Abstract

Purpose: To evaluate the degree of conversion (DoC) of self-adhesive resin luting cements when irradiated through different fiber post lengths.

Methods: A total of 60 teeth were sectioned to achieve lengths of 4 mm, 7 mm, and 10 mm, while 60 fiber posts were trimmed to give 3 mm, 6 mm, and 9 mm lengths. Post space was created to accommodate the fiber post and 1 mm of luting cement apically. Two self-adhesive resin luting cements (Multilink Speed and RelyX U200) were used. A total of four cycles of 20 s irradiation was done with an attenuated total reflectance Fourier transform infrared spectroscopy reading between each cycle.

Results: The mean ± standard deviation DoC achieved with a light-emitting diode and quartz tungsten halogen for Multilink Speed was 67.4 ± 2.7% and 72.4 ± 4.0%, respectively, while for RelyX U200, the corresponding values were 56.5 ± 2.7% and 62.0 ± 3.8%, respectively. For Multilink Speed, there was no significant difference between the control and the 3 mm group, while for RelyX U200, no significant difference was found between the 6 mm and 9 mm groups. All the other groups showed significant differences.

Conclusion: The DoC reduced as the post length increased.

Keywords: curing lights, degree of conversion, fiber posts, FTIR, resin cement

Introduction

A dental post can be used in structurally compromised teeth to help retain core material and may assist in supporting the remaining tooth structure, allowing the clinician to build a provisional or definitive restoration. Fiber posts exhibit high tensile strength and a modulus of elasticity similar to dentine and can be placed in areas where esthetics are a concern [1]. However, fiber posts require cements such as glass ionomer or resin cements for their fixation into the post channel [2]. Light cured and dual cured resin cements have been commonly used for cementing posts as they have been shown to provide higher retention than conventional cements [3,4]. However, a major drawback of resin cements in root canals is the inability of light to penetrate into the deeper regions of the canal, leading to incomplete conversion (DoC) and consequently poor bond strength [5]. To overcome this problem, translucent fiber posts that allow light penetration apically have been used, thus improving the DoC. However, inadequate DoC in the middle and apical thirds of the root has still been reported [6].

Much research has focused on the restoration of endodontically treated teeth [7,8]. In recent years, reconstruction involving fiber posts has become widespread, and great reliance has been increasingly placed on the use of adhesive technologies. The detailed dynamics of adhesive behavior within post channels are, however, under-researched, and concerns have been expressed about the quality of curing as a function of compromised light penetration. It has been reported that the DoC decreases as the length of the root canal increases, due to the attenuation of light penetration from the source [5]. Although translucent fiber posts have been used in root canals to allow better apical penetration of light and thus improve the DoC, inadequate conversion rates in the middle and apical thirds of the root have still been reported [9,10]. Consequently, this potential for incomplete curing of adhesive cements in the deeper regions may compromise the physical properties of the cement, leading to poor bonding and clinical performance [11]. There is a need for comprehensive research to determine the influence of various factors such as the type of post, the type of cement, and the type and duration of light required to achieve adequate DoC in root canals, thus helping to prolong tooth survival.

This present study was designed to assess the DoC of two resin luting cements at different root canal depths when light-activated via light-emitting diode (LED) or quartz tungsten halogen (QTH) curing units. The working hypotheses tested were (1) that there would be no difference in the DoC of resin luting cements light-activated with LED or QTH curing lights, and (2) that the DoC would be reduced as the length of the post increased.

Materials and Methods

Two self-adhesive dual cured resin luting cements were used in this study: Multilink Speed (Ivoclar Vivadent, Schaan, Liechtenstein) and RelyX U200 (3M ESPE, Saint Paul, MN, USA) (Table 1). The manipulation of the materials was performed in accordance with the manufacturers’ instructions, and all experiments were carried out at room temperature. A translucent fiber post system and two types of curing lights were utilized (Table 1).

Specimen preparation

A total of 60 maxillary central incisors that had been extracted for reasons not related to the study were prepared after obtaining ethical approval (IRB-2014-02-033) from Deanship of Scientific Research, Imam Abdulrahman Bin Faisal University, Saudi Arabia. A diamond saw was used to section the teeth coronally and apically to obtain samples 4 mm, 7 mm, and 10 mm long. Fiber posts were trimmed apically to give lengths of 3 mm, 6 mm, and 9 mm when measured from their coronal heads. Post space was created using a ParaPost drill (size 1.0 mm) to accommodate the prepared fiber posts and 1 mm of resin luting cement apically (Fig. 1). To reduce the influence of ambient light on the test material, all the procedures were conducted under dimmed light.

