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Effects of light attenuation by fibre posts on polymerization of a dual-cured resin cement and microleakage of post-restored teeth

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SUMMARY

Objectives: The influence of light transmitting ability of different fibre posts on the polymerization of a dual-cured resin cement, and the further microleakage of the post-restored endodontically treated teeth were examined.
Methods: An LED curing light was used as light source and the measurements of 470 nm irradiances were made at 1 mm intervals along the posts (P-Lux, P-White, and P-Steel). The polymerization of a dual-cured resin cement surrounding the posts at five depths (0, 2, 5, 8, and 10 mm) from the top was evaluated using micro-Raman spectra after 40 s light-curing. Meanwhile, 36 human single-rooted endodontically treated teeth were randomly divided into three groups and restored with these posts and the cement according to the manufacturers' instructions. Microleakages of the post-restored teeth were compared using an electrochemical measurement system on three consecutive days, and statistically analysed using nonparametric tests.
Results: Light transmission through fibre posts was exponentially reduced as the depth increased ($p < 0.05$, $R^2 > 0.95$), and the polymerization of the resin cement beyond the depth of 5 mm significantly declined for all specimens ($p < 0.05$). Fibre posts displayed higher value of light transmission, exhibited a higher polymerization rate of surrounding resin cement, and also demonstrated less microleakage; whilst P-Steel posts had the lowest polymerization rate and produced higher microleakage ($p < 0.017$).
Conclusions: The effective radiance along the post was diminished exponentially, which features the insufficient polymerization of a dual-cured resin cement surrounding the posts at apical region and might therefore influence the microleakage of post-restored teeth.

1. Introduction

The endodontically treated teeth with extensive loss of coronal structure often require posts and cores for retention of final restorations.[1] Due to the demand for aesthetics and the development of all-ceramic crown, the use of non-metallic posts has recently increased in popularity.[2] The aesthetic posts exhibit not only aesthetic results, but also good mechanical properties justifying their clinical usage.[3]

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Basically aesthetic fibre posts contain a high volume percentage of continuous unidirectional fibres embedded in a polymer matrix.[4–6] These fibres reinforce the composite posts and allow more light transmission into the root canals. dos Santos Alves Morgan et al.[4] measured the quantity of luminous energy transmitted to the apical terminal of post, and found that the transmitted light significantly decreased as the post length increased. However, Goracci et al.[5] claimed that the ability of the post to transmit the light radially is rather critical than transversely for cement polymerization. They measured the quantities of photons at three different levels (coronal, middle, and apical) along the posts, and proposed a linear negative correlation of photon counts amongst different levels.Resinous cements are thought to be more effective for post cementation owing to recent improvements in dental adhesives, which not only retain the post but also reinforce the tooth.[7] However, the use of self-cured resin can be a problem due to the insufficient working time. Light-curing resin cements possess better handling properties, but light transmission through the bulk of intraradicularly resin can be limited.[8,9] Recently, dual-cured resin cement has been widely used in cementation of aesthetic posts.[10,11] It was developed to overcome unfavourable characteristics of self-cured and light-cured resin cements. Nevertheless, when dual-cured resin is not exposed to light or light is attenuated, it had been shown to decrease the degree of conversion (DC).[12–16]

An insufficient DC of a resin may lead to unfavourable mechanical properties and biocompatibility.[17–20] Consequently the solubility and permeability of resin cement layer to water can be challenged, which shall then alter the microleakage of the post-restored root canals. The purposes of this study were, therefore, to examine the light attenuation through post systems, and investigate its effect on the DC of a dual-cured resin cement surrounding the posts and the microleakage of post-restored teeth. We hypothesized that the light attenuation by aesthetic posts can retard the DC of dual-cured resin cements and subsequently increase leakage potential of post-restored teeth.

2. Materials and methods

Three post systems with different light-transmission properties were selected for this study, namely Parapost Fiber Lux (P-Lux), Parapost Fiber White (P-White), and conventional metal Parapost (P-Steel) (Table 1). All of these posts were from the same company (Coltène/Whaledent, Cuyahoga, OH, USA) and had the same diameter (1.25 mm).

