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Effects of Gadolinium Oxide Nanoparticles and Curing Techniques on the Acrylic Mechanical Properties

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Abstract

Objective: This study investigated the effects of gadolinium oxide (Gd_2O_3) nanoparticles on polymethyl methacrylate (PMMA) and compared the mechanical properties of denture base resins cured via UV laser and conventional water bath techniques.

Methods: Forty PMMA specimens were prepared, with half incorporating Gd_2O_3 nanoparticles. Samples were cured using one of two methods: a UV laser (150–400 nm wavelength, 10–25 minutes irradiation time) or a conventional water bath (74°C for 8 hours). The mechanical properties of all specimens were evaluated through transverse strength testing, porosity analysis, and surface roughness measurements.

Results: UV laser-cured specimens exhibited significantly higher transverse strength and significantly reduced porosity compared to water bath-cured specimens. Surface roughness showed a slight, non-significant increase with laser curing. The findings suggest that UV laser curing, combined with Gd_2O_3 nanoparticles, enhances PMMA's mechanical properties, offering a faster, more precise alternative to traditional water bath curing with potential clinical benefits in denture durability.

Conclusion: The findings indicate that UV laser curing, especially when combined with Gd_2O_3 nanoparticles, enhances PMMA's mechanical properties by improving polymerization efficiency and reducing porosity. This method offers a faster and more precise alternative to traditional water bath curing, with potential clinical benefits for denture durability and performance.

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Introduction

PMMA has been used since the 1930s [1]. It is distinguished by user-friendly operation, cost-effectiveness, and acceptable clinical results. They consist of polymers and monomers; these components are combined, and the resultant combination requires curing, which may be either self-curing or heat-curing [2]. The conventional polymerization approach involves a lengthy, low-temperature water-bath process, during which the acrylic resin is maintained at 74°C for 6 hours [3]. Post-polymerization cycles include terminal boiling at 100°C for periods of 30 minutes (short-term) or over 1-hour (long-term) [4]. The characteristics that have contributed to the success of acrylic resin as denture bases encompass exceptional aesthetic properties, adequate strength, low water absorption, minimal solubility, non-toxicity, ease of repair,

