Effect of Exposure Time and Distance of The Light Curing Unit on The Modulus of Elasticity of Dual Cure Resin Cements

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Abstract

This research aims to study the modulus of elasticity of dual-cure resin cement with different exposure time and distance from the light-curing unit. The study divided sample groups into nine groups (A to I) from a total of 90 specimens (10 pieces per group). The specimens (stainless steel molds) of size 2 x 12 x 2 mm^3 were prepared, and ceramic disc size 6 x 14 x 2 mm^3 was placed over the specimens. Then, the specimens were cured for 20 s, 40 s, and 60 s from a distance of 0 mm, 5 mm, and 10 mm. After being stored in an incubator at 37^{o} C for 24 hours, the specimens were three-point bending tested with a universal testing machine. The results are that Group G (D0, T60) showed the closest distance and the longest exposure time with the greatest the modulus of elasticity of 3067.85 N/mm^2. On the other hand, Group C (D10, T20) showed the lowest modulus of elasticity of 2562.36 N/mm^2. The results also demonstrated that a more prolonged light exposure led to a higher modulus of elasticity of resin cement with a statistical significance. However, the modulus of elasticity of resin cement is not statistically significantly different when there is an increase in distance between the light-curing unit and the specimens. This study concluded that an increase in the exposure time resulted in an increase in the modulus of elasticity of resin cement.

Keywords: *Degree of conversion, Distance, Exposure time, Modulus of elasticity, Resin cement*

1. Introduction

The longevity of the restoration is one of the essential criteria in choosing the material, and the restoration success is the demonstrated ability of restoration to perform as expected, whereas the length that as restoration survives is often used as a measure of clinical performance. To achieve these goals, many factors involved longevity of the restoration; such as patient's oral hygiene, oral habits, dentist's skill, and material factors (Fernandes et al., 2015). Failure of the restoration is mostly caused by improper biomechanics tooth preparation, improper cementation techniques, and improper luting cement. Thus, luting procedure is a critical step in providing the best longevity of the restoration (Ladha et al., 2010).

Resin luting cement is at the center of developing predictable adhesive dentistry. Properties of resin-based cement critical to the success of adhesive restorations include adequate bond strength, low solubility, biocompatibility, film thickness and polymerization shrinkage. Resin cement is classified according to a mode of activation (photo, chemical and dual-cure) and bonding mechanism (self-etch, self-adhesive and total-etch). Resin cement is set via polymerization reaction, which the characteristics and properties of resin-based cement depended on the degree of conversion of monomers to polymers. Inadequate degree of conversion compromises the mechanical properties of the cement affecting bond stability, strength, and therefore, clinical longevity. The resin-luting agent also should provide mechanical support to prevent fracture of ceramic restorations. Increasing the elastic modulus of the supporting core structure has been suggested as a means of increasing the fracture resistance of all-ceramic crowns (Scherrer et al., 2000).

With dual-cure polymerization mechanism of dual-cure resin cement which polymerization is affected by both chemical and light activation. The mechanical properties of a dual-cure resin cement via light cure polymerization are mainly influenced by the amount of energy delivered during irradiation (Dewaele et al., 2009). The relationship between total energy was light intensity and exposure time. When increasing the light intensity and exposure time, it resulted in an increment of total energy. The light intensity depended on the distance from the tip of the light-curing unit and its type and brand (Felix et al., 2003). The distance of the light-curing unit and exposure time are also essential factors to the degree of conversion of resin cement. Inadequate curing is usually associated with poor mechanical, physical properties and also fracture resistance (Fahim et al., 2013). Thus, the effect of exposure time and distance of the light-curing unit has been proposed (Moore et al., 2008). In this experiment, the researcher used (Variolink®N) to test the effect of exposure time and distance of the light-curing unit on the modulus of elasticity. A dual-cured resin cement was developed to combine the desirable properties of chemical polymerization with those of light-curing to assure enough working time and adequate polymerization, or degree of conversion. Mechanical of resin cement depended on the rate of polymerization, in which degree of conversion represents the percentage of carbon double bond (C = C) in monomer break the bond to single carbon (carbon single-bond, C-C) and connected to polymer in the polymerization process. A higher rate of polymerization resulted in a higher strength of materials, resistance to surface hardness, higher of elastic modulus, and flexural strength (Hofmann et al., 2001; Arrais et al., 2009). An increase in the polymerization of resin cement increases the modulus of elasticity; thus, increases the resin cement's flexural strength (Habekost et al., 2007; Aguiar et al., 2015). From the previous study, it was found that flexural strength and elasticity modulus are useful basic parameters for the assessment of mechanical characteristics of dental materials. The failure resistance of cemented restorations under applied forces is related to the mechanical properties of the individual parts, and flexural strength and elastic modulus are essential properties that may reflect the ability of the cement to manage stress without resulting into the fracture and permanent deformation (Saskalauskaite E. et al., 2008).

