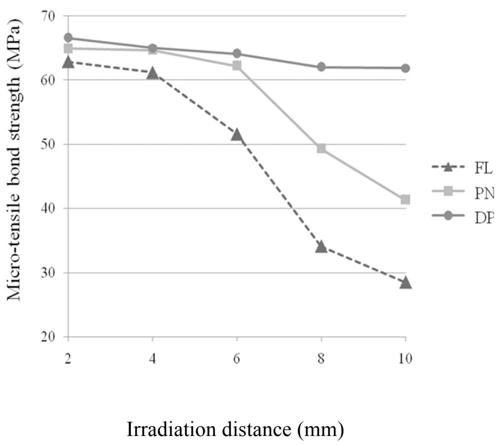


Fig. 6. **Fig. 7.**

Fig. 6. Light intensity in accordance with the irradiation distance. A significant liner relationship was found for each unit. The line slope (i.e. decrease rate) was smallest for DP.

Fig. 7. Microtensile bond strength in accordance with the irradiation distance. As the distance increased, the drop in bond strength was the slightest for DP.

Microtensile bond strength

The microtensile bond strength of resin composite to dentin is shown in Table 4 (Fig. 7). Two-way ANOVA revealed a significant interaction between the two factors. Pair-wise comparisons revealed that in case of FL there were significant differences between 2 and 8 mm, 2 and 10 mm, 4 and 8 mm, 4 and 10 mm, 6 and 8 mm, and 6 and 10 mm ($p<0.05$). For Pencure, there were significant differences between 2 and 8 mm, 2 and 10 mm, 4 and 8 mm, 4 and 10 mm, and 6 and 10 mm ($p<0.05$). On the other hand, in case of DP, there was no significant difference in bond strength among any subgroups of different distances ($p>0.05$). At 2, 4, and 6 mm irradiation distances, there were no statistically significant differences in the bond strength values produced by the three units. However, for irradiation distances 8 and 10 mm, there were significant differences between the three LCUs ($p<0.05$).

Table 4. Mean (SD) of microtensile bond strength of resin composite in MPa.

	Irradiation distance (mm)				
LCU	2	4	6	8	10
FL	62.9 (15.7)^{A,a}	61.2 (16.0)^{A,b}	51.6 (12.4)^{A,c}	34.1 (16.1)^{B,d}	28.5 (12.1)^{B,g}
PN	64.9 (14.4)^{C,a}	64.7 (11.2)^{C,b}	62.2 (19.7)^{C,D,c}	49.3 (13.4)^{E,F,e}	41.3 (14.4)^{F,h}
DP	66.6 (8.7)^{F,a}	65.0 (10.9)^{F,b}	64.1 (8.6)^{F,c}	62.0 (12.4)^{F,f}	61.9 (11.7)^{F,i}

n=30. Within the same row, means with the same capital superscript letter are not statistically different ($p<0.05$).
Within the same column, means with the same lower case superscript letter are not statistically different ($p<0.05$).

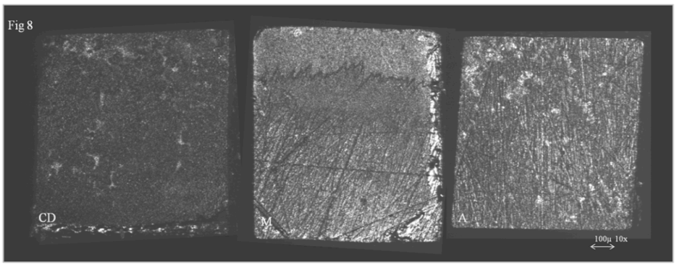


Fig. 8.

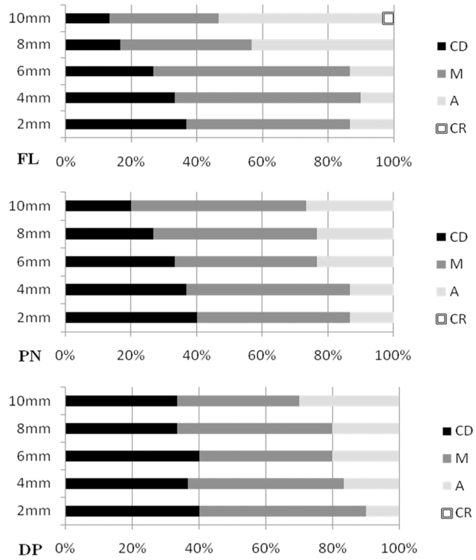


Fig. 9.

Fig. 8. Representative CLSM images of fractured surface on the dentin side after microtensile bond test at 10x magnification. CD, cohesive failure in dentin; M, mixed failure; A, adhesive failure.

Fig. 9. Percentage distribution of failure modes in the microtensile test for each LCU at different distances. CD, cohesive failure in dentin; M, mixed failure; A, adhesive failure; CR, cohesive failure within resin.