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accurate reproduction of details and dimensions, and uncomplicated moulding and processing methods [5].
Irrespective of the curing technique employed, the existence of unreacted residual monomer in denture base acrylic resins is unavoidable and may pose challenges for both clinicians and patients; therefore, measures should be implemented in laboratory and clinical environments to reduce exposure as much as possible [6]. The incomplete transformation of monomers into polymers is referred to as residual monomer, which may lead to inflammation, irritation, and allergic responses in the oral mucosa [7]. Mechanical characteristics of residual monomer are intricately linked to the polymerization conditions. The use of terminal boils in polymerization cycles significantly reduced residual monomer levels [8].
Gadolinium oxide nanoparticles have thermal properties that benefit numerous applications. Size, shape, and composition may impact nanoparticle thermal properties including specific heat capacity and thermal conductivity. Effective electronic devices and thermal management systems need thermal property control in nanoelectronics and materials research. Researchers are enhancing nanotechnology and related fields by producing gadolinium oxide nanoparticles for precise thermal applications [9]. Miaman introduced lasers to dentistry in the 1960s. Many methods classify dental lasers: Lasing medium (gas or solid), tissue adaptability (hard or soft tissue lasers), wavelength range, and laser application hazards determine classification [10].
UV laser curing is an advanced method for polymerizing acrylic denture base materials. The process involves exposing the acrylic resin to a high-energy UV laser, which initiates the polymerization reaction. The UV light breaks down photo initiators (camphorquinone) in the resin, generating free radicals that facilitate cross-linking of the polymer chains. This results in a highly durable and stable denture base [11]. UV laser curing offers several advantages over traditional heat or chemical curing methods. It provides faster curing times, improved mechanical properties, and reduced residual monomer content. Additionally, UV laser curing allows for precise control over the polymerization process, minimizing shrinkage and distortion of the denture base [12].
The filled flasks are typically positioned in a temperature-controlled water bath for a designated duration to polymerize the acrylic resin for denture bases, which may also undergo polymerization by irradiation using laser technology [8]. This research aimed to assess the physical parameters of transverse strength and porosity in conventionally long-term cured acrylic resin with a novel fiber flask manufactured from fiberglass. The light energy emitted by a laser may engage in four distinct interactions with target tissue [13,14]. “Reflection, Transmission, Scattering, and Absorption. When a laser is absorbed, it raises the temperature and induces photochemical responses contingent upon the water content of the tissues” [15,16]. Upon reaching a temperature of 100°C, the water inside the tissue undergoes vaporization, a phenomenon known as ablation. At temperatures above around 60°C but still below 100°C, proteins commence denaturation without the vaporization of the underlying tissue [17]. Conversely, at temperatures over 200°C, the tissue undergoes dehydration followed by combustion, leading to an undesirable phenomenon known as carbonization [18]. Absorption requires chromophores, which absorb certain wavelengths of light. Melanin, hemoglobin, and water are the major chromophores in intraoral soft tissue and water and hydroxyapatite in dental hard tissue. Laser selection depends on wavelength since various wavelengths absorb these vital tissue components [14,19,20]. The use of laser technology in dentistry may be classified based on its application across different tissues as follows: Applications for soft tissue and rigid tissue [21].
The introduction of laser technology in dentistry has provided an alternative curing method. Laser curing, particularly using UV lasers, has been shown to improve the mechanical properties of dental materials, including transverse, compressive, and tensile strengths [22]. Additionally, the incorporation of nanoparticles, such as gadolinium oxide (Gd_2O_3), into PMMA has been explored to enhance its mechanical and thermal properties [15].
This study aims to evaluate the effect of gadolinium oxide (Gd_2O_3) nanoparticles on polymethyl methacrylate (PMMA) and compare the mechanical properties (transverse strength, porosity, and surface roughness) of denture base resins cured via UV laser versus conventional water bath techniques. The goal is to determine whether UV laser curing, combined with nanoparticle reinforcement, offers superior performance over traditional curing methods.

Material and Methods

Master wax plates measuring 8 cm in length, 0.8 cm in width, and 0.3 cm in thickness (Figure 1) were fabricated for testing transverse strength, porosity, and surface roughness, utilizing modelling wax (T.P regular, Major Prodotti Dentari, S.P.A., Italy). Dental stone (Silky Rock, Whipmix Louisville, USA) was utilized for the investment of wax plates within flasks. Following the removal of wax, a fine brush (no. zero) was used to apply the separating medium (Isol Major, Major Prodotti Dentari, S.r.I., Italy) to heated and sanitized stone moulds. The manufacturer's guidelines were adhered to during the measurement and mixing of heat-cured acrylic resin powder and liquid (Major Base 2, Major Prodotti Dentari, S.P.A., Italy). Acrylic resin filled the flasks. The observable detachment of resin from the walls of the glass mixing jar suggests packing during the dough preparation process.

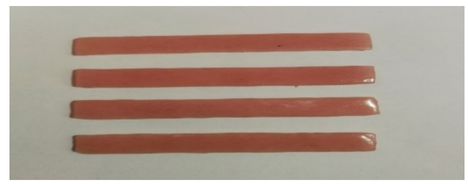

Figure 1. The samples with dimension (8,0.8,0.3) cm length, width, thickness.

Addition of Gadolinium oxide nanofillers

Nano Gadolinium Oxide nanoparticles were integrated into the liquid monomer, and efficient dispersion of the nanoparticles was achieved using probe sonication (120 W, 60 KHz) for three minutes to ensure individual nanoparticle separation [23].
The ingredients are processed and mixed per manufacturer's instructions. The monomer with nano powder is quickly combined with acrylic powder to minimize particle aggregation and phase separation. Cover the ingredients and let it sit until doughy.