Determination of the degree of conversion

The DoC of the test materials was determined using attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) (Nicolet 6700, Thermo Scientific, Dreieich, Germany) with a Smart-iTR diamond accessory at a resolution of 4 cm⁻¹. The DoC was calculated by comparing the ratio of aliphatic carbon-carbon double bonds (C = C) at 1,640 cm⁻¹ and C = O at 1,710 cm⁻¹ for Multilink Speed, while the ratio of aliphatic carbon-carbon double bonds (C = C) at 1,640 cm⁻¹ and C = O at 1,610 cm⁻¹
was be used for RelyX U200. The following formula was used according to the material.

$$\text{DoC} = 100 \times \left(1 - \frac{R_{\text{polymerized}}}{R_{\text{unpolymerized}}} \right)$$

Where $R = \text{peak height}_{1,640\, \text{cm}^{-1}}$ or peak height $1,710\, \text{cm}^{-1}$

For the control group, the material was dispensed directly on the FTIR crystal and a glass coverslip was placed to obtain a thickness of 1 mm. A reading of the uncurled material was taken before continuous light activation for 3 min, followed by another reading of the cured material.

For the 3 mm, 6 mm, and 9 mm groups, the fiber posts were placed in their corresponding prepared teeth, followed by direct placement of the luting cement via an automix syringe at the apical end. The apical end of the specimen was placed in direct contact with the FTIR crystal and a glass coverslip was placed to obtain a thickness of 1 mm. A reading of the uncured material was taken before continuous light activation through lengths of 3 mm, 6 mm, and 9 mm. It was evident that DoC was reduced as the length of the posts increased.

The difference in the DoC achieved using LED and QTH at 3 mm was statistically significant ($t$-test; $P < 0.05$). For QTH, there was statistically non-significant differences between all of the groups ($P > 0.05$). For LED, there was no statistically significant difference between the control and the 3 mm groups ($t$-test; $P > 0.05$), while all the other groups showed statistically significant differences ($P < 0.05$). For QTH, there were statistically significant differences between all of the groups ($P < 0.05$).

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Figure 3 shows the DoC of Multilink Speed when light activated with LED and QTH curing units through different post lengths for 80 s.

### Results

**Degree of conversion for Multilink Speed**

The mean ± standard deviation (SD) DoC for Multilink Speed after 3 min of light activation through the LED and QTH curing units was 67.36 ± 2.73% and 72.44 ± 4.0%, respectively. The DoC achieved by the two lights was statistically significant ($t$-test; $P < 0.05$).

Table 2 shows the DoC achieved for Multilink Speed when light activation was performed through posts 3 mm, 6 mm, and 9 mm in length. It was evident that DoC was reduced as the length of the posts increased. For LED, there was no statistically significant difference between the control and the 3 mm groups ($t$-test; $P > 0.05$), while all the other groups showed statistically significant differences ($P < 0.05$). For QTH, there were statistically significant differences between all of the groups ($P < 0.05$).

The difference in the DoC achieved using LED and QTH at 3 mm was statistically non-significant ($t$-test; $P > 0.05$), while at 6 mm and 9 mm, statistically significant differences were evident ($t$-test; $P < 0.05$).

Figure 4 shows the DoC of RelyX U200 when light-activated with LED and QTH curing units through different post lengths for 80 s.

**Degree of conversion for RelyX U200**

The mean (SD) DoC for RelyX U200 after 3 min of light activation via LED and QTH curing units was 56.54 ± 2.72% and 62.04 ± 3.77%, respectively. The DoC achieved using the two lights was statistically significant ($t$-test; $P < 0.05$).

Table 3 shows the DoC achieved for RelyX U200 by light activation through lengths of 3 mm, 6 mm, and 9 mm. It was evident that DoC was reduced as the length of the posts increased. For both LED and QTH, there was no statistically significant difference between the 6 mm and 9 mm groups ($t$-test; $P > 0.05$), while all the other groups showed statistically significant differences ($P < 0.05$).

