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Effect of different light sources in combination with a light-transmitting post on the degree of conversion of resin composite at different depths of simulated root canals

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Abstract – *Aim:* The aim of this study was to evaluate the degree of conversion (DC) of composite resin at different depths of simulated immature root canals using light-transmitting plastic post (LTPP) and three different light sources. *Methodology:* Composite resin was packed into 60 black plastic cylinders 12 mm in length with 4 mm internal diameters to simulate immature root canals. LTPPs were inserted into half of the simulated canals and the other half acted as controls. Both the simulated canals with LTPPs and the controls were divided into three groups of 10, and each group was cured using either a quartz–tungsten–halogen (QTH), light-emitting diode (LED), or plasma arc (PAC) curing unit. Specimens were sectioned in three horizontally 24 h after curing to represent cervical, middle, and apical levels. DC for each section of composite resin was measured using a Fourier transform infrared spectrophotometer, and data were analyzed using three-way ANOVA and Tukey tests. *Results:* At the cervical level, no significant differences were found between specimens cured using different light sources or between specimens with and without LTPPs ($P > 0.05$). However, DC was significantly higher in specimens with LTPPs than in those without LTPPs at both the middle and apical levels ($P < 0.05$). The mean DC of all specimens with LTPPs was significantly higher than that of specimens without LTPPs ($P < 0.05$). PAC unit showed lower DC than QTH and LED units at both the middle and apical levels; however, the differences were not statistically significant ($P > 0.05$). *Conclusions:* The results of this study suggest that the use of a LTPP increased the DC of composite resin at the middle and apical levels of simulated immature root canals, but that DC was independent of type of light source.

The restoration of endodontically treated teeth with excessive loss of mineralized tissues still presents a challenge to clinicians. The risk of fracture in such cases is high because the strength of the treated tooth is directly related to the amount of the remaining dentin (1). Therefore, any canal restoration technique should seek to reinforce the remaining tooth structure.

Many dental injuries in immature teeth may result in a loss of tooth vitality and incomplete root formation. Andreasen et al. (2) showed that calcium hydroxide therapy weakens the root structure in the long term. Some type of post and core is often indicated in order to assist in the retention of the final restoration (3). However, posts and cores used in situations with little remaining root dentin or thin root walls may have a compromised prognosis (4). The weakness of these teeth makes some type of reinforcement necessary.

One way of strengthening remaining root structure that has been mentioned by several studies is the use of composite resin to replace lost root dentin (5, 6). The use of self-cured composite resin can be a problem, especially when used as root canal reinforcement, because of the difficulty in controlling curing time. In contrast, light-cured composites allow for sufficient time and control to ensure that the restorative material is properly placed in the canal. Several types of curing units are available today for routine use in the light activation of composite resins. These include quartz–tungsten–halogen (QTH), light-emitting diodes (LED), plasma arcs (PAC), and laser (7, 8).

The ultimate physical and mechanical properties of resin composites are greatly affected by the degree of conversion (DC) in the cross-linked polymeric system (9). This may in turn affect the fracture strength of restorative material (10). In light-activated materials, DC varies inside the material mass, partly because of its dependence on light energy for activation (11). Because of limited light transmission, complete polymerization cannot be guaranteed at depths >5 mm (12).

Light-transmitting plastic posts (LTPP) were introduced to aid in the transmission of the curing light and ensure adequate polymerization of composite resin at deeper levels within the root canal. The microhardness of composite resins in simulated root canals with LTPPs has been evaluated by a previous study (13). However, the DC of composite resins used with LTPPs in simulated root canals has not been investigated.

The aim of this study was to evaluate the DC of composite resin in different depths of the simulated immature root canals using LTPP and three different light sources.

Material and methods

Composite resin was packed in a darkroom into 60 black plastic cylinders 12 mm in length with 4 mm internal diameters to simulate immature root canals. The cylinders were then divided into two groups: Group A: LTPPs were inserted using a parallelometer, Group B: LTPPs were not used and the group acted as control. Both groups were then divided into three subgroups according to the curing units used: Subgroup 1: QTH; Subgroup 2: LED; Subgroup 3: PAC (Table 1). The bulk technique was used for all groups. Tip-to-tooth curing distance was standardized by placing the tip of the light source 2 mm away from the composite resin for all specimens. To prevent overheating, a 5-min pause was taken between curing specimens. The groups, curing time, manufacturer of composite resin and light-curing units were given in Table 1.

Immediately following polymerization, the LTPPs were removed, and the specimens were stored at 37°C in light-proof boxes. After 24 h, each specimen was sectioned horizontally using a diamond saw. Sectioning was performed at approximately 4-mm intervals to represent cervical, middle, and apical levels.

