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Effect of Nd: YAG Laser on Hardness and Color Change of High Impact Acrylic Denture Base Material

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Abstract
Polymethyl methacrylate (PMMA) is widely used for denture bases but suffers from limited fracture resistance; high impact acrylic, enhanced with butadiene styrene rubber, improves strength. Lasers, particularly the Nd: YAG type, have been used to modify acrylic surfaces, mainly to enhance bonding with soft liners; however, little is known about the effect of Nd: YAG laser treatment on other properties like hardness and color, which are critical for clinical performance and esthetics. The study objective was to evaluate the effect of nanosecond pulsed Nd: YAG laser irradiation with two different hatch values on the hardness and color of high-impact acrylic denture base material. Fifty acrylic samples were made and divided into three groups: untreated control, laser-treated at 0.03 mm hatch (H3), and laser-treated at 0.05 mm hatch (H5). Hardness was measured using a Shore D durometer, and color changes were evaluated with a digital colorimeter using the CIELab system; chemical surface analysis was conducted by FTIR spectroscopy. Statistical analysis included ANOVA and independent t-tests, with a significance level at $p \leq 0.05$. The results of FTIR spectra showed no chemical changes in acrylic after laser treatment, and hardness values did not differ significantly among groups ($p > 0.05$); however, laser treatment resulted in a significant color change, with ΔE values corresponding to a "much" perceptible color difference, which may compromise esthetics ($p \leq 0.05$). In conclusion, Nd: YAG laser treatment does not alter the chemical structure or hardness of high-impact acrylic denture base material but induces significant color changes that could adversely affect esthetic outcomes.
Keywords: Nd: YAG laser, Hardness, Color, Denture base.

1. Introduction

Walter Wright used polymethyl methacrylate (PMMA) material for the first time in 1937. Since that time, it has been considered the most common material to be used for the construction of partial and complete dentures, as it is easily processed, economical, lightweight, and has some other good mechanical properties [1,2]. However, it does not have sufficient strength to resist fractures resulting from falling on a hard surface or fatigue fractures due to continuous exposure to masticatory forces [3]. As a result of these frequent fractures, it became crucial to enhance the fracture resistance and impact strength of the PMMA denture base material. The high-impact acrylic denture base material was produced to overcome this problem by incorporating butadiene styrene rubber into the conventional PMMA[4].

From the time of inventing the first functional laser in 1960 by Maiman, lasers have been used extensively by many dental specialties. In dental practice, lasers have been approved to be effective in several applications due to their simplicity and safety. It is used in surgeries for soft tissues, making tooth surfaces more resistant to caries, reducing root canal bacterial contamination, decreasing dentin sensitivity, and sealing pits and fissures sealing [5]. Lately, they have been proven to be a valuable tool in modifying materials' surfaces [6]. Modifying surfaces with lasers allows easy regulation and reproduction of the surface patterns, assuming that the parameters are modified to make them suitable for each type of material and for each purpose [7].

The amount of laser optical penetration, which depends on laser specifications and surface nature, makes it a suitable option for treating acrylic surfaces. Other factors that may influence the result of laser treatment are the scanning rate and the amount of space between the laser head and the treated surface. The space affects the focusing and defocusing modes, which modify the capacity of the device to make holes by radiation [8]

Different types of lasers are used in dentistry; an example is the Neodymium: yttrium-aluminum-garnet (Nd: YAG) laser. It is effective in removing caries, reducing bacterial infection in root canals, lowering the sensitivity of dentin, and mineralizing initial caries [5]. The nano-pulse Nd: YAG laser uses shorter pulses that are considered an economical way to make a controlled change in surface micromorphology by the elimination of slight parts of the material without causing damage to the nearby areas [7].

Lasers have been widely used in the literature, besides other mechanical and chemical techniques, for surface modification of the acrylic denture base before the application of soft liners in order to enhance the adhesion strength between the two materials [9]. Most of the studies focused on studying the influence of laser irradiation on the acrylic denture bases on the acrylic surface roughness and the bonding strength between the soft liners and the denture base material [10-14]. On the other hand, the influence of laser treatment on other properties of acrylic denture base materials, such as hardness and color, has not been widely reported.