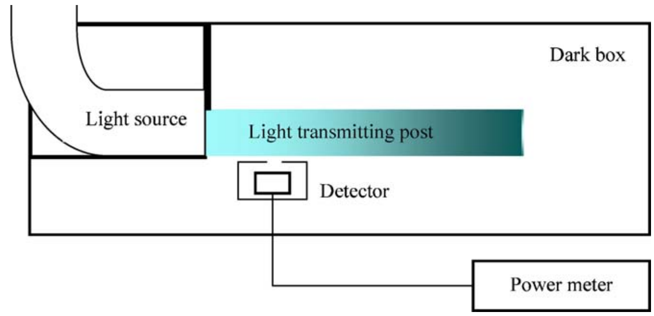

Fig. 1 – Schematic illustration of radiance measurements along the post using a power metre. The light curing unit was attached to the top of the post in such a way that the post was the only path through which light could pass into the dark box.

2.1. *Effective radiance surrounding the posts*

Ten posts of each group were cut to 10 mm in length to obtain a uniform parallel shape. A post was placed into a custom-made black plastic box to measure the light transmitted through it (Fig. 1). The box had an upper and lower chamber, and the upper chamber had two compartments. The post was inserted into the right compartment and secured with black silicon and adhesive to ensure that the post was the only path for illumination to pass through from the left chamber. An LED light-curing unit (Elipar^{TM} Freelight 2, 3M ESPE, St. Paul, MN, USA) which served as the light source was placed in the left compartment and contacted the top of the post.

The light irradiance through the post was measured by a power metre (1930-C, Newport, Irvine, CA, USA) and a light detector (918-UV, 190–1110 nm, Newport). The power metre was set to a wavelength of 470 nm, and the light detector was covered by a black mount with an aperture window of 1.25 mm in diameter. To standardize the light source, a brand new light-curing unit was used. During the experiment, a 20-s exposure of the curing unit was used, and the power density value at 10 s was recorded.

Radiance was measured at 1-mm intervals along the posts, from top to bottom. Meanwhile, the radiance at the apical limit, after the light had passed through the entire post (10 mm), was recorded as well. To calculate the light intensity of the irradiance ($\mu W/cm^2$), the optical power value (μW) measured with a power metre was divided by the aperture area. The output intensity of the LED light-curing unit was constantly monitored (1023 mW/cm^2) throughout the experiment.

Table 1 – Post systems and the dual-cured resin cement used in the study.

Material	Code	Composition	Manufacturer	Lot. no.
Parapost Fiber Lux	P-Lux	60% Glass fibre, 40% resin	Coltène/Whaledent, Cuyahoga, OH, USA	MT-40890
Parapost Fiber White	P-White	42% Glass fibre, 29% resin, 29% filler	Coltène/Whaledent, Cuyahoga, OH, USA	MT-53081
Parapost	P-Steel	Stainless steel	Coltène/Whaledent, Cuyahoga, OH, USA	MT-25887
Duolink (translucent)	Duolink	Monomer: Bis-GMA	Bisco, Schaumburg, IL, USA	0700003787

2.2. DC of the dual-cured resin cement surrounding the posts

A 10-μl pipette tip (4840, Corning Inc., Corning, NY, USA) was used to simulate a root canal. The experimental post was luted with a dual-cured resin cement (Duolink, Bisco, Schaumburg, IL, USA) into the canal, and irradiated by an LED light-curing unit (Elipar™ Freelight 2) for 40 s at room temperature (25 °C). Before post cementation, the lateral walls of the simulated root canals were covered with black adhesive tape to avoid any external light irradiation. Five specimens were prepared for each group, and the specimens were stored dry for 24 h in a light-proof container at 37 °C. The simulated root canals were then embedded in aluminium moulds with Ortho resin (Dentsply De Trey, Weybridge, Surrey, UK), and sectioned in parallel along the long axis of the post using a low-speed diamond saw (Isomet; Buehler, Lake Bluff, IL, USA), and polished to high gloss with a grinder (Ecomet 3; Buehler) using a series of silicon carbide papers to 2000-grit with copious water.

Raman spectra of the dual-cured resin at five different depths (0, 2, 5, 8, and 10 mm from the top) along the post were obtained by micro-Raman spectroscopy (Ventuno; Jasco, Tokyo, Japan) to measure the DC. Specimens were excited by a 30-mW green (532 nm) solid-state laser through a microscopic objective (×100). The pixel resolution was 1.3 cm^{-1}. The spectra were obtained in the 1830–700 cm^{-1} range, with a 15-s irradiation time and accumulation of 10 times. JASCO Spectra Manager software (Jasco) was used for data processing. Spectra were repeatedly acquired at the midpoint of each depth of the resin cement.