Each specimen was pulverized into a fine powder using a mortar and pestle, and potassium bromide (KBr) pellets were prepared by mixing 50 μg of the ground powder with 5 mg of KBr powder (Fluka, Sigma-Aldrich, St. Louis, MO, USA) using a press (Spex Industries Inc., Metuchen, NJ, USA) at 10 tons. Pellets were also prepared from unpolymerized composite resin mixed with pure KBr in a darkroom. Absorbance peaks for each pellet were recorded using a Fourier transform infrared spectrophotometer (FTIR) (Spectrum One; Perkin-Elmer, Waltham, MA, USA). Each spectrum was acquired from 100 scans at a resolution of 4 cm^{-1}. DC was calculated by comparing the ratio of aliphatic to aromatic carbon-carbon double bond (C=C) peak intensities of cured and uncured samples using the following formula:

$$\begin{aligned}\mathrm{DC}(\%) = [1 - (\mathrm{C} = \mathrm{C}_{1638}/\mathrm{C} = \mathrm{C}_{1609})\\ \text{of cured resin}/(\mathrm{C} = \mathrm{C}_{1638}/\mathrm{C} = \mathrm{C}_{1609})\\ \text{of uncured resin}] \times 100\end{aligned}$$

Data were analyzed using three-way analysis of variance (ANOVA), with DC as the dependent variable and LTPP, type of curing unit, and root region as the fixed factors. *Post hoc* comparisons were made using Tukey's test.

Results

DC means and standard deviations for all parameters (LTPP, light source, and root region) are presented in Table 2. At the cervical level, no significant differences were found among DCs of specimens cured using different light sources or between specimens with and without LTPPs ($P > 0.05$). However, at both the middle and apical levels, DC was significantly higher in specimens with LTPPs than in those without LTPPs ($P < 0.05$). In addition, the mean DC of specimens cured with a PAC unit was lower than the DCs of specimens cured using QTH and LED units at both the middle and apical levels; however, the differences were not statistically significant ($P > 0.05$). The highest mean DC was obtained at the cervical level using LED unit without LTPP, whereas the lowest mean DC was obtained at the apical level using PAC unit without LTPP.

Three-way ANOVA revealed that DC was significantly influenced by the use of LTPP and by the root regions ($P < 0.05$). Three-way ANOVA showed that there were no interactions between using LTPP and different curing units and between different curing units and root region ($P > 0.05$). However, strong interaction was present between using LTPP and root region ($P < 0.05$).

Discussion

Clinicians have a number of alternative restorative materials from which to choose when faced with the

Table 1. The groups, resin composite and light-curing units used in this study

	Subgroups and light-curing units	Manufacturer	Light intensity (mw cm^{-2})	Curing time (s)
60 Plastic cylinders, filled with composite resin (Clearfil AP-X, Shade A2; Kuraray, Tokyo, Japan)				
Group A: LTTP (No.4 Luminex System; Dentatus, New York, NY, USA) n = 30	1. Blue Swan Digital High Power QTH (n = 10)	Dentanet, Istanbul, Turkey	1000	90
	2. Blue LED Curing Unit (n = 10)	Dentanet, Istanbul, Turkey	1100	90
	3. Remecure CL15 PAC (n = 10)	Remedent, Deurle, Belgium	1850	12
Group B: control n = 30	1. QTH (n = 10)	Same as Group A1		
	2. LED (n = 10)	Same as Group A2		
	3. PAC (n = 10)	Same as Group A3		

LTPP, light-transmitting plastic post; QTH, quartz–tungsten–halogen; LED, light-emitting diode; PAC, plasma arc.

Table 2. The mean and standard deviation values of DC obtained using all parameters (LTPP, light sources and the root regions)

	Cervical	Middle	Apical
LTPP			
QTH	63.17 ± 7.56[ab]	47.74 ± 10.18[cd]	32.01 ± 8.52[ef]
LED	61.66 ± 5.91[ab]	52.69 ± 10.25[bcd]	30.43 ± 8.96[f]
PAC	62.90 ± 5.91[ab]	44.03 ± 5.00[de]	21.58 ± 3.30[fg]
Control			
QTH	59.07 ± 18.82[abc]	15.31 ± 6.47[gh]	5.97 ± 4.99[hi]
LED	66.66 ± 7.73[a]	11.73 ± 6.53[ghi]	10.92 ± 7.57[ghi]
PAC	62.70 ± 5.50[ab]	8.85 ± 4.19[hi]	1.92 ± 0.60[i]

Lower case letters represent significant differences with regard to factor root region ($P < 0.05$).
LTPP, light-transmitting plastic post; DC, degree of conversion; QTH, quartz–tungsten–halogen; LED, light-emitting diode; PAC, plasma arc.

necessity of restoring missing tooth structure. The use of dentin-bonded resins for root reinforcement aims to improve fracture resistance by increasing the internal thickness of the root through the adhesion of a resin composite material that is elastically compatible with dentin (13).