The hardness of the acrylic denture base is a major contributing factor that governs the ease of polishing and the ability to withstand scratching and abrasion during clinical use and during cleaning [15]. It can also affect the bond strength of soft denture liners to the denture base. The increased acrylic hardness and the high degree of crosslinking can negatively affect the adhesion of soft liners, especially the polymer-based liners. This is due to the inability of the monomer from the soft liner to penetrate the high-density polymer network, thus impairing the adhesion [16]. The hardness test is considered an accurate and easy approach to investigate the mechanical properties of polymeric materials [17].

A natural-appearing denture foundation is usually slightly transparent in order to create a "chameleon effect" that allows the surrounding structures and underlying tissues to gently show through and enhance its natural look [18]. Although this property is essential for giving a natural appearance, it also presents potential aesthetic concerns when internal modifications are made. For instance, laser application on the tissue side of the denture base can produce localized areas of surface changes that may be detectable through the thickness of the translucent denture base, compromising the denture esthetics. Thus, it is essential to investigate the optical effects of laser treatment when it is applied to areas that can be visible in the oral cavity.

This in-vitro study aims at investigating the effect of nanosecond pulsed Nd: YAG laser irradiation with two different hatch values on the hardness and the color of the high-impact acrylic denture base material.

2. Materials and Methods

Fifty acrylic specimens (30 for the hardness test and 20 for the color change test) were fabricated in **Figure 1** and divided into the following groups (n=10): Control group (for the hardness test only) was with no laser treatment, group (H3) was irradiated with an Nd: YAG laser at 0.03 mm hatch, and group (H5) was irradiated with an Nd: YAG laser at 0.05 mm hatch. For the construction of the test specimens, a plastic block measuring 30 mm in length and width with 6 mm thickness was duplicated in a laboratory silicone putty (Zhermack, Italy), which was prepared according to the instructions of the manufacturer. The plastic patterns were invested in silicone and left to allow the silicone to set. Then, the blocks with the silicone molds were invested into a fresh mixture of dental die stone type IV (Zhermack, Italy), filling the lower compartment of a dental flask. After stone setting, all surfaces were covered with separating medium, including the silicone and the patterns, then allowed to dry. Another mixture of dental die stone was then proportioned and mixed to pour the upper part of the flask, which was positioned accurately over the lower part, and poured with the use of a vibrator to eliminate the air bubbles. After the second layer of stone had set, the flask was opened and the plastic blocks were removed carefully by using a Lecron carver, leaving a space (mold) for the heat-cured high-impact acrylic material to be packed.

High-impact acrylic (Vertex, Netherlands) was mixed in accordance with the manufacturer's guidelines. Once the material had achieved the dough-like consistency, it was packed into the mold, flasked, and polymerized in a water bath using the manufacturer's suggested curing technique. Subsequently, it was left to cool gradually at room temperature and deflasked to remove the acrylic blocks from the silicone. All specimens were finished by grinding with Aluminium oxide abrasive paper with grit 600 [19]. The specimens were cleaned by using an ultrasonic cleaning device filled with distilled water with vibration for 10 minutes and conditioned according to ISO specifications 20795-1, 2013 [20] in distilled water at 37˚±1˚C temperature for 50 ± 2 hours before testing.

