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Research Article

Effect of Light-Curing Duration on the Surface Hardness of Nanohybrid Composite Resin

[1]I Gusti Ngurah Bagus Tista, [1]Kadek Lusi Ernawati, [2]I Gusti Ayu Raras Mayfanka

[1]Department of Conservative Dentistry, Faculty of Dentistry, Mahasaraswati University Denpasar, Indonesia
[2]Undergraduate Student, Faculty of Dentistry, Universitas Mahasaraswati Denpasar, Denpasar, Indonesia

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ABSTRACT

Introduction: Nanohybrid composite resin is widely used due to its favorable esthetic and mechanical properties. Surface hardness is an important property influencing resistance to masticatory forces and wear, and it depends on the effectiveness of polymerization. Inadequate light-curing can reduce cross-link formation, resulting in lower hardness. This study evaluated the effect of different light-curing durations on the surface hardness of nanohybrid composite resin.
Materials and Methods: This in vitro experimental study used a post-test-only design with 27 samples of Filtek Z250. Samples were divided into three groups based on light-curing durations of 20, 30, and 40 seconds. Surface hardness was measured using a Vickers Hardness Tester. Data were analyzed using One-Way ANOVA followed by Tukey HSD post hoc test.
Results and Discussion: The mean surface hardness values for 20, 30, and 40 seconds were 82.52 VHN, 84.69 VHN, and 92.85 VHN, respectively, showing increased hardness with longer curing time. A significant difference was found between the 20-second and 40-second groups ($p < 0.05$), while no significant differences were observed between 20 vs 30 seconds and 30 vs 40 seconds ($p > 0.05$). These findings indicate that longer light-curing improves polymerization and enhances surface hardness.
Conclusion: Light-curing duration significantly affects the surface hardness of nanohybrid composite resin, with longer curing times producing higher hardness values.

Corresponding Author:
I Gusti Ngurah Bagus Tista
Department of Conservative Dentistry, Faculty of Dentistry
Universitas Mahasaraswati Denpasar, Denpasar, Indonesia
Email: tistabagus@gmail.com

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INTRODUCTION

The increasing public awareness of physical appearance in the modern era has made dental esthetics one of the main concerns in oral health care. Esthetic problems such as tooth discoloration, minor fractures, diastema, disproportionate tooth shape, and surface wear often lead to decreased self-confidence. The use of restorative materials that resemble the color and structure of natural teeth has therefore become the preferred choice to overcome these problems. Composite resin is one of the most used materials in esthetic dentistry because it offers excellent esthetic properties, good adhesion to tooth structure, and can be applied directly (direct restoration) in a single visit. Advances in technology have led to the development of more sophisticated composite resins, such as nanohybrid composites, which provide superior esthetic results along with improved mechanical strength, thereby offering a long-term solution for contemporary esthetic dental problems.[1]

Nanohybrid composite resin is a restorative material composed of three main components: a resin matrix, filler particles, and a coupling agent. Innovations in this type of composite involve the combination of nano- and micro-sized filler particles to enhance the mechanical and esthetic properties of the material. The incorporation of nanoparticles allows for a higher filler loading, which contributes to a reduction in the resin matrix content and simultaneously decreases polymerization shrinkage to approximately 1%.[1] Nanohybrid composite resin is used for direct restoration of dental cavities in clinical applications. This material enables shade and contour adjustment of teeth, thereby improving the esthetic outcome of restorations. The addition of nanoparticles such as zirconia and alumina to nanohybrid composite resin has been shown to increase Vickers hardness and fracture strength, making the material more resistant to masticatory loads and wear.[2] Another advantage of nanohybrid composite resin is its ability to produce a smoother restoration surface after polishing, which is important for esthetic restorations. A uniform distribution of filler particles within the resin matrix contributes to improved compressive and flexural strength of the material.[3]

The degree of polymerization during the curing process is primarily determined by light intensity and exposure time. In general, the recommended light-curing time for nanohybrid composite resin is approximately 20–40 seconds for a 2-mm thick layer, with a minimum light intensity of 1000 mW/cm^2 to achieve adequate polymerization and optimal surface hardness. Similar to conventional composites, nanohybrid composites are usually applied using an incremental technique, with each layer having a maximum thickness of 2 mm to ensure sufficient light penetration for complete polymerization. Light intensity below the recommended level or insufficient curing time may result in incomplete polymerization, leading to reduced mechanical properties such as hardness and wear resistance.[4-5]

