Effects of distance from tip of LED light-curing unit and curing time on surface hardness of nano-filled composite resin

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Abstract. Polymerization process depends on several variables, including the hue, thickness, and translucency of the composite resin, the size of the filler particles, the duration of exposure to light (the curing time), the intensity of the light, and the distance from the light. This study aimed to analyze the effects of the distance from the tip of the light-emitting diode (LED) light-curing unit and of curing time on the surface hardness of nano-filled composite resin. 60 specimens were prepared in a mold and divided into 6 groups based on various curing distances and times: 2 mm, 5 mm, and 8 mm and 20 seconds and 40 seconds. The highest surface hardness was seen in the group both closest to the tip and having the longest curing time, while the lowest hardness was seen in the group both farthest from the tip and having the shortest curing time. Significant differences were seen among the various tip distances, except for in the two groups that had 8-mm tip distances, which had no significant differences due to curing time. Both decreased distance from the tip of the LED light-curing unit and increased curing time increase the surface hardness of nano-filled composite resin. However, curing time increases the surface hardness only if the tip distance is ≤ 5 mm.

1. Introduction
Composite resin is a direct restorative material frequently used for tooth restoration treatments [1]. With advancements in nanotechnology in dentistry, modifications in organic matrix and inorganic filler materials have led to the development of new materials with nano-sized particles and increased numbers of particles that do not alter the material’s viscosity, producing better mechanical and esthetic properties. This material is called nano-filled composite resin. The mechanical properties of light-cured composite resin can be studied by evaluating its surface hardness. In the clinical environment, decreased surface hardness of a material contributes to anatomical form and discoloration, which result in failure of the restoration [2]. The present study evaluated the surface hardness of composite resin using the Vickers hardness test as seen on a Zwick Roell™ Hardness Tester.

The quality of a composite resin restoration depends on its polymerization process, and this process depends on several variables, including the hue, thickness, and translucency of the composite resin, the size of the filler particles, the duration of exposure to light (the curing time), the intensity of the light, and the distance from the light source [3]. Strassler noted that the type of light-curing unit most frequently used in dental practice is the light-emitting diode (LED) unit, due to its high efficiency in photo-polymerization compared to other types of light-curing units. LED lights have a longer life and less output degradation with use over time and produce minimal heat compared to halogen lights [4].
To produce a long-lasting restoration, the curing time for nano-filled composite resins with body shade and a 2-mm thickness can be reduced to 20 seconds if the distance of the surface from the tip of the LED light-curing unit is less than 5 mm [5]. However, according to Groninger, curing time does not significantly affect the surface’s hardness. Groninger studied the hardness of nano-filled composite resin with body shade that had been polymerized using LED and quartz tungsten halogen (QTH) at various curing times and a distance of 8 mm [6].

Thome et al. used 1 mm as the distance from the tip of the LED light-curing unit; however, this is not always clinically applicable [3]. During the polymerization process, cusp tips, proximal restorations, or the position of the tooth in the dental arch may prevent the ideal positioning of the light-curing unit relative to the surface of the restoration, thereby preventing complete polymerization of the composite resin [7]. Price et al. found that in Class I restorations, the distance from the tip of the LED light-curing unit to the composite resin can as little as 2 mm, but in Class II restorations, the distance between the cavity surface and the gingival margin can be more than 7 mm. Other studies have shown that curing distance is seldom ideal but that doubling the recommended curing time to 40 seconds can increase the effectiveness of the process [8].

2. Materials and Methods
First, a cylindrical metal mold 4 mm in diameter and 2 mm in height was prepared. Then, nano-filled composite resin (Filtek™ Z350 XT (3M ESPE, USA) body shade A3) was applied to the mold. The composite resin was cured using an LED light-curing unit (LITEX™) for various curing times and smoothed and polished using a Sof-Lex™ Extra Thin Contouring and Polishing System (3M ESPE, USA). Next, the specimen was removed from the mold, placed in a pot filled with artificial saliva, and incubated at 37 °C for 24 h. After 24 h, the surface hardness of the specimen was evaluated using a Zwick Roell™ Hardness Tester.

Plasticine was used to fixate each specimen, positioned flat and even, on a glass slide, with the indenter tool located at the edge of the specimen. Surface hardness was evaluated using the Vickers hardness test, measured at 3 points with a load of 300 g for 10 s, and the results were recorded.

The data obtained were statistically analyzed using the SPSS version 17 software program. If the data distribution was normal and homogenous, a One-Way ANOVA test was conducted, followed by a Post-Hoc test using Tukey’s Multiple Comparison with a 5% significance. If the results obtained were \( p \leq 0.05 \), then they were significantly different, but if the results were \( p \geq 0.05 \), then they were not significantly different. If the data distribution was not normal and homogenous, a Kruskal-Wallis test was conducted, followed by a Mann-Whitney analysis.