Heat – Cured Activation

The flask containing the samples is immersed in a water bath at specified temperature (74 co) for a specified time (8 hours), the technique applied for all the 20 sample of acrylic resin by using metal flask of brass.

Curing cycle for laser technique

By using UV laser with wave length (150-400 nm) the sample were divided into five groups each of 5 samples, according to the duration time of irradiation which is A, B, C, D, and as follow:
Group A: Irradiated for 10 mins.
Group B: Irradiated for 15 mins.
Group C: Irradiated for 20 mins.
Group D: Irradiated for 25 mins.

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The sample situated in fiber glass (Figure 2A) and then putting in a chamber and irradiated by UV laser light (Figure 2B).

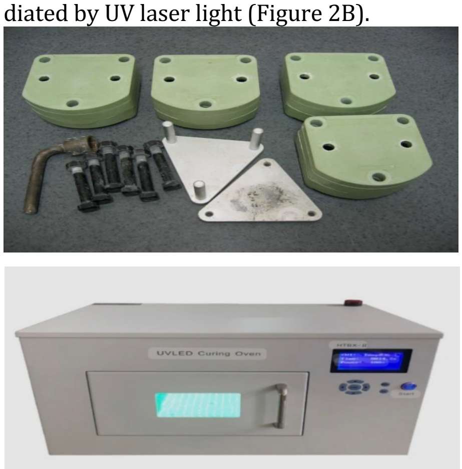

Figure 2. A. Fiber glass flask that used in laser technique B. Irradiation chamber of specimens by UV laser (150-400 nm).

Transverse Strength Test
Forty acrylic samples measuring 8 x 0.8 x 0.3 cm were prepared, with twenty samples subjected to a water bath approach including an overnight curing cycle at 74°C for eight hours, while the other twenty samples were processed using a laser technique. Finishing and smoothing were performed with silicon carbide grit papers. Initially, grit 120 was used, followed by grit 600, after which the samples were cleaned using a polishing cloth and soap in accordance with ADA specifications. The samples were meticulously sectioned into five pieces, each measuring 8 x 0.8 x 0.3 cm, using a band saw.
The aggregate number of samples for transverse strength was 40: Twenty acrylic samples were cured using a traditional water bath, whilst another twenty acrylic samples were treated using a laser approach.
Subsequently, all samples were preserved in distilled water at 37°C using an incubator (Memmert GmbH & CoKG). The materials were evaluated using a three-point bending test that closely simulates in-service conditions (Figure 3).
The sample was supported at both ends by rollers with a diameter of 3.2 mm, and the distance between the two rollers was 50 mm.
Transverse strength (TS) calculated by the following equation [23]:
TS = 3 WL/2bd2
W= Maximum load at midpoint of the sample (Kg)
L= Distance between the supports (50 mm)
b= Width of the sample (8 mm), d= Thickness of the sample (3 mm)

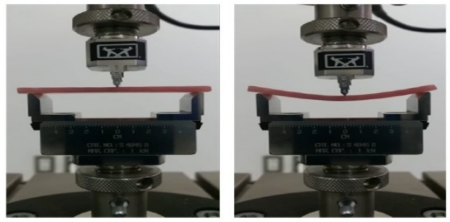

Figure 3. Transverse strength. the load was measured by a compression machine (inc. model cn 472, Evanston, ill–USA) at cross–head speed of 0.5 cm per minute.

Surface roughness
The samples used in this study were 8 cm long, 0.8 cm wide, and 0.3 cm thick. A profilometer was used in this surface analysis. This surface analyzer has a diamond-tipped pen to trace surface imperfections. The stylus can catch all the test specimen's surface peaks and troughs with its 2 cm moving range. Three places were chosen: one central and two outskirts. The average of three measurements at each location was then calculated for further study.
Porosity Test
Twenty acrylic samples measuring (8 x 0.8 x 0.3) cm were subjected to Heat-Cured Activation, a technique involving a prolonged polymerization cycle in a constant temperature water bath at 74°C for 8 hours, utilizing a brass flask. An additional twenty acrylic samples of identical dimensions were processed using a laser technique. The acrylic samples were completed and polished according to the process outlined in the preceding test. The acrylic samples were organized and analyzed using a light microscope (Olympus, Japan) at 20× and 40× magnifications.