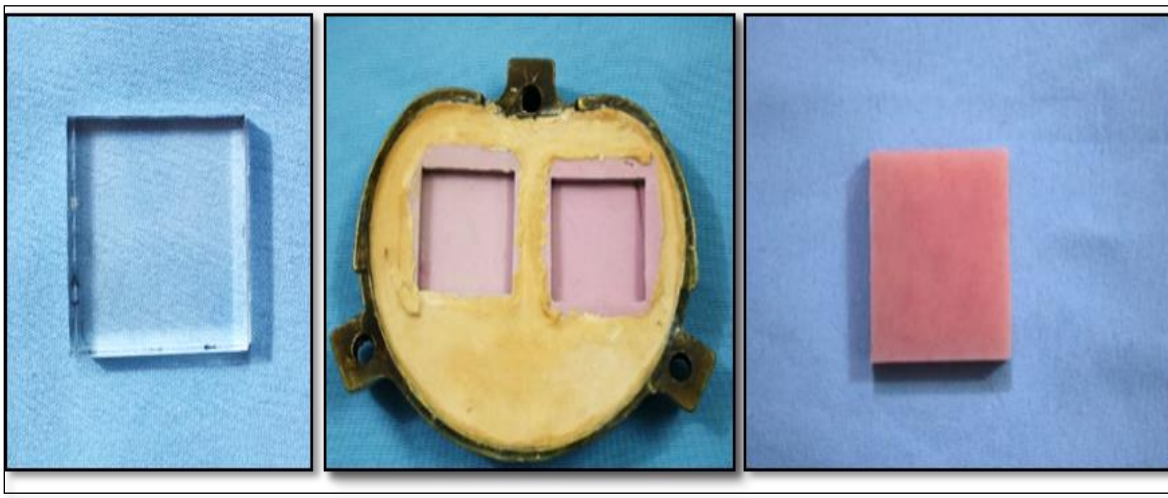

Figure 1. Acrylic sample preparation

Study specimens were treated by Nano-pulsed with a fiber optic lens Nd: YAG laser (Wuxi Raycus Laser Technologies Co., Ltd., China). The surface treatment was done with the following parameters: power of 1 watt, speed of 1 mm/s, hatch of 0.03 mm and 0.05 mm, frequency of 20 kHz, and standoff distance of 120 mm. The term "hatch" refers to the spacing between consecutive laser lines. Under the supervision of a laser specialist, the procedure was carried out at the Institute of Laser for Postgraduate Studies, University of Baghdad, in Baghdad, Iraq.

The hardness test was performed according to the ISO specification 868, 2003 [21], at the University of Babylon, Department of Material Engineering, by a Shore D hardness tester (Durometer TH210, TIME Group Inc., China) **Figure 2**. The test specimen was placed on the hard horizontal plane surface, and the device applied an even force (5 kg) to the specimen with the point of the indenter 9 mm away from any margin of the test specimen. Five hardness measurements were taken at different positions on each specimen, 6 mm apart, and the mean value of the measurements was determined.

Figure 2. Surface hardness testing by Shore D durometer

A digital colorimeter was used for color measurements **Figure 3**. Each specimen was examined for the color difference before and after laser treatment, and it was calculated with the aid of the Commission Internationale de l'Eclairage L* a* b* (CIELab) colorimetric system. The L, a, and b values of each specimen were measured before and after laser treatment. The ΔE^* was calculated by applying **Equation (1)** [22]:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad \textbf{(1)}$$

Where ΔE^* is the color change, L* indicates the amount of lightness of the material, a* corresponds to the chroma in the red-green region, and b* describes the chroma in the yellow-blue area. This system allows for determining the amount of the visible change in color for each acrylic specimen by using the National Bureau of Standards (NBS) units to describe the changes in ΔE [22]. To convert the ΔE values to NBS values, **Equation (2)** [23] was applied:

$$NBS = \Delta E \times 0.92 \quad \textbf{(2)}$$

Based on the resultant values, the amount of color change could be classified into trace, slight, noticeable, appreciable, much, and very much [23].

Figure 3. Color change test by colorimeter

One sample from each group was randomly selected to be examined for chemical surface analysis before and after laser treatment by using a Fourier Transform Infra-Red spectrophotometer device (Shimadzu, Japan).

GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA) was used to perform statistical analysis. Testing the normality of the distribution was through the Shapiro-Wilk test, the ANOVA test (one-way analysis of variance) was utilized for the mean value comparison among the tested groups of the hardness test, and the independent T-test was used to compare the two treatment groups for the color change test.

3. Results

3.1. Chemical surface analysis (FTIR)

The chemical analysis of the laser-treated and untreated samples using the FTIR analyzer revealed that there was no change in the position and the shape of the existing peaks, nor the formation of new peaks. The fingerprint region showed a similar appearance.

3.2. Surface hardness test

Descriptive statistics of the surface hardness test results showed a slightly higher mean of hardness in the laser-treated group (H3) in comparison to the other groups, as shown in **Table 1**.

Table 1. Descriptive statistics of surface hardness values of all experimental groups

Group	N	Mean	SD	SE	Minimum	Maximum
Control	10	80.99	1.377	0.4355	78.70	83.04
H3	10	81.60	1.332	0.4212	79.40	83.52
H5	10	80.96	0.8363	0.2645	79.90	82.26

A one-way ANOVA test was used to compare the means of the surface hardness values. The results revealed a non-significant difference among all of the tested groups. The results are shown in **Table 2**.