3. Results and Discussion

3.1 Results
The specimens were produced and the surface hardness of the nano-filled composite resin was evaluated in the Faculty of Mechanical and Aerospace Engineering Institute of Technology Bandung between August 15 and August 30, 2016. The specimen criteria were nano-filled composite resin that had been manipulated according to the manufacturer’s guidelines and then applied to a metal mold 4 mm in diameter and 2 mm in height (ISO 4049). The study used 10 specimens each in 6 groups, for a total of 60 specimens.

The study was laboratory experimental research (an in-vitro study), the objective of which was to analyze the effects of curing time and distance from the tip of an LED light-curing unit on the surface hardness of nano-filled composite resin. The 6 test groups used various combinations of the following curing distances and times: 2 mm, 5 mm, and 8 mm and 20 seconds and 40 seconds. Because the number of samples was less than 50, after the data were obtained, a normality test was conducted using the Shapiro-Wilk test. The results of the normality test showed that the \( p \) value for each group was 0.05, indicating that the data distribution was normal. Therefore, the significance analysis for the surface hardness was conducted using the statistical parametric method, the One-Way ANOVA, which showed that the \( p \) value (\( p = 0.00 \)) was obtained. Table 1 represents the statistical significance score of
the surface hardness of the nano-filled composite resin for each test group. From these results, it can be concluded that there was a significant difference for each test group (p < 0.05) except for groups E (curing distance 8 mm and curing time 20 seconds) and F (curing distance 8 mm and curing time 40 seconds), for which the p values were 0.983.

Table 1. Significance scores between test groups

|       | A    | B    | C    | D    | E    | F    |
|-------|------|------|------|------|------|------|
| Group |      |      |      |      |      |      |
| A     | -    | 0.000| 0.000| 0.001| 0.000| 0.000|
| B     | 0.000| -    | 0.000| 0.000| 0.000| 0.000|
| C     | 0.000| 0.000| -    | 0.000| 0.000| 0.000|
| D     | 0.001| 0.000| 0.000| -    | 0.000| 0.000|
| E     | 0.000| 0.000| 0.000| 0.000| -    | 0.983*|
| F     | 0.000| 0.000| 0.000| 0.000| 0.983*| -    |

* no significant difference

Group A : curing distance 2 mm and curing time 20 seconds
Group B : curing distance 2 mm and curing time 40 seconds
Group C : curing distance 5 mm and curing time 20 seconds
Group D : curing distance 5 mm and curing time 40 seconds
Group E : curing distance 8 mm and curing time 20 seconds
Group F : curing distance 8 mm and curing time 40 seconds

This insignificant difference between groups E and F indicated that at a distance of 8 mm, the effect of curing time on surface strength was no longer significant. However, at curing distances of 2 mm and 5 mm, curing time still had a significant effect on surface strength. Groups A, C, and E were cured for 20 seconds and 2, 5, and 8 mm, respectively, and groups B, D, and F were cured for 40 seconds at the same respective distances. The significance of each group was 0.000 (p < 0.05), meaning that at any distance, curing time significantly affected surface hardness.

3.2 Discussion

Based on the results presented in Table 2, it can be concluded that curing distance and time both significantly affect the surface hardness of nano-filled composite resin. The results showed that the average surface hardness of the test groups ranged from 72.40 kg/mm² to 80.33 kg/mm². A range of hardnesses is acceptable because a composite resin restoration must have a surface hardness that is at least equal to that of dentin, which has a surface hardness of 57–60 kg/mm².

The range in the study’s results showed that the surface hardness of nano-filled composite resin is closer to that of dentin. However, the highest surface hardness results obtained were only ¼ than that of enamel, which is 343 kg/mm². Group B obtained the highest surface hardness, and it experienced both the closest curing distance (2 mm) and the longest curing time (40 seconds). By minimizing curing distance while prolonging curing time, it enhanced the surface hardness of the restoration. These results were also in accordance with those of Segal et al. (2015), who found that longer distances from the tip of the LED light-curing unit to the restoration resulted in decreased intensity of the light received by the restoration [8]. That study also found that the intensity of light on the surface was inversely proportional to the distance between the light source and the surface squared [8].
Table 2. Surface hardness scores of each test group (vhn)

| Group | Mean  | Standard Deviation | Minimum Score | Maximum Score |
|-------|-------|--------------------|---------------|---------------|
| A     | 78.79 | 0.60               | 78.34         | 79.24         |
| B     | 80.33*| 0.53*             | 79.89*        | 80.78*        |
| C     | 76.00 | 0.66               | 75.55         | 76.45         |
| D     | 77.43 | 0.70               | 76.99         | 77.88         |
| E     | 72.40 | 0.90               | 71.95         | 72.85         |
| F     | 72.62 | 0.77               | 72.17         | 73.06         |