The difference in the DoC achieved using LED and QTH at 3 mm was statistically significant ($t$-test; $P < 0.05$), while at 6 mm and 9 mm, there were no statistically significant differences between LED and QTH ($t$-test; $P > 0.05$).

Figure 4 shows the DoC of RelyX U200 when light-activated with the LED and QTH curing units through different post lengths for 80 s.
peak at 1,610 cm$^{-1}$ were used to evaluate the DoC for RelyX U200, the with a resin luting cement using an aromatic peak at 1,710 cm$^{-1}$ [19]. In the study conducted by Khabeer et al. in 2015 reported the results obtained and easy, does not require destruction of the sample, and it allows monitor study, a more recent ATR-FTIR technique was used as it is relatively quick and might be unable to adequately activate the initiators and co-initiators present in the resin cements, including differential scanning calorimetry [12], Raman spectroscopy [13], differential thermal analysis [14], electron paramagnetic resonance [15] and nuclear magnetic resonance [16]. In the present study, a more recent ATR-FTIR technique was used as it is relatively quick and easy, does not require destruction of the sample, and it allows monitoring of the progress of the reaction in real time [17]. The mechanism of ATR-FTIR is based on total internal reflection and its attenuation. During total internal reflection, infrared light is passed through a crystal of high refractive index, leading to the formation of an evanescence wave. When the test material comes in contact with this wave, there is some absorption of energy leading to wave attenuation, which can then be detected and a spectrum obtained [18].

In the present study, the aliphatic C = C peak at 1,640 cm$^{-1}$ and the C = O peak at 1,710 cm$^{-1}$ were used for determining the DoC for Multilink Speed, as the aromatic peak at around 1,610 cm$^{-1}$ was absent. A previous study conducted by Khaeeber et al. in 2015 reported the results obtained with a resin luting cement using an aromatic peak at 1,710 cm$^{-1}$ [19]. In the present study, however, as an aliphatic peak at 1,640 cm$^{-1}$ and an aromatic peak at 1,610 cm$^{-1}$ were used to evaluate the DoC for RelyX U200, the results would not have allowed comparison of differences between the two materials.

In the present study, the mean DoC for Multilink Speed after light activation for 3 min with the LED and QTH was 67.36 and 72.04%, respectively. Lopes et al. (2015) reported a DoC of 66.3% after light activation for 120 s with a QTH curing unit (Optilux 501) [21]. These findings are similar to those of the present study, suggesting that QTH curing lights might be able to achieve higher DoC values due to their wider wavelength, which can activate the initiators and co-initiators present in the resin cements [22].

The present study showed that both materials had a tendency for decreased DoC as the length of the post increased. This finding is comparable to other studies that showed decreased DoC for resin luting cements as the depth of the canal increased [10,19]. One explanation could be that the light intensity becomes attenuated with increased distance [23]. In this study, two types of light curing units were used, the LED unit providing a higher light intensity than QTH unit. However, it has been reported that LED curing lights have a narrower wavelength than QTH curing lights and might be unable to adequately activate the initiators and co-initiators present in the cement, resulting in an inadequate degree of conversion [23-25]. Additionally, the high refractive index of dentine (1.54) and the filler content of a fiber post (1.64) can influence the DoC of the luting cement, as multiple refraction and reflection occurs at the resin-filler interface [25,26].

Another explanation could be the use of natural teeth, which are not opaque and thus tend to disperse the light, which may reduce the light intensity and affect the DoC of the material.

Other contributing factors that may affect the DoC include the diameter of the fiber posts. Liu reported that the depth of cure is reduced as the diameter of the fiber post decreases [27]. In the present study, as parallel-sided fiber posts 1 mm in diameter were used, the results obtained might not be extrapolated to fiber posts of other diameters.

It has been suggested that DoC may be related to fiber post retention, as previous studies have shown that higher bond strength values are directly proportional to the DoC of resin luting cement [28]. Moreover, it has been shown that inadequate DoC may lead to leakage of residual monomers into the surrounding tissues, leading to adverse effects [29].