DC, the percentage of vinyl functions converted to aliphatic functions, was evaluated by comparing the vibrational band of the residual unpolymerized methacrylate C=C at 1640 cm^{-1} with the aromatic C=C stretching band at 1610 cm^{-1}. The aromatic C=C was used as an internal standard, and the DC of the resin at each depth was calculated by the following equation:[21]

$$DC\,(\%) = 100 \times \left[1 - \left(\frac{R_{polymerized}}{R_{unpolymerized}}\right)\right];$$

where R is (the peak height of C=C at 1640 cm^{-1}/peak height of the aromatic group at 1610 cm^{-1}).

2.3. Microleakage test

According to a protocol approved by the Institutional Review Board of the Taipei Veterans General Hospital, single-rooted human teeth with fully developed roots were stored in a 0.2% thymol solution at 4 °C after extraction, and the stored teeth were used for testing within 1 month. Teeth with defects or multiple canals were excluded, and the selected teeth were radiographically evaluated in both the mesiodistal and the buccolingual planes. Thirty-six teeth with similar sizes and shapes were selected, and their clinical crowns were removed at the cementoenamel junction (CEJ) using a low-speed diamond saw (Isomet), leaving a root of approximately 14 mm in length.

The working lengths of the root canals were established at 1 mm from the apical foramen by a #10 K-file. Root canals were prepared by the same operator with a ProFile (Dentsply, New York, NY, USA) following this sequence: Orifice Shapers #2 and #3; ProFile .06 taper #30, #25, and #20; ProFile .04 taper #30, #25, and #20; and ProFile .06 taper #20, #25, #30, #35, and #40. The canal was prepared according to the manufacturer's recommendations in a crown-down fashion. A #10 K-file was used between each ProFile to verify the apical patency. Two millilitres of the irrigant, 2.5% NaOCl, was delivered with a 25-gauge needle between each file size. After instrumentation, the root canals were filled with gutta-percha cones (Hygenic Corp., Akron, OH, USA) and Roth's 801 canal sealer (Roth International, Chicago, IL, USA) using a lateral compaction technique. The coronal 3 mm of gutta-percha was removed with hot pluggers, and the space was filled with Caviton (GC Corp., Tokyo, Japan). Specimens were then stored at 37 °C and 100% humidity for 1 week before post space preparation.

The length of the post was standardized to nearly 12 mm by cutting off the coronal portion. Gutta-percha was removed with 1.25-mm diameter drills supplied with the post systems, leaving a post space to a depth of 10 mm. Following the manufacturer's instructions, the canal walls were etched with 32% phosphoric acid (Uni-etch, Bisco) for 15 s, rinsed with 10 ml of deionized water, and gently blot-dried with a large paper point, leaving the dentine visibly moist. The post spaces were then primed with 2 coats of All-Bond 2 (Bisco), blot-dried with paper points and luted with one of the three post systems using dual-cured resin cement (Duolink). Excess cement was removed with an explorer, and the specimen was irradiated

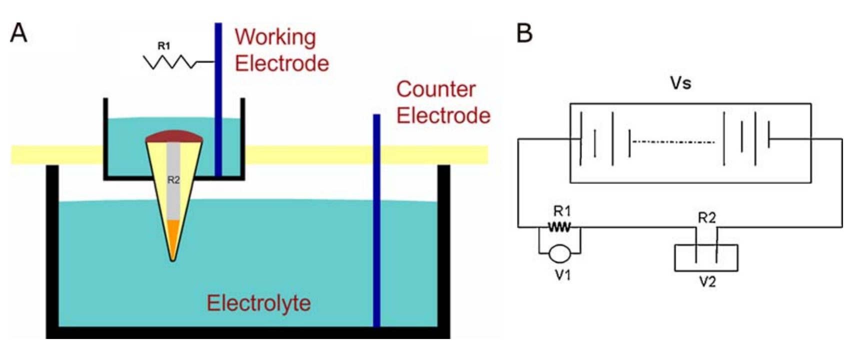

Fig. 2 – Schematic drawing of (A) the electrochemical test apparatus and (B) the circuit diagram. Vs: 6.2 V; R1: 50.2 kΩ; R2: impedance of the specimen.

with an LED light-curing unit (Elipar™ Freelight 2) on top of the post for 40 s at room temperature. The core was reconstructed with a dual-cured composite (Bis-Core, natural shade, Bisco) incrementally to 2 mm in height and with an emergence profile consistent with that of the root. The core was light-cured for 20 s, and the specimen was then stored at 37 °C and 100% humidity for 24 h before the microleakage measurements.