Failure mode

Representative image of each mode is shown in Fig. 8, and the percentage distribution of failure modes are presented in Fig. 9. The dominant observed failure mode in the current study was mixed. Only one of the specimens showed complete cohesive fracture in resin (FL, 10 mm). While cohesive failure in dentin was frequently observed for all subgroups of DP, the frequency of cohesive failures in dentin showed notable decrease at 8 and 10 mm irradiation distances compared to the base irradiation distance for both FL and PN.

Discussion

This study investigated the effects of curing light convergence and irradiation distance of three LED LCUs on the bond strength of resin to dentin. The experimental light-curing hand-piece in this study (DP) was based on the Dentaport ZX device, designed to emit a convergent light. While the power density of the commercially available device both PN and DP is 1,000 mW/cm^2, the power density of the unit in the current study was adjusted to 600 mW/cm^2 to match those of FL used in the experiment.

According to the inverse-square law, the apparent intensity of a light source should be proportional to the inverse of distance squared. However, it has been argued that the theory is true only with the light is emitted from a non-coherent point source, and that the relationship between intensity and distance may be dependent on characteristics of individual light sources.[3] Moreover, this study used a handheld dental radiometer to measure the intensity of light at different distances. While the results of light intensity measurement depend on several factors related to the light-source and measurement device, it has been reported that a halogen handheld radiometer can be appropriately used to determine and compare the clinically relevant irradiance of LED LCUs, when the diameter of light guides are in the same range (as shown on Table 1).[14]

In the present study, as the distance from light-cure tip increased, the extent of decline in the light intensity was the highest for FL, followed by PN and DP. Similar linear trends were observed between intensity and distance for FL and PN (Fig. 6); in this fashion, at 10 mm the intensity values of these units decreased to about 28% (170 mW/cm^2) and 30% (180 mW/cm^2) of the initial value, respectively. Previous studies[11,13,15-17] have demonstrated a similar trend of the percentage reduction for various LCUs.

DP could maintain 84% of its maximum intensity at 6 mm irradiation distance. This unit showed significantly higher light intensity at the distances over 2 mm, compared to FL and PN. Considering that all the three LCUs have non-fiber-optic tips and equal initial output intensities in the study, these findings should be attributed to the design of the tip. In FL and PN, lenses and metal reflective mirrors at the tip, conduct the light towards the target. In DP, however, the metal reflective mirrors have been eliminated from the structure, and a combination of two lenses composed of transparent polymer resin materials has been incorporated. These lenses have a higher light penetration rate and less distortion compared to the ordinary lenses, and their refractive index, shape and positioning are adjusted so that total internal reflection would occur to conduct the light. The assembly of lenses is designed to collimate and slightly concentrate the light beams emitted from the LED source, aimed at decreasing the dispersion and thus maintaining intensity of the light beam at the resin target area (Fig. 1). Light dispersion images obtained using the digital camera, confirm that this assembly could maintain a uniform irradiation and lower divergence angles of the outgoing light (Fig. 5).

In order to predict the actual effect of the LCU on the clinical performance of resin restorations, microtensile bond strength was also investigated in the present study. The composite was placed on the flat dentin, to eliminate the effect of contraction stress due to the polymerization shrinkage of light-cure composites.[18,19] The composite material was a translucent single-shade resin, selected for this study because irradiation distance was relatively long in some groups.

The emission spectrum of the light has been suggested as a contributing factor in curing efficiency.[20] The LED LCUs in this study had similar irradiation wavelength (Fig. 4), thus factors associated with light intensity should have affected the bonding efficiency of the resin materials.

At 8 mm and 10 mm, DP showed significantly higher bond strength values compared to FL and PN. It has been reported that a minimum light intensity of 300 to 400 mW/cm^2 is required to adequately cure a 1.5- to 2-mm increment of resin composite in the manufacturers' recommended curing time.[17] Results of the intensity measurement and microtensile bond strength of the present study support that recommendation. Interestingly, the first steep drops in the bond strength of FL (4-6 mm) and PN (6-8 mm) in Fig. 7, correspond to the irradiation distances where light intensity level fell below 350 mW/cm^2 on Fig. 6 (5-6 mm for FL and 6-7 mm for PN).

In an average occlusal preparation, the mean distance from the tip of a molar cusp to the pulpal floor is around 5 mm,[13] the irradiation distance may in fact be greater than this, due to the cavity location, tooth position or existence of proximal teeth. A previous study[9] has reported that the gingival floor of a Class II preparation could be as far as 6.3±0.7 mm away from the light tip. It should be noted that even prolonged curing times may not guarantee higher curing depths when the light-intensity has degraded.[21]

Increased incidence of adhesive failures and the single case of complete cohesive failure in resin (CR) observed for FL at 10 mm may indicate inadequate polymerization of the resin. The lower degree of conversion in monomers may leave uncured bonding resin, resulting in a weak bond to the tooth at the bottom of the restoration.[22] Incomplete polymerization may also increase cytotoxicity[23] and reduce the ultimate hardness,[2,10,24,25] elastic modulus,[26] and increase wear and breakdown at the margins.[27]

In the clinical practice, deeper and larger cavities are being restored with direct resin composites, and the importance of polymerization and adhesion at the deep cavity is evident. The clinician should be aware of the probable performance level and potential limitations of the light-curing units in order to achieve the best results with adhesive restorations.