2. Objectives

This research aims to study the effect of different exposure time and distance from the light-curing unit on the modulus of elasticity of dual-cure resin cement.

3. Materials and Methods

The dual-cure resin cement used in this study was Variolink ® N (Transparent, Ivoclar Vivadent, Schaan, Liechtenstein). According to the manufacturer's instructions is working time of about 3.5 min at 37°C/99°F and mix base past and catalyst in a 1:1 ratio.

Table 1 The Composition of Variolink ® N

Type	Composition
Catalyst	Bis-GMA*, UDMA**, TEGDMA***, inorganic filler, ytterbium trifluoride, benzoyl peroxide and stabilizer
Base	Bis-GMA*, UDMA**, inorganic filler, ytterbium trifluoride, initiator and stabilizer

*Bis-GMA(bisphenol-A-glycidyldimethacrylate),**UDMA(Urethanedimethacrylate), ***TEGDMA(Triethylglycoldimethacrylate)

To observe the modulus of elasticity, the specimens were prepared by mixing the resin cement according to the manufacturer's instruction. The mixed cement was inserted to stainless steel molds with a dimension of 2x12x2 mm^3. Then, the cement was covered with a mylar strip to ensure smooth surfaces and to avoid any inhibition of polymerization by oxygen. After that, lithium disilicate ceramic (IPS e.max Press high translucent shade A3, Ivoclar Vivadent, Schaan, Liechtenstein) with a size of 6x14x2 mm^3 was placed to cover the top of the mylar strip. The specimens were cured in different ranges of time; 20, 40, and 60 seconds. Besides, the distance between the tip of the light-curing unit (LED Demi plus, Kerr, with 13 mm Tip, Intensity from 800-900 mW/cm^2 throughout curing cycle) and the ceramic's surface were at 0, 5, and 10 mm. At the zero-mm distance, the tip of the light-curing unit was placed on the surface of the ceramic plate. It was necessary to place the tip of the light-curing unit at the center of the specimens at 90-degree angle.

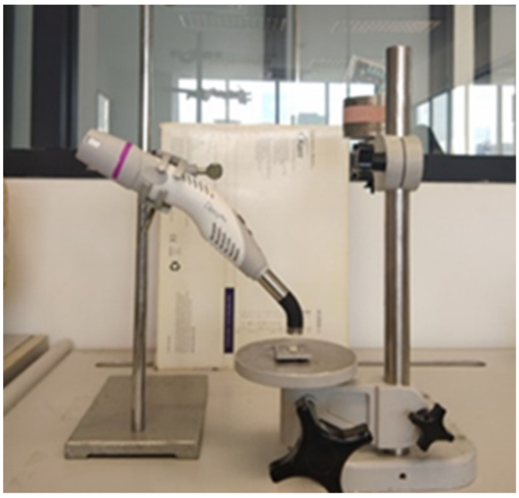

Figure 1 Picture shown the tip of the curing unit placed at the center of specimens with an angle of 90 degrees.