A modified electrochemical method was used to measure tooth microleakage (Fig. 2).[22,23] Roots were completely coated with two layers of nail varnish 1 mm from the apex to the CEJ. The coronal part of the root was embedded in silicone through the bottom of a plastic cylinder, which was filled with 0.9% NaCl as an electrolyte. The cylinder with the root was then mounted in the lid of a plastic electrochemical cell filled with NaCl electrolyte. The apical part of the root coming out of the box was submerged in the electrolyte to a depth of 5 mm. Copper electrodes of 1.43 mm in diameter were placed into the upper and lower chambers of the electrochemical cell. The two electrodes were connected via a function generator (GFG-8255A, GW Instek, Taipei, Taiwan) to a digital multimeter (GDM-8245, GW Instek). A 6.2-V DC current with a frequency of 62 Hz was applied. The voltages of the reference resistance (50.2 kΩ) and specimen were measured to enable calculation of the impedance of the specimen. Measurements were made on days 0, 1, and 3. Between analyses, the specimen was reimmersed in the tightly closed box containing a 0.9% NaCl solution. A higher impedance value means that there was less fluid connection between the coronal and apical areas of the specimen.

The consistency of the electrochemical microleakage system was verified by the negative and positive controls before a specimen was measured at each time point. The plastic insulating bars were used as negative controls, and instrumented teeth without sealing served as positive controls.

2.4. *Statistical analysis*

Because the normality assumptions of the data were met, the light intensity at different depths of different posts were analysed by two-way analysis of variance (ANOVA) (SPSS vers. 13.0, Chicago, IL, USA) followed by Tukey's post hoc tests ($p < 0.05$). Whilst the normality of the data distribution of the DC of the resin cement and the impedance measured in the microleakage tests were rejected by Shapiro–Wilk tests ($p < 0.05$); thereafter, the data were compared and statistically analysed using nonparametric tests.

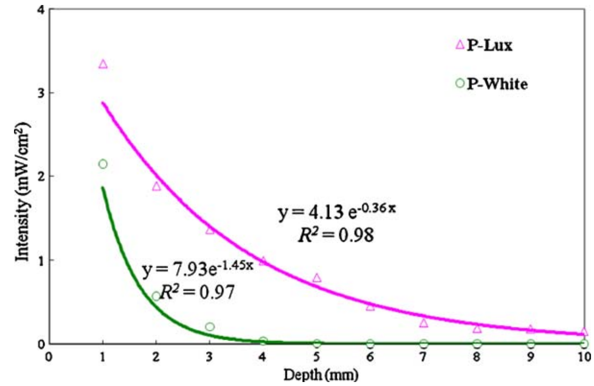

Fig. 3 – Light attenuation (at 470 nm wavelength) as a function of depth along two aesthetic posts.

3. Results

3.1. *Effective radiance surrounding the posts*

The mean and standard deviation of the light intensity along the various posts tested are summarized in Table 2. Statistically significant differences in light intensity values amongst groups were noted at each depth ($p < 0.001$). The P-Lux group displayed the highest value of light transmission, followed by the P-White group. Light attenuation with depth was shown for the two aesthetic posts, whilst there was no light transmission through the P-Steel post.

There was a significant negative exponential relationship between the depth and light intensity in both aesthetic posts, P-Lux and P-White (Fig. 3). Applying Lambert–Beer's Law, the light attenuation along fibre posts can be expressed as:

$$P(x) = P(0)\exp(-\alpha_p x);$$

where $P(x)$ is the light intensity at a distance, x, down the fibre post, $P(0)$ is the initial light intensity at the post cervix, and α_p is the quasi attenuation coefficient. In which, the quasi attenuation coefficients (α_p) of P-Lux and P-White were derived to be 0.36 and 1.45 mm^{-1}, respectively.

Table 2 – Mean and standard deviation (SD) of the light intensity ($\mu W/cm^2$) at different depths and at the apex for each post type ($n = 10$).