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References

1. Katahira N, Foxton RM, Inai N, Otsuki M, Tagami J. Comparison of PAC and QTH light sources on polymerization of resin composites. Am J Dent 2004; 17: 113-7.
2. Hubbezoğlu I, Bolayir G, Doğan OM, Doğan A, Ozer A, Bek B. Microhardness evaluation of resin composites polymerized by three different light sources. Dent Mater J 2007; 26: 845-53.
3. Aravamudhan K, Rakowski D, Fan PL. Variation of depth of cure and intensity with distance using LED curing lights. Dent Mater 2006; 22: 988-94.
4. Sakaguchi RL, Douglas WH, Peters MG. Curing light performance and polymerization of composite restorative materials. J Dent 1992; 20: 183-8.
5. Kramer N, Lohbauer U, Garcia-Godoy F, Frankenberger R. Light curing of resin-based composites in the LED era. Am J Dent 2008; 21: 135-42.
6. Watts DC, Amur O, Combe EC. Characteristics of visible-light-activated composites systems. Br Dent J 1984; 156: 209-15.
7. Warren K. An investigation into the micro hardness of a light cured composites when cured through varying thickness of porcelain. J Oral Rehabil 1991; 17: 327-34.
8. Sadr A, Shimada Y, Tagami J. Effects of solvent drying time on micro-shear bond strength and mechanical properties of two self-etching adhesive systems. Dent Mater 2007; 23: 1114-9.
9. Price RB, Derand T, Sedarous M, Andreou P, Loney RW. Effect of distance on the power density from two light guides. J Esthet Dent 2000; 12: 320-7.
10. Rueggeberg FA, Caughman WF, Curtis JW, Davis HC. Factors affecting cure at depths within light-activated resin composites. Am J Dent 1993; 6: 91-5.
11. Prati C, Chersoni S, Montebugnoli L, Montanari G. Effect of air, dentin and resin-based composite thickness on light intensity reduction. Am J Dent 1999; 12: 231-4.
12. Yamauti M, Nikaido T, Ikeda M, Otsuki M, Tagami J. Microhardness and Young's modulus of a bonding resin cured with different curing units. Dent Mater J 2004; 23: 457-66.
13. Vandewalle KS, Roberts HW, Andus JL, Dunn WJ. Effect of light dispersion LED curing lights on resin composite

polymerization. J Esthet Restor Dent 2005; 17: 244-54.
14. Roberts HW, Vandewalle KS, Berzins DW, Chariton DG. Accuracy of LED and halogen radiometers using different light sources. J Esthet Restor Dent 2006; 18: 214-22.
15. Pires JA, Cvitko E, Denehy GE, Swift EJ. Effects of curing tip distance on light intensity and composite resin microhardness. Quintessence Int 1993; 24: 517-21.
16. Meyer GR, Ernst C, Willershausen B. Decrease in power output of new light-emitting diode (LED) curing devices with increasing distance to filling surface. J Adhes Dent 2002; 4: 197-204.
17. Felix CA, Price RB. The effect of distance from light source on light intensity from curing lights. J Adhes Dent 2003; 5: 283-91.
18. Felizer AJ, de Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restration. J Dent Res 1987; 66: 1636-9.
19. Kishikawa R, Koiwa A, Chikawa H, Cho E, Inai N, Tagami J. Effect of cavity form on adhesion to cavity floor. Am J Dent 2005; 18: 311-4.
20. Nomoto R. Effect of light wavelength on polymerization of light-cured resins. Dent Mater J 1997; 16: 60-73.
21. Rode KM, Kawano Y, Turbino ML. Evaluation of curing light distance on resin composite microhardness and polymerization. J Adhes Dent 2007; 32: 571-8.
22. O'Keefe KL, Powers JM. Adhesion of resin composite core materials to dentin. Int J Prosthodont 2001; 14: 451-6.
23. Caughman WF, Caughman GB, Shiflette RA. Correlation of cytotoxicity, filler loading and curing time of dental composite. Biomaterials 1991; 12: 737-40.
24. Correr Sobrinho L, De Goes MF, Consani S, Sinhoreti MAC, Knowles JC. Correlation between light intensity and exposure time on the hardness of composite resin. J Mater Sci Mater Med 2000; 11: 361-4.
25. Nayif MM, Nakajima M, Foxton RM, Tagami J. Effect of light irradiation time on the mechanical properties of two flowable composites with different initiation systems in bonded and unbonded cavities. Dent Mater J 2007; 26: 687-93.
26. Harris JS, Jacobsen PH, O'Doherty DM. The effect of curing light intensity and test temperature on the dynamic mechanical properties of two polymer composites. J Oral Rehabil 1999; 26: 635-9.
27. Ferracane JL, Mitchem JC, Condon JR, Todd R. Wear and marginal breakdown of composites with various degree of cure. J Dent Res 1997; 76: 1508-16.

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