The specimens were removed from the mold after the light-curing process. However, during removing the specimens from the mold, the specimens were stuck to the mold and hard to remove. The researcher resolved this problem by carefully loading the specimens not to exceed the mold's rim. Then, the specimens' sizes were measured with a digital caliper with a 10% margin of error. The total of 90 specimens was prepared by immediately being stored in an incubator (Contherm Scientific Ltd., New Zealand) for 24 hours at 37 ˚C with 100% humidity without soaking into the water. The measurement of the modulus of elasticity was performed after a post-cure of 24 hours.

The modulus of elasticity was tested with the universal testing machine (Shimadzu 3-point bending test). The apparatus consisted primarily of two rods (2 mm in diameter), mounted parallel with a gap of 10 mm between their centers. A third rod (2 mm in diameter) was mounted between and parallel to the other two so that the three rods in combination can be used to give a three-point loading to the specimen. Then, a load was applied to the specimen at a cross-head speed of 0.75 mm/min and a rate of loading of 50 N/min until the specimen fractured.

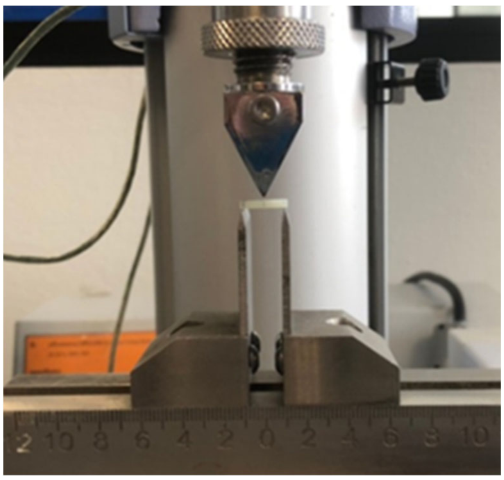

Figure 2 Picture shown the crosshead is specified for a 50 N axial load at 0.75 mm/min speed until the specimens fractured.

Statistically analysis

The data was analysed normal distribution with Kolmogorov Smirnov test and equality of variances with the Levene's test, respectively. The data were analyzed with two-way ANOVA at a 95% significance level. Tukey's post hoc test was used to determine the statistical significance among the groups based on the distance and exposure time of the light-curing unit. The data was analyzed by SPSS.

The results, which were analysed by Two-way ANOVA, showed that the relationship between the exposure time and the distance from the tip of the light-curing unit and resin cement's modulus of elasticity had no interaction. Therefore, the study decided to modify the method analysis test from Two-way ANOVA test to One-way ANOVA test instead.

4. Results and Discussion

The study was laboratory-based experimental research (in-vitro study) to analyze the effects of curing time and distance of the tip of an LED light-curing unit on the modulus of elasticity of resin cement. The results of the modulus of elasticity test are presented in Table 2. These results illustrated that the closest distance and the longest curing time lead to the highest modulus of elasticity of 3067.85 N/mm^{2,} as shown in group G (D0, T60). In contrast, comparing to other groups, Group C (D10, T20) had the lowest modulus of elasticity of 2562.36 N/mm^2.

Table 2 Descriptive statistics

Distance (mm)	Exposure time (second)	Mean	Std. Deviation	N
D0	T20	2775.49	397.82	10
	T40	2769.07	443.41	10
	T60	3067.85	315.25	10
	Total	2870.81	401.33	30
D5	T20	2648.63	275.10	10
	T40	2945.11	349.13	10
	T60	2973.80	262.82	10
	Total	2855.85	324.20	30
D10	T20	2562.36	353.59	10
	T40	3018.62	429.06	10
	T60	3047.47	418.75	10
	Total	2876.15	448.80	30
Total	T20	2662.16	345.44	30
	T40	2910.93	409.04	30
	T60	3029.71	329.22	30
	Total	2867.60	390.43	90

Dependent variable: the modulus of elasticity of resin cement that this table showed all of the study's results.

Tables 3 Statistical multiple comparisons results from one-way ANOVA by Tukey's test of the time of light-curing unit on the modulus of elasticity of resin cement.