* Test group with highest surface hardness

Group A: curing distance 2 mm and curing time 20 seconds
Group B: curing distance 2 mm and curing time 40 seconds
Group C: curing distance 5 mm and curing time 20 seconds
Group D: curing distance 5 mm and curing time 40 seconds
Group E: curing distance 8 mm and curing time 20 seconds
Group F: curing distance 8 mm and curing time 40 seconds

Therefore, it can be concluded that increased curing distance results in decreased intensity of the light received by the composite resin. Furthermore, light intensity is maximized if the curing distance is 0 mm and the light source is perpendicular to the composite resin surface [8]. Thus, it can be stated that a curing distance as close as possible to the surface of the restoration maximizes the polymerization of the composite resin. Malhotra and Mala [9] noted that a short distance between the tip of the LED light-curing unit and the surface of the restoration more evenly distributed light throughout the restoration. This is because light disperses in open spaces. A longer curing distance causes light to disperse rather than focus on a certain area, thus decreasing the degree of polymerization. This decreased degree of polymerization results in incomplete polymerization of the monomers, causing decreased surface hardness and increasing the risk of thermal injury [9, 10]. The results presented in Table 1 support the minor hypothesis, which stated that shorter curing distances and longer curing times increase the surface hardness of nano-filled composite resin. At a distance of 5 mm or less, the effect of curing time was still significant. However, at a curing distance of 8 mm, curing time no longer significantly affected surface hardness because the curing distance was too long, minimizing the light intensity received by the composite resin due to dispersal and lack of focus. This effect is important, because light intensity produces light energy, which is needed to initiate the polymerization process.

According to the energy formula stated by Malhotra and Mala, light energy is light intensity times the duration of light exposure [9]. This means light energy is directly proportional to light intensity. Thus, if the intensity received is minimal, the light energy received by the composite resin will also be minimal, causing a low degree of polymerization. At longer curing distances, decreased light intensity results in decreased activated photo-initiators, which are needed for polymerization. Filtek Z350 XT composite resin has three types of photo-initiators: champleoroquinone, iodonium salt, and tertiary amine. Unreacted photo-initiators result in incomplete conversion of monomers to polymer chains, and the hardness of composite resin depends on the degree of monomer conversion [9]. At a curing distance of 8 mm, the curing time was not significant, which is in accordance with the results of Groninger’s study of the effects of various types of light-curing units and curing times on the surface hardness of nano-filled composite resin at a curing distance of 8 mm. The study used light intensities of 700 mW/cm² and 1100 mW/cm². The study found that to increase the quality of the polymerization process at a distance of 8 mm, a light-curing unit with a light intensity greater than 1100 mW/cm² is needed [6].

In clinical application, when a short curing distance is not possible, curing time and the intensity of the light from the light-curing unit must be increased to achieve maximum surface hardness. However, the curing distance must still be no more than 5 mm. A few other factors must also be considered,
including tooth structure, the light-curing unit, and the environment [9]. The status of the curing unit should be evaluated periodically to ensure that it is still in optimal condition. Studies have found that light-curing units used in dental practices do not emit sufficient radiation to achieve maximum photopolymerization [11]. This was supported by a study by Maghaireh et al. [12], who found that the radiation of the light-curing unit was affected by the type of unit, how long the unit was, the number of times the unit was used each day, residual composite resin on the unit tip, the size of the tip, and the curing time. According to that study, composite resin restorations generally did not experience sufficient polymerization, causing them to be resistant to low abrasion [12]. Therefore, to compensate, the light energy emitted by the light-curing unit must be increased [5].

4. Conclusion
The closer the tip of the LED light-curing unit is to the surface of the nano-filled composite resin restoration, the greater the surface hardness of the restoration. In addition, when the curing distance is longer than 5 mm, longer curing times increase the surface hardness of nano-filled composite resin. Therefore, future studies should place the tip of the LED light-curing unit 2 mm from the resin and perpendicular to the surface of the restoration. However, in practice, if the tip of the unit cannot be 2 mm from the restoration, dentists can use a longer curing time to increase the degree of polymerization. Furthermore, dentists should periodically evaluate the condition of their light-curing units to ensure that they produce maximal light intensity, which achieves optimal polymerization. Further study is needed to evaluate the effects of light intensity and curing time on the surface hardness of nano-filled composite resin and to evaluate and compare the surface hardness of nano-filled composite resin and enamel.

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