Table 2. One-way ANOVA test of surface hardness values between groups tested

	Sum of squares	df	Mean square	F	P-value
Between Groups	2.632	2	1.316	0.9034	0.4171
Within Groups	39.33	27	1.457		
Total	41.96	29			

3.3. Color change test

Descriptive statistics of the color change test showed that the laser-treated group (H3) had a higher mean of color change than the other group, as shown in **Table 3.**

Table 3. Descriptive statistics of the color change test of all experimental groups

Group	N	Mean	SD	SE	Minimum	Maximum
H3	10	9.742	0.538	0.170	9.01	10.78
H5	10	6.934	0.532	0.168	6.33	7.98

The unpaired t-test revealed that the means of the two groups differ significantly **(Table 4).**

Table 4. Unpaired t-test results for the color change test

Group	Mean	t-value	Df	*P*-value
H3	9.742	12.68	18	<0.0001
H5	6.934			

4. Discussion

4.1. Chemical Surface Analysis (FTIR)

The unchanged fingerprint region indicates that the core structure remained stable, proving that laser treatment did not cause a change in the main composition of the treated acrylic samples. These results are in line with the results of other studies [24,25], who stated that there was no evidence of chemical change in the PMMA following laser ablation.

4.2. Surface Hardness Test

Since the hardness of a material is greatly influenced by its chemical structure and crosslinking, any change in the microstructure can influence the material's hardness [26,27]. As mentioned earlier, the findings of the chemical analysis of the samples (FTIR) confirmed that the chemical structure of the acrylic polymer remained unchanged and the applied laser parameters did not cause polymer degradation, oxidation, or crosslinking. Therefore, the unaltered hardness values obtained from the Shore D test can be attributed to the inherent stability of the polymer microstructure under the laser conditions used. There was only one research found in the literature that discusses the effect of Nd: YAG laser on the hardness of the denture base material [28], where they found that the hardness of the acrylic denture base was increased following treatment with Nd: YAG laser. This contrary result may be attributed to the differences in the laser wavelength and parameters applied, the type of hardness test performed, and the denture base material used.

4.3. Color Change Test

The test results showed that both laser-treated groups showed a significant change in color of the acrylic samples after irradiation with the Nd: YAG laser. This change was expressed as “Much” when related to the NBS critical levels of the color changes. The mean ΔE obtained was in the range of 6-12 NBS units, which is listed as “Much”. This color change was not acceptable in vitro since the ΔE is higher than the accepted threshold, which is 3.7 [29]. The laser-treated samples showed areas of grayish-white appearance at the sites of the laser ablation. This can be explained by the fact that the surface of a polymer reacts with the applied laser beam by absorbing energy that causes a localized increase in temperature at the radiation site, leading to what is called “thermal degradation”. The amount of energy absorbed and the thermal properties of the irradiated material influence the lightness or darkness of the ablated areas [30].

Another explanation for that color change is the change in surface roughness. A study stated that the material color is highly governed by the spectral reflectance of its surface, which is extensively affected by its roughness [31]. The significant increase in surface roughness observed after laser irradiation, which was confirmed by a surface roughness test, affected the light-reflection characteristics of the acrylic polymer surface, which in turn affected the color and appearance of the material by changing the amount of light reflecting out of the surface, giving different values of color [32,33]. It was difficult to compare this result to other works, as there was no article found in the literature that discusses the effect of the laser radiation on the color of the acrylic denture base material.

5. Conclusion

From the study's results, it can be concluded that surface treatment of high-impact acrylic denture base material with a nanosecond Nd: YAG laser does not alter the chemical structure of the acrylic material, and therefore, there is no change in its hardness. In addition, this treatment can cause an obvious change in the appearance and color of the denture base material, which in turn negatively affects its esthetics.

Acknowledgment

Not applicable.

Conflict of Interest

The study's authors certify that they have no conflicts of interest.

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Ethical Clearance

There were no human or animal subjects in the study, and no personal information was gathered in any way. Thus, informed consent and ethical clearance were not necessary.

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