Exposure time(second)	N	Modulus of elasticity(N/mm^2)	Standard deviation
20	30	2662.16 ^{a}	345.44
40	30	2910.93 ^{b}	409.04
60	30	3029.71 ^{c}	329.22

Mean having a similar letter (lower case letter-column) are not significantly different for $p < 0.05$

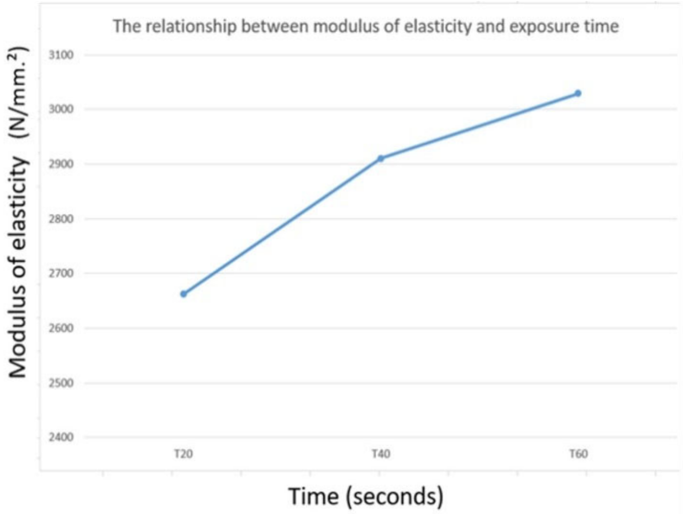

Figure 3 The following graph represented the relationship between modulus of elasticity and exposure time.

The exposure time of 60 seconds showed the highest modulus of elasticity of 3029.71 N/mm^2 while the exposure time of 20 seconds showed the lowest the modulus of elasticity of 2662.16 N/mm^2.

The results of one-way ANOVA and post hoc test of exposure time were significantly different (*p < 0.05), as shown in Table 3 and Figure 3, respectively. The results demonstrated that a more prolonged light exposure leads to a statistically significant higher modulus of elasticity of resin cement.

Tables 4 Statistical multiple comparison results of the distance of the light-curing unit on the modulus of elasticity of resin cement.

Distance(mm)	N	Modulus of elasticity(N/mm^2)	Standard deviation
0	30	2870.81	401.33
5	30	2855.85	324.20
10	30	2876.15	448.80

Meaning of no sign * is the modulus of elasticity of resin cement that were not statistically significantly different at p < 0.05.

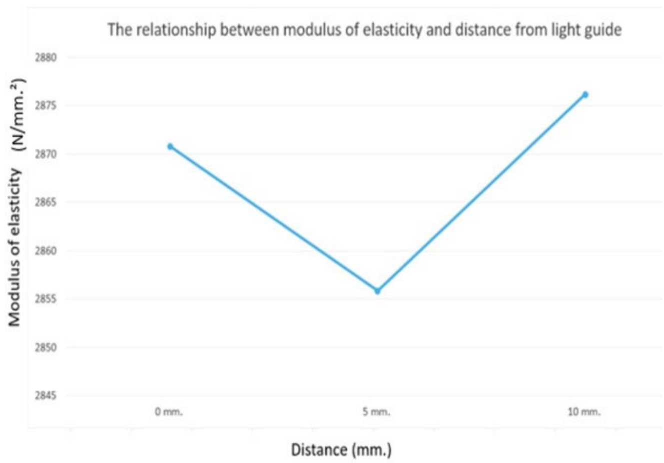

Figure 4 The following graph represented the relationship between modulus of elasticity and all distances from the light guide at exposure time 20, 40, and 60 seconds.

The resulted modulus of elasticity at a distance of 0 mm was 2870.81 N/mm^2, at 5 mm was 2855.85 N/mm^2, and at 10 mm was 2876.15 N/mm^2.

The results of one-way ANOVA and post hoc test of distances displayed in Table 4 showed that the modulus of elasticity of resin cement was not statistically significantly different when there is an increasing distance between light-curing unit and specimens. However, the distance results could not be explained by the one-way ANOVA and post hoc test. It must be explained using qualitative results with the graph as in Figure 4.