Type	Depth (mm)	1	2	3	4	5	6	7	8	9	10	Apex
P-Lux	Mean (SD)	3342.8^{Ba} (0.8)	1882.2^{Ca} (0.6)	1367.1^{Da} (0.4)	994.6^{Ea} (0.2)	793.8^{Fa} (0.2)	451.3^{Ga} (0.2)	250.4^{Ha} (0.2)	183.4^{Ia} (0.3)	178.3^{Ja} (0.1)	147.3^{Ka} (0.3)	3970.0^{Aa} (0.3)
P-White	Mean (SD)	2145.7^{Ab} (0.2)	570.7^{Bb} (0.1)	202.0^{Cb} (0.1)	34.7^{Eb} (0.0)	3.4^{Fb} (0.0)	0.6^{Gb} (0.0)	0.1^{Hb} (0.0)	0.0^{Hb} (0.0)	0.0^{Hb} (0.0)	0.0^{Hb} (0.0)	58.3^{Db} (0.2)
P-Steel	Mean (SD)	0.0^{Ac} (0.0)	0.0^{Ac} (0.0)	0.0^{Ac} (0.0)	0.0^{Ac} (0.0)	0.0^{Ac} (0.0)	0.0^{Ac} (0.0)	0.0^{Ab} (0.0)	0.0^{Ab} (0.0)	0.0^{Ab} (0.0)	0.0^{Ab} (0.0)	0.0^{Ac} (0.0)

Means with the same capital letters in the same line and small letters in the same column do not significantly differ ($p < 0.05$).
Post types are described in Table 1.

Table 3 – Mean and standard deviation (SD) of the degree of conversion (%) of the dual-cured resin cement at different depths for each post type (n = 5).

Type	Depth (mm)	0	2	5	8	10
P-Lux	Mean (SD)	78.23^{Aa} (1.27)	77.18^{Aa} (1.50)	75.95^{Aa} (1.71)	62.18^{Ba} (5.99)	63.27^{Ba} (4.25)
P-White	Mean (SD)	78.41^{Aa} (2.66)	75.43^{Aa} (2.36)	71.21^{Ab} (2.60)	58.45^{ABa} (8.36)	52.45^{Bb} (9.10)
P-Steel	Mean (SD)	78.59^{Aa} (1.19)	76.74^{Aa} (1.22)	70.86^{Ab} (4.58)	51.06^{Bb} (9.40)	50.15^{Bb} (10.96)

Means with the same capital letters in the same line and small letters in the same column do not significantly differ ($p < 0.05$).
Post types are described in Table 1.

At the post terminal, a significantly higher value of light intensity was presented in the P-Lux group, whilst there was only a small amount of light transmitted to the apex of the P-White group. However, all experimental groups showed that the amount of light reaching the apex radially was rather lower than that reaching it transversely.

3.2. DC of the dual-cured resin cement surrounding the posts

Mean DC values of the resin cement along various posts are given in Table 3. Kruskal–Wallis tests showed that both variables, post type and depth, had significant effects on the DC of the surrounding cements. DC values of Duolink were significantly higher in the P-Lux post, and values significantly decreased in the apical region. Moreover, interactions between post type and depth were also statistically significant.

In the coronal portion, there were no significant differences in DC values amongst the three posts ($p > 0.05$); whilst at a 5-mm depth, the DC values of the resin cement were significantly higher in the P-Lux post than the other two posts ($p < 0.01$). The P-White post revealed higher DC values than the P-Steel post ($p < 0.05$) only at a depth of 8 mm. In the apical portion, the P-Lux post demonstrated the best result ($p < 0.05$), whereas no significant differences in DC values between the P-White and P-Steel post were noted ($p > 0.05$).

3.3. Microleakage test

In the microleakage test, both positive and negative controls remained stable throughout the study. The negative controls revealed high impedance (36.87 ± 1.87 MΩ) showing no significant leakage, whilst the positive controls demonstrated low impedance (0.015 ± 0.001 MΩ). The impedance of the teeth decreased with time for all experimental groups (Table 4). P-Lux cemented with Duolink showed the highest impedance throughout the study, whilst P-Steel cemented with Duolink revealed the lowest impedance ($p < 0.05$).