Surface hardness is one of the most important mechanical properties of nanohybrid composite resin, as it determines the material's resistance to masticatory forces and surface wear. Hardness is defined as the resistance of a material to penetration or localized deformation under an applied force.[6] This property is highly dependent on the success of the polymerization process, which determines the quality of the resin matrix and the bonding between filler particles.[6] Suboptimal light-curing, either in terms of duration or intensity, may result in incomplete polymerization. A lower degree of polymerization leads to fewer cross-links within the resin matrix, which in turn reduces surface hardness.[7]

Based on this background, the research problem was formulated as whether the duration of light curing affects the surface hardness of nanohybrid composite resin. This study aimed to evaluate the effect of light-curing duration on the surface hardness of nanohybrid composite resin. The academic significance of this study lies in contributing to the body of knowledge regarding nanohybrid composite resins in dentistry and providing a basis for further research on the influence of curing time on their surface hardness. Clinically, the results are expected to serve as a reference for determining the appropriate curing time for nanohybrid composite resin in dental practice.

MATERIALS AND METHODS

This study was an in vitro laboratory experimental study with a Post-Test Only Group Design aimed at evaluating the effect of variations in light-curing duration on the surface hardness of nanohybrid composite resin. The population of this study consisted of all brands of nanohybrid composite resin available on the market. The sample used was a nanohybrid composite resin (Filtek Z250, USA) molded into specimens with a diameter of 6 mm and a height of 5 mm. The number of samples was determined using Federer's formula, resulting in 9 specimens for each treatment group, with a total of 27 specimens. The study consisted of three groups: P1 (light curing for 20 seconds at an intensity of 1000 mW/cm^2 and a wavelength of 468 nm), P2 (light curing for 30 seconds at an intensity of 1000 mW/cm^2 and a wavelength of 468 nm), and P3 (light curing for 40 seconds at an intensity of 1000 mW/cm^2 and a wavelength of 468 nm).

Purposive sampling was employed to ensure that the samples met the research criteria. The independent variable was light-curing duration (20, 30, and 40 seconds), while the dependent variable was the surface hardness of the nanohybrid composite resin expressed in Vickers Hardness Number (VHN), measured using a load of 60 kg for 30 seconds. Controlled variables included the type of composite material, the light intensity of the curing unit, specimen mold dimensions, curing distance, and the loading rate of the Vickers Hardness Tester.

The specimen molds were made of wax/plasticine with a diameter of 6 mm and a height of 5 mm using plastic straws on a glass slab. A light-curing unit with an intensity of 1000 mW/cm^2 was used for polymerization. Surface hardness testing was performed using a Vickers Hardness Tester equipped with a microscope.

The molds were evenly coated with petroleum jelly, and the composite resin was inserted into the molds using a plastic filling instrument until completely filled without air bubbles. The surface of the composite was flattened using a celluloid strip to obtain a smooth and flat surface. Light curing was performed perpendicular to the specimen surface at a distance of 1 mm according to the assigned curing time for each group. This procedure was repeated until all specimens in each group were prepared. After polymerization, the specimens were removed from the molds using a mouth mirror handle and tested using a Vickers Hardness Tester with a diamond pyramid indenter (136° angle). A load of 60 kg (1471 N) was applied for 30 seconds. After loading, the lengths of the two diagonals of the indentation (d_1 and d_2) were measured under a microscope, and the Vickers hardness value was calculated based on the average of the two diagonals using the standard formula: VHN =

$1.854 \times P / d^2$, where VHN is the Vickers hardness value (kg/mm^2), P is the applied load (kg), and d is the average diagonal length of the indentation (mm). This study was conducted in October 2025 at the Materials Laboratory, Faculty of Mechanical Engineering, University of Mataram.

RESULTS AND DISCUSSIONS

Table 1. Descriptive Statistics of Surface Hardness Values

Light curing duration	N	Mean	Standard Deviation
20 seconds	9	82.52	8.343
30 seconds	9	84.69	8.386
40 seconds	9	92.85	4.587

Table 1 shows the surface hardness values of nanohybrid composite resin cured for 20, 30, and 40 seconds. The mean surface hardness values were 82.52 VHN ± 8.343, 84.69 VHN ± 8.386, and 92.85 VHN ± 4.587, respectively. These results indicate that specimens cured for longer durations tended to exhibit higher surface hardness values.

To evaluate the effect of light-curing duration on the surface hardness of nanohybrid composite resin, statistical analyses were performed, including normality testing, homogeneity testing, one-way ANOVA, and post hoc Tukey HSD analysis. Normality testing was conducted using the Shapiro–Wilk test because the sample size in each group was fewer than 50 specimens. The test was performed using a significance level of $\alpha = 0.05$. The results of the normality test are presented in Table 2.