Discussion

In this study, dual-cure resin cement used in this was Variolink®N (Transparent, Ivoclar Vivadent, Schaan, Liechtenstein) because Variolink®N can be used for all clinical situations from full metal to tooth-colored restoration and become mostly used in dentistry. The esthetic luting resin from the N-Cement Collection is characterized by a high radiopacity and harmonious shade spectrum. At room temperature, two basic mechanisms are available for the polymerization reaction of the luting composite consisting of fillers and monomers:

Self-curing: Redox-initiated polymerization (two-component system)

Light-curing: Photochemical polymerization (single-component system)

Both types of polymerization are utilized in Variolink®N. This system demonstrates comparatively low sensitivity to ambient light, without compromising the other properties, such as long-term stability and curing depth. At the beginning of the polymerization process, Variolink®N enters a deliberate inhibition phase and, subsequently, polymerizes as quickly as other tried-and-tested composites. While the inhibition phase is prolonged under the influence of ambient light, it is much shorter under the exposure of light from a polymerization unit (approx. 0.5 s). Then, we used Variolink®N shade transparent because the study showed that higher translucency of resin cement would increase the modulus of elasticity. (Daiana Kelly Lopes H. et al., 2016). The ceramic that was used in this study is lithium disilicate ceramic (IPS e.max Press high translucent shade A3). This shade was the most used color for Thai people's indirect restoration in Thai dental clinic.

The study found that there was a significant difference in the modulus of elasticity of resin cement in different times of light curing. The longer time of light-curing increases the resin cement's modulus of elasticity. The total energy was coherently increased because the total energy is theoretically varied according to the increased light-curing time. The formula was presented as *total energy = light intensity x exposure time*, where the total energy stimulated the initiator, which caused the free radical disintegration even more and led to more polymerization. The polymerization process is related to the degree of conversion, in which the degree of conversion is low. There are more residual monomer left (DeWald et al., 1987; Taqa et al., 2016).

The degree of conversion illustrated the percentage of carbon double bond dissolution changed to carbon single-bond and then connected to a polymer chain. The degree of conversion is an indicator of the efficiency of the reaction polymerization. When the rate of polymerization increased, the modulus of elasticity of resin cement also increased (DeWald et al., 1987; Hofmann et al., 2001; Arrais et al., 2009).

The study concluded that the closest distance increased the modulus of elasticity of resin cement. The resulted modulus of elasticity is shown in Table 2. At a distance of 0 mm, it that 2870.81 N/mm^2. The closer distance between the light-curing and the specimen increased the light intensity, which, therefore, resulted in higher total energy value. The reason was that the total energy has a corresponding variation according to the theory *total energy = light intensity x exposure time,* where the total energy stimulated the initiator, which causes the free radical disintegration even more and led to more polymerization (DeWald et al., 1987; Taqa, Suliman et al., 2016).

An error of our experimental group results might be found due to the below reasons;

1. The crack of specimens could occur during the process of specimen removal from the mold.
2. Void could happen during the process of inserting resin into the mold.

3. Upside-down between top and bottom surface of specimens before applied a load to the specimens.

Therefore, the study would like to recommend for improvement in future research

1. Caution to remove material from the mold.

2. Void might occur anytime when we load the resin into the mold. Therefore, every specimen should be checked for void through a light microscope before compressing. Also, it should be rechecked through Scanning Electron Microscope (SEM) after compressing. The specimen should be excluded from the experimental test when the void is found.

3. Accurately marked position at the top surface of specimens before applied a load to the specimens.

5. Conclusion

From this study, an increase in the exposure time led to an increase in the modulus of elasticity of dual-cure resin cement. The tip of the light-curing unit should be placed as close to the surface of restoration as possible to obtain the highest modulus of elasticity. Besides, a longer time of curing and a shorter distance between the light cure and the resin cement will also increase the modulus of elasticity of resin cement. Lastly, the increasing modulus of elasticity will increase the mechanical property of resin cement. If the fractural strength of resin cement were increased, it would improve the fracture resistance of restoration.

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