4. Discussion

The results of this study confirmed that the effects of light attenuation by aesthetic fibre posts were evident.[4,24] Whilst Goracci et al.[5] reported that there were significant negative linear relationships between the post levels and the amount of photons, we found that irradiance along the post decreased exponentially as the light penetrated more deeply and the data fit well with Beer–Lambert's Law. P-White post possessed a higher quasi attenuation coefficient ($1.45\ mm^{-1}$), even demonstrated similar results with the P-Steel post beyond 6 mm. The effect of light attenuation by fibre posts might drastically affect the DC of dual-cured resin cements than expectation. Future studies enrolling more posts with different light-transmitting property merit attention.

The light transmission in the fibre posts can be through fibres and resin matrix. We found that the irradiance surrounding the aesthetic posts was considerably lower than through the post at the same depth. An interesting finding was that the P-Lux post presented the highest value of light transmission at the apex rather than at other depths along the post, which could be due to the alignment of the glass fibres inside posts.[6,25] Although it was speculated that the direction of the fibres might dominate the patterns of light transmission, features of composite posts can also influence the light transmission properties.[4]

Because the metal post cannot convey light, the increased DC of the surrounding resin cement could be due to the translucency of resin cement itself, which allowed certain light reached to the 5 mm depth along the post. Whilst, the polymerization of the apical resin cement was irrelevant to light-curing and can only reach around 50% DC. The better light transmitting properties of P-Lux posts do help polymerization

Table 4 – Mean and standard deviation (SD) of the impedance measured at different times for each experimental group (n = 12).

Group		Resistance (MΩ)		
		Day 0	Day 1	Day 3
1	P-Lux with Duolink	$47.95 (8.69)^{Aa}$	$35.42 (8.15)^{Ba}$	$6.69 (3.31)^{Ca}$
2	P-White with Duolink	$39.98 (11.61)^{Aa}$	$25.55 (12.61)^{Ba}$	$0.68 (0.32)^{Cb}$
3	P-Steel with Duolink	$38.48 (13.53)^{Aa}$	$3.67 (2.54)^{Bb}$	$0.44 (0.31)^{Cb}$

Means with the same capital letters in the same line and small letters in the same column do not significantly differ ($p < 0.05$).

of apical resin cement; however, the P-White posts showed significantly reduced DCs behind 5 mm in depth, and even demonstrated similar results with the P-Steel post at 10 mm, which denoted that little or no light reached the apex (Table 2).

Nomoto et al.[26] suggested that the minimum light energy density required to produce a saturated DC of a light-cured resin was about 1000 mJ/cm^2. Although no investigation has evaluated the minimal energy density for adequate polymerization of a dual-cured resin, the light attenuation phenomenon was dominant in all three post systems, and the DC of the cement significantly dropped as the depth increased. Although the cement cured at room temperature (25 °C) might have a lower DC than that cured at 37 °C as it is done clinically, the difference was rather limited comparing to the light attenuation effect of fibre posts.[5,27] Consequently, 40 s of curing recommended by the manufacturer was insufficient for dual-cured resin cements around the post apex.[4] Increasing the curing light intensity or curing time, or developing a new post with less attenuation would be beneficial when light-cured or dual-cured resin cements are used for post cementation.

In this study, dowel posts had a significant impact on microleakage of post-restored teeth. This finding is similar to previous studies that aesthetic fibre posts cemented with resin cement exhibited better results than metal posts in terms of microleakage.[28,29] Recently, the potential of adhesive cements leads to the concept of post-resin-dentine ''monoblock'' in root canal.[30] The increased leakage of the ''monoblock'' in root canal is probably a combination of weak adhesion of resin cement to post or root dentine, and the increased solubility and sorption of the resin cement surrounding the posts. Both shortages are highly correlated to the DC of the resin cement. An insufficient DC of resinous materials can result in detrimental effects on the mechanical and adhesive strengths of the resin cement,[31–33] moreover it has been proven that inadequate polymerization of a resin can facilitate water sorption and monomer elution, which might produce microscopic channels or pores and thus hasten the penetration of water and ions.[34]

The impedance measured in the study significantly decreased over time for all three groups (Table 4). The non-uniform leakage flow infers a pathway other than ionic migration in the material core. It is possible that the destruction of resin cement and cement interfaces rather than water sorption of resin itself might dominate the later microleakage. Moreover, the declining resin polymerization along the post, especially in the apical region, might aggravate leakage over time.