Table 2. Shapiro–Wilk Normality Test Results

Group	Statistic	df	Sig	Interpretation
20 sec	0.870	9	0.122	Normal
30 sec	0.962	9	0.816	Normal
40 sec	0.953	9	0.718	Normal

The results of the Shapiro–Wilk test demonstrated that all groups showed significance values greater than 0.05. Specifically, the significance values were 0.122 for the 20-second group, 0.816 for the 30-second group, and 0.718 for the 40-second group. Based on the decision criteria, these findings indicate that the data in all groups were normally distributed.

Following confirmation of normal data distribution, homogeneity of variance among groups was assessed using Levene's test, with a significance level of $\alpha = 0.05$.

Table 3. Levene's Test for Homogeneity of Variance

Variable	Lev Statistic	df1	df2	Sig.	Interpretation
Surface hardness of composite resin	2.867	2	24	0.076	Homogeneous

The Levene's test results showed a significance value of 0.076, which is greater than 0.05, indicating that the variances among the groups were homogeneous.

After fulfilling the assumptions of normality and homogeneity, one-way ANOVA was performed to determine the effect of light-curing duration on surface hardness. The results are presented in Table 4.

Table 4. One-Way ANOVA Results

	Sum of Squares	df	Mean	F	Sig.
Between groups	534. 133	2	267.067	4.977	0.016
Within groups	1287.838	24	53.660		
Total	1821.972	26			

The one-way /ANOVA analysis revealed a significance value of 0.016, which is lower than the significance level of 0.05. Based on these results, the null hypothesis was rejected, indicating that there was a statistically significant difference in surface hardness among the groups cured for 20, 30, and 40 seconds. These findings suggest that light-curing duration significantly influences the surface hardness of nanohybrid composite resin, with longer curing durations generally resulting in higher hardness values.

A post hoc Tukey HSD test was performed to identify specific differences between groups. A significance level of $p < 0.05$ was considered statistically significant.

Table 5. Tukey HSD Post Hoc Test Results

Comparison	Mean ± SE	p-value	95% CI
20 vs 30	-2.170 ± 3.453	0.806	-10.794 to 6.454
20 vs 40	-10.331 ± 3.453	0.017*	-18.955 to -1.708
30 vs 40	-8.161 ± 3.453	0.066	-16.784 to 0.462

Note: Mean= mean difference (I–J); SE = standard error.; $p < 0.05$ indicates statistically significant difference; CI = confidence interval; Only unique pairwise comparisons are presented.

The post hoc test results showed that there were significant differences among several light-curing time groups. The comparison between the 20-second and 40-second curing groups revealed a mean difference of −10.33111 with a significance value of 0.017, indicating $p < 0.05$; therefore, the difference was statistically significant. This means that light curing for 40 seconds produced significantly higher surface hardness of nanohybrid composite resin compared with curing for 20 seconds. In contrast, the comparisons between the 20-second and 30-second groups and between the 30-second and 40-second groups yielded significance values of 0.806 and 0.066, respectively, both greater than 0.05, indicating that these differences were not statistically significant.

The results demonstrated that the mean surface hardness increased with increasing curing time, namely 82.52 VHN at 20 seconds, 84.69 VHN at 30 seconds, and 92.85 VHN at 40 seconds. This increase indicates that curing duration plays an important role in the polymerization process of nanohybrid composite resin, particularly within certain time ranges, with a significant effect observed at 40 seconds of curing. The increase in surface hardness with longer curing times is consistent with the basic principles of free-radical polymerization, in which prolonged exposure to curing light results in a greater conversion of C=C double bonds into C–C single bonds, thereby increasing the degree of conversion.[8]

The findings of this study are in accordance with previous studies by Haifa Barakah[9], Duratbegović[10], and Oglakci[11,] which reported that increasing curing time leads to an increase in surface hardness.[9–11] Barakah[9] evaluated the effect of different curing times (20, 40, and 60 seconds) on the surface hardness (Vickers Hardness Number, VHN) of a nanofilled resin-based composite (Tetric-N-Ceram) using high-intensity LED light-curing units and found that VHN increased as curing time was extended, with 40-second and 60-second curing producing significantly higher VHN values than 20-second curing.