The ultimate physical and mechanical properties of a polymeric restorative material – and thus its degree of fracture resistance and clinical performance – are greatly affected by its degree of polymerization (9). Studies have shown that polymerization of light-cured composite resins is significantly affected by a variety of factors. Light source-related factors include spectral output, light intensity, curing mode, heating of the light source, and tip-to-tooth curing distance (14, 15). Composite-related factors include resin composition, filler particle size, load and distribution as well as shade and translucency (16). In the present study, the standard mode of each curing unit was used, with a tip-to-tooth distance of 2 mm for standardization, and overheating of the light source was prevented by waiting 5 min between each polymerization. In addition, the same type of resin composite in the same shade was used for all specimens. Earlier studies recommend longer or extended curing times in order to improve the DC of composite resin used for root reinforcement (13, 17). Therefore, the exposure time was increased by three times the manufacturer's recommendations for all light sources in this study.

Techniques used to measure DC include FTIR spectroscopy (18), FT-RAMAN spectroscopy (19), electron paramagnetic resonance (EPR) (20), nuclear magnetic resonance (NMR) (21), differential scanning calorimetry (DSC) (21), and differential thermal analysis (DTA) (18). FTIR measures the decrease in vinyl (C = C) stretching vibrations in materials directly before and after curing (18) and has become a very popular technique for evaluating the DC of dental resin systems (22). It is said FTIR has been proven to be a powerful technique for the evaluation of DC in dental composites (23); therefore, FTIR was used in this study.

Use of the shortest irradiation time necessary to achieve the necessary level of performance in a light-cured resin or resin composite is important for dentists and patients in terms of reduced chair time. (24) PAC light-curing units were introduced as time-saving devices for use in curing resin composites; however, Feng et al. (24) have shown that the use of PAC units result in lower DCs when compared to QTH units. A previous study comparing QTH and LED units have found no statistical differences between the two (8). The findings of the present study showed that no statistical differences in the mean DCs of specimens cured using QTH, LED, and PAC units at cervical region (Table 2). This could be attributable to the longer exposure time and the closeness of curing units. However, in the present study, evaluation of DC by root level showed that differences in DC values for the middle and apical root levels did not vary significantly by light-curing unit, although the mean DC for PAC-cured specimens was still lower than those of QTH- and LED-cured specimens (Table 2).

LTPPs were introduced with the aim of transmitting light further inside the root canal, thus making it possible to increase the DC of light-cured composite resin at greater depths. In the present study, mean DC values were significantly higher in specimens with LTPPs compared to those without LTPPs. Although the use of an LTPP did not affect the DC of composite resin at the cervical level, the use of an LTPP significantly increased the DC of composite resin at the middle and apical levels. Whereas DCs, in specimens cured without LTPPs, for the middle and apical levels ranged from 9–15% to 2–11%, respectively, DCs were significantly higher in specimens cured with LTPPs (44–53% for the middle level and 22–32% for the apical level). Our study found a strong correlation between the use of an LTPP and an increase in DC in the deeper layer. This finding is in agreement with previous studies (13, 25). Lui (26) reported adequate intraradicular DC of composite resin at a depth of 11 mm using an LTPP with an exposure time of 40 s. In another experiment in simulated root canals, Yoldas and Alacam (13) showed greater photoactivation of composite used with an LTPP. The authors observed polymerization up to a depth of 14 mm with a light exposure time of 90 s. Nevertheless, even with the use of an LTPP, DC was comparatively lower in regions further away from the LCU. According to Teixeira et al. (27), although light-transmitting posts are capable of transmitting light to considerable depths, the amount of transmitted light is < 40% of the incident light. This may explain the fact that even with the use of longer light exposure times, the present study also found lower mean DCs in the middle and apical regions when compared to the cervical region.

Recently, dual-cured resin composites have become available for the dental market. Dual-cured resins possess favorable characteristics of both self-cured and light-cured resins; however, studies have shown that some dual-cured resins may not achieve an adequate DC in the absence of light (28). For this reason, light curing is recommended for dual-cured resins (29). Dual-cured resins have been shown to have a DC of approximately 60% (25, 28, 30) The present study obtained similar DC values for light-cured composite resin at the cervical layer (59–66%). Additional research is needed to examine the differences in DCs of dual-cured and light-cured resin composite when used to reinforce immature root canals.

Conclusion

Within the limits of this *in vitro* study, DC was not affected using different curing units. The DC of composite resin was increased using an LTPP at both the middle and apical third of simulated immature root canals. However, the use of LTPP did not sufficiently increase the DC of composite at deeper levels. These results emphasize the need to develop new strategies that optimize light transmission for composite polymerization in canal apical regions.

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