Use of metal posts in electrochemical leakage test should be with caution. Because the rapid electrical conductance driven by the steel post could interfere with the impedance measurements, the metal posts were carefully embedded within the resin cement to avoid direct contact with the fluid, and an indirect electrical current was used in the models to reduce the galvanic corrosion of the metal posts. Moreover, a small reference resistance (R1) was chosen to minimize the parallel effect of the multimeter in measuring the impedance of the specimens (Fig. 3).

Ideally both DC and microleakage measurements should be taken of the same specimen to test the hypothesis that the light attenuation by aesthetic posts can retard the DC of dual-cured resin cements and subsequently increase microleakage. However, the Raman signals of resin detected in tooth specimens were drastically disturbed by the fluorescence of the gutta-percha; therefore, the DC of the dual-cured resin cements was measured in a simulated root canal model instead.

Although some recent references showed poor correlations amongst different microleakage tests,[23,35] Iwami et al.[22,36] revealed the accuracy of an electrical method for the evaluation of microleakage of composite restoratives by a three-dimensional analysis of dye penetration. In the present study, an electrochemical method for the leakage test was chosen because it is simple and non-destructive, and allows repeated measuring of quantitative values over time. The consistent results of the positive and negative controls throughout the study demonstrated the stability of the system. The fluid connection between the coronal and apical areas of post-retaining teeth determines the impedance of specimens. Because tooth selection, root canal preparation, resin cement, and post dimensions were well controlled in this study, the observed differences can be attributed to the properties of the different posts, which should provide relevant information regarding the leakage potential of different posts with dual-cured resin cements. Whilst the clinical relevance of in vitro leakage evaluations should still be accepted with caution, the detrimental effects of insufficient polymerization of resin cement surrounding the posts warrant further investigations.

5. Conclusions

In conclusion, the effective radiance along the post was diminished exponentially to a level insufficient for photo-initiation of a dual-cured resin cement surrounding the posts in the apical region, which might influence the microleakage of post-restored teeth. Therefore, care must be taken when applying light-cured and dual-cured resin cements for post cementation.

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REFERENCES

1. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. *Journal of Endodontics* 2004;**30**:289–301.
2. Qualtrough AJE, Mannocci F. Tooth-colored post systems: a review. *Operative Dentistry* 2003;**28**:86–91.
3. Asmussen E, Peutzfeldt A, Heitmann T. Stiffness, elastic limit, and strength of newer types of endodontic posts. *Journal of Dentistry* 1999;**27**:275–8.