Furthermore, Duratbegović[10] investigated the effect of curing time (20 and 40 seconds) on surface hardness (Vickers Microhardness, VHM) and the bottom-to-top hardness ratio (HR) of Tetric EvoCeram composite. Their results showed that increasing the exposure time from 20 to 40 seconds significantly affected both VHM-bottom and HR. In another study, Oglakci[11] evaluated the effect of different curing times using third-generation LED LCUs on the mechanical properties of nanocomposites, particularly microhardness (Vickers hardness), flexural strength, and resilience modulus. The composite materials tested were Estelite Posterior Quick (EP), a supra-nanohybrid composite, and Solare X (SX), a nanohybrid composite, which differ in filler size, filler content, and photoinitiator systems. For both composite types, longer curing times resulted in higher microhardness values. Their main findings indicated that curing with high-power mode for 20 seconds produced higher hardness values than curing for 12 seconds on both the top and bottom surfaces, demonstrating that increasing curing time from 12 to 20 seconds significantly improved hardness. In the supra-nanohybrid composite (EP), standard-mode curing for 20 seconds produced higher hardness values than extra-power-mode curing for 6 seconds, indicating that a longer curing time was more effective than a very short exposure, even when irradiance was higher. In the EP composite, extra-power-mode curing for 6 seconds yielded the lowest hardness values, significantly lower than those obtained with standard-mode curing for 20 seconds and high-power-mode curing for 12 seconds, despite the high irradiance (3200 mW/cm^2) used in the extra-power mode.

The main results of the present study (82.52 VHN, 84.69 VHN, and 92.85 VHN) show a pattern consistent with the literature, indicating that longer curing durations tend to produce higher surface hardness. Mechanistically, this can be explained by an increased degree of monomer conversion, a higher number of cross-links, and the formation of a denser polymer network. Barakah's study demonstrated that a nanohybrid composite (Tetric-N-Ceram) cured for 40 or 60 seconds exhibited significantly higher hardness than that cured for 20 seconds, supporting the conclusion that nanocomposites require sufficient light energy to achieve optimal polymer chain formation. Oglakci's findings further support that curing for 40 seconds results in a significant increase in hardness because longer exposure increases the degree of conversion, which in turn enhances hardness. Oglakci[11] also showed that excessively short curing times hinder polymerization, particularly in composites with densely packed nano-fillers, as insufficient exposure does not allow adequate light penetration, resulting in incomplete polymerization and lower hardness. Although curing mode and irradiance influence polymerization, curing duration plays a more stable and consistent role in increasing microhardness, especially compared with very short exposures at high irradiance.

These observations are in agreement with the present results, which showed that increasing curing time from 20 to 30 seconds did not produce a significant difference (p = 0.806), whereas increasing curing time from 20 to 40 seconds resulted in a significant increase in hardness (p = 0.017). This supports the concept of a certain time threshold before an increase in the degree of conversion becomes mechanically significant, thereby validating the finding that the 40-second group exhibited the highest hardness.

At a curing time of 20 seconds, the hardness values were lower than those of the other groups, which may be attributed to insufficient time to achieve maximal polymerization, particularly in nanohybrid materials with dense nano- and micro-filler content that require longer exposure for adequate light penetration.[7] Curing for 30 seconds showed an increase in hardness compared with 20 seconds, but the difference was not statistically significant (p = 0.806). This indicates that an additional 10 seconds from 20 to 30 seconds was not sufficient to produce a substantial increase in the degree of conversion, as the composite may have reached the initial stage of polymerization but not yet formed an optimally dense polymer network. In contrast, curing for 40 seconds produced a significant increase in hardness compared with 20 seconds (p = 0.017), as this duration allows the formation of a denser and more highly cross-linked polymer network, thereby enhancing resistance to surface deformation.

Nanohybrid materials contain densely packed nano- and micro-fillers, which may hinder light penetration compared with conventional composites and therefore require longer curing times to achieve optimal polymer network formation.[7] The surface hardness of composite resin is influenced by the degree of conversion, the size and amount of filler particles, and the density of cross-linking formed during polymerization.[1,3,8] The higher the filler content and the more efficient the cross-link formation, the higher the surface hardness.[1,3] With increasing curing duration, more free radicals are generated, accelerating the propagation reaction and resulting in the formation of longer and more numerous polymer chains. Consequently, the polymer network becomes denser, contributing to increased hardness and improved mechanical stability under masticatory loads.[12] Curing for 40 seconds provides sufficient energy to overcome light attenuation caused by the dense filler content of nanohybrid composites, which explains the significant increase in hardness observed in this group.

These findings provide important information regarding the optimal curing duration for nanohybrid composite resin in clinical applications. Based on the results, curing for 20 seconds can produce surface hardness, but it is not yet optimal. Curing for 30 seconds is clinically acceptable but does not yield a significant increase in hardness. Curing for 40 seconds is recommended to achieve optimal polymerization quality, particularly for thicker restorations, posterior teeth, or nanohybrid composites with high filler density. This implication is clinically relevant, as surface hardness is closely associated with abrasion resistance, restoration longevity, and resistance to long-term masticatory loads.

CONCLUSION

Curing time significantly influences the surface hardness of nanohybrid composite resin. A longer curing duration, particularly 40 seconds, was proven to significantly increase the surface hardness of nanohybrid composite resin.

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