Therefore, it can be suggested that a fiber post system with high light transmission efficiency and the use of curing lights with high intensity

Table 2: Degree of conversion (%) of Multilink Speed material polymerized with LED and QTH units.

| Post length | LED | Mean | SD | QTH | Mean | SD |
|-------------|-----|------|----|-----|------|----|
| Control     | 67.4 | 2.7  | 72.4 | 4.0 |
| 5 mm        | 62.5 | 1.7  | 65.3 | 3.9 |
| 6 mm        | 56.0 | 4.3  | 47.8 | 3.4 |
| 9 mm        | 43.5 | 4.2  | 33.6 | 4.2 |

Sample size (n = 5). Superscript letters indicate groups with no significant difference (ANOVA, Tukey’s multiple range test, $P < 0.05$). *showing no significant difference between the LED and QTH groups.

Table 3: Degree of conversion (%) of RelyX U200 material polymerized with LED and QTH units.

| Post length | LED | Mean | SD | QTH | Mean | SD |
|-------------|-----|------|----|-----|------|----|
| Control     | 35.6 | 2.7  | 62.0 | 3.8 |
| 3 mm        | 49.5 | 1.7  | 39.8 | 2.1 |
| 6 mm        | 28.9 | 2.0  | 28.4 | 2.2 |
| 9 mm        | 25.2 | 2.5  | 24.3 | 3.8 |

Sample size (n = 5). Superscript letters indicate groups with no significant difference (ANOVA, Tukey’s multiple range test, $P < 0.05$). *showing no significant difference between the LED and QTH groups.

Fig. 3: Showing the degree of conversion of Multilink Speed when light-activated with the LED and QTH curing units through different lengths of post for 80 s. *showing no significant difference between the LED and QTH groups at 3 mm after 80 s.

Fig. 4: Showing the degree of conversion of RelyX U200 when light-activated with the LED and QTH curing units through different lengths of post for 80 s. *showing no significant difference between LED and QTH groups at 6 mm and 9 mm after 80 s.

Discussion

This laboratory-based study evaluated the DoC of two types of self-adhesive dual cured resin luting cements when light-activated with a LED or QTH curing unit through a light-transmitting fiber post 3 mm, 6 mm, or 9 mm in length. Several methods have been utilized to evaluate the DoC of resin cements, including differential scanning calorimetry [12], Raman spectroscopy [13], differential thermal analysis [14], electron paramagnetic resonance [15] and nuclear magnetic resonance [16]. In the present study, a more recent ATR-FTIR technique was used as it is relatively quick and easy, does not require destruction of the sample, and it allows monitoring of the progress of the reaction in real time [17]. The mechanism of ATR-FTIR is based on total internal reflection and its attenuation. During total internal reflection, infrared light is passed through a crystal of high refractive index, leading to the formation of an evanescence wave. When the test material comes in contact with this wave, there is some absorption of energy leading to wave attenuation, which can then be detected and a spectrum obtained [18].

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In the present study, the mean DoC for Multilink Speed after light activation for 3 min with the LED and QTH was 67.36% and 72.44%, respectively. Zhang et al. (2018) reported a DoC of 59.6% for Multilink Speed after light activation for 40 s [20]. However, they light-activated the material through zirconia disks, which might explain the lower DoC they obtained. To the authors’ knowledge, no other study has reported the DoC for Multilink Speed after direct light activation, and therefore no reliable comparison can be made. On the other hand, the mean DoC for RelyX

U200 after 3 min of light activation via LED and QTH was 56.54% and 62.04%, respectively. Lopes et al. (2015) reported a DoC of 66.3% after light activation for 120 s with a QTH curing unit (Optilux 501) [21]. These findings are similar to those of the present study, suggesting that QTH curing lights might be able to achieve higher DoC values due to their wider wavelength, which can activate the initiators and co-initiators present in the resin cements [22].

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Therefore, it can be suggested that a fiber post system with high light transmission efficiency and the use of curing lights with high intensity...
should be encouraged to allow greater penetration of light, leading to a higher DoC. Further research needs to be conducted to clarify the factors affecting the DoC in deeper regions of root canals.

The hypothesis that the DoC for the test resin luting cement would be similar when light-activated with LED or QTH curing light was rejected. The QTH curing unit resulted in a higher DoC than the LED curing unit for both of the test materials when light activation was conducted directly for 180 s. The other hypothesis that the DoC would be reduced as the length of the post increased was partially accepted. The LED curing unit produced a significantly higher DoC than the QTH curing unit for Multilink Speed at 6 mm and 9 mm, while for Relix U200, the LED curing unit produced a significantly higher DoC at 3 mm length.

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Conflict of interest
All authors have no conflict of interest to declare.

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