4. dos Santos Alves Morgan LF, Peixoto RT, de Castro Albuquerque R, Santos Corrêa MF, de Abreu Poletto LT, Pinotti MB. Light transmission through a translucent fiber post. *Journal of Endodontics* 2008;**34**:299–302.
5. Goracci C, Corciolani G, Vichi A, Ferrari M. Light-transmitting ability of marketed fiber posts. *Journal of Dental Research* 2008;**87**:1122–6.
6. Seefeld F, Wenz HJ, Ludwig K, Kern M. Resistance to fracture and structural characteristics of different fiber reinforced post systems. *Dental Materials* 2007;**23**:265–71.
7. Pest LB, Cavalli G, Bertani P, Gagliani M. Adhesive post-endodontic restorations with fiber posts: push-out tests and SEM observations. *Dental Materials* 2002;**18**:596–602.
8. Rueggeberg FA, Caughman WF, Curtis Jr JW. Effect of light intensity and exposure duration on cure of resin composite. *Operative Dentistry* 1994;**19**:26–32.
9. Lui JL. Depth of composite polymerization within simulated root canals using light-transmitting posts. *Operative Dentistry* 1994;**19**:165–8.
10. Ceballos L, Garrido MA, Fuentes V, Rodríguez J. Mechanical characterization of resin cements used for luting fiber posts by nanoindentation. *Dental Materials* 2007;**23**:100–5.
11. Schwartz RS. Adhesive dentistry and endodontics. Part 2: bonding in the root canal system – the promise and the problems: a review. *Journal of Endodontics* 2006;**32**:1125–34.
12. Darr AH, Jacobsen PH. Conversion of dual cure luting cements. *Journal of Oral Rehabilitation* 1995;**22**:43–7.
13. el-Badrawy WA, el-Mowafy OM. Chemical versus dual curing of resin inlay cements. *Journal of Prosthetic Dentistry* 1995;**73**:515–24.
14. Shimura R, Nikaido T, Yamauti M, Ikeda M, Tagami J. Influence of curing method and storage condition on microhardness of dual-cure resin cements. *Dental Materials Journal* 2005;**24**:70–5.
15. Braga RR, César PF, Gonzaga CC. Mechanical properties of resin cements with different activation modes. *Journal of Oral Rehabilitation* 2002;**29**:257–62.
16. Koishi Y, Tanoue N, Atsuta M, Matsumura H. Influence of visible-light exposure on colour stability of current dual-curable luting composites. *Journal of Oral Rehabilitation* 2002;**29**:387–93.
17. Issa Y, Watts DC, Brunton PA, Waters CM, Duxbury AJ. Resin composite monomers alter MTT and LDH activity of human gingival fibroblasts in vitro. *Dental Materials* 2004;**20**: 12–20.
18. Yoshii E. Cytotoxic effects of acrylates and methacrylates: relationships of monomer structures and cytotoxicity. *Journal of Biomedical Materials Research* 1997;**37**:517–24.
19. Ferracane JL, Greener EH. The effect of resin formulation on the degree of conversion and mechanical properties of dental restorative resins. *Journal of Biomedical Materials Research* 1986;**20**:121–31.
20. Ferracane JL. Correlation between hardness and degree of conversion during the setting reaction of unfilled dental restorative resins. *Dental Materials* 1985;**1**:11–4.
21. Pianelli C, Devaux J, Bebelman S, Leloup G. The micro-Raman spectroscopy, a useful tool to determine the degree of conversion of light-activated composite resins. *Journal of Biomedical Materials Research* 1999;**48**:675–81.
22. Iwami Y, Hayashi M, Takeshige F, Ebisu S. The accuracy of electrical method for microleakage evaluation by a three-dimensional analysis. *Journal of Dentistry* 2007;**35**:268–74.
23. Pommel L, Jacquot B, Camps J. Lack of correlation among three methods for evaluation of apical leakage. *Journal of Endodontics* 2001;**27**:347–50.
24. Teixeira EC, Teixeira FB, Piasick JR, Thompson JY. An in vitro assessment of prefabricated fiber post systems. *Journal of the American Dental Association* 2006;**137**:1006–12.
25. Lassila LV, Tanner J, Le Bell AM, Narva K, Vallittu PK. Flexural properties of fiber reinforced root canal posts. *Dental Materials* 2004;**20**:29–36.
26. Nomoto R, Asada M, McCabe JF, Hirano S. Light exposure required for optimum conversion of light activated resin systems. *Dental Materials* 2006;**22**:1135–42.
27. Trujillo M, Newman SM, Stansbury JW. Use of near-IR to monitor the influence of external heating on dental composite photopolymerization. *Dental Materials* 2004;**20**:766–77.
28. Reid LC, Kazemi RB, Meiers JC. Effect of fatigue testing on core integrity and post microleakage of teeth restored with different post systems. *Journal of Endodontics* 2003;**29**:125–31.
29. Usumez A, Çobankara FK, Ozturk N, Eskitascioglu G, Belli S. Microleakage of endodontically treated teeth with different dowel systems. *Journal of Prosthetic Dentistry* 2004;**92**:163–9.
30. Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. *Journal of Endodontics* 2007;**33**:391–8.
31. Lee SY, Lai YL, Hsu TS. Influence of polymerization conditions on monomer elution and microhardness of autopolymerized polymethyl methacrylate resin. *European Journal of Oral Sciences* 2002;**110**:179–83.
32. Roberts HW, Leonard DL, Vandewalle KS, Cohen ME, Charlton DG. The effect of a translucent post on resin composite depth of cure. *Dental Materials* 2004;**20**:617–22.
33. Yoldas O, Alaçam T. Microhardness of composites in simulated root canals cured with light transmitting posts and glass-fiber reinforced composite posts. *Journal of Endodontics* 2005;**31**:104–6.
34. Pearson GJ, Longman CM. Water sorption and solubility of resin-based materials following inadequate polymerization by a visible-light curing system. *Journal of Oral Rehabilitation* 1989;**16**:57–61.
35. Karagenç B, Gençoğlu N, Ersoy M, Cansever G, Külekçi G. A comparison of four different microleakage tests for assessment of leakage of root canal fillings. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics* 2006;**102**:110–3.
36. Iwami Y, Yamamoto H, Ebisu S. A new electrical method for detecting marginal leakage of in vitro resin restorations. *Journal of Dentistry* 2000;**28**:241–7.