Results

Transverse Strength Test (Kg/cm^2)
The transverse strength of PMMA samples cured using the UV laser technique was significantly higher ($p=0.0001$) than that of the water bath-cured samples.as shown in Table 1.
Porosity Test
In the porosity test, the mean porosity value for the UV laser-cured group was 2.462 with a standard deviation of 0.322, while the water bath-cured group had a mean of 1.462, also with a standard deviation of 0.322. With a statistical analysis a highly significant difference ($p>0.01$). as shown in Table 1.
Surface Roughness Test
In the surface roughness test, the UV laser-cured specimens exhibited a mean surface roughness of 0.115 with a standard deviation of 0.019, while the water bath-cured specimens had a slightly lower mean of 0.098 and a standard deviation of 0.023. Although there is a minor increase in surface roughness in the UV laser group (+0.017 units), the p-value of 0.187 indicates that this difference is not statistically significant as shown in Table 1.

Discussion

The findings of this study demonstrate that UV laser curing significantly enhances the mechanical properties of PMMA reinforced with gadolinium oxide (Gd_2O_3) nanoparticles compared to conventional water bath curing. The transverse strength of laser-cured specimens (109.300 kg/cm^2) was significantly higher ($p = 0.0001$) than that of water bath-cured specimens (88.300 kg/cm^2), suggesting improved polymerization efficiency and structural integrity with UV laser curing [12,22]. This aligns with previous research indicating that UV laser polymerization provides faster, more controlled curing, leading to superior cross-linking and reduced residual monomer content [11,22].
Additionally, porosity was significantly reduced in laser-cured samples (mean=2.462) compared to water bath-cured samples (mean = 1.462) ($p < 0.01$). This reduction may be attributed to the uniform energy distribution of the UV laser, which minimizes air entrapment and enhances resin consolidation [8,16]. Conversely, water bath curing, which relies on gradual heat transfer, may lead to uneven polymerization and higher porosity [3,5].
Interestingly, surface roughness showed a slight increase in laser-cured specimens (0.115) compared to water bath-cured specimens (0.098), though the difference was not statistically significant ($p = 0.187$). This minor increase could be due to the higher energy density of the UV laser, which may cause slight surface irregularities [17,20]. However, since the difference was not significant, UV laser curing remains a viable alternative without compromising surface smoothness.
The incorporation of Gd_2O_3 nanoparticles likely contributed to the improved mechanical performance by enhancing polymer matrix reinforcement and thermal stability [15,23]. These nanoparticles may also improve radiation shielding properties, making them beneficial for dental applications where durability and biocompatibility are essential [22].

Conclusion

This study demonstrates that UV laser curing significantly enhances the mechanical properties of PMMA reinforced with

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gadolinium oxide (Gd_2O_3) nanoparticles compared to conventional water bath curing. The laser-cured specimens exhibited superior transverse strength, reduced porosity, and comparable surface roughness, indicating improved polymerization efficiency and structural integrity. These findings suggest that UV laser curing, combined with nanoparticle reinforcement, offers a faster and more effective alternative for denture base fabrication, with potential clinical benefits in durability and performance. Further research is recommended to optimize laser parameters and assess long-term clinical outcomes.

Conflicts of Interest

The authors declare no conflicts of interest.

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Table 1. Comparison of transverse strength, porosity, and surface roughness between UV Laser and water bath cured PMMA specimens.

Groups		**Transverse strength test Kg/cm2**	**Porosity test**	**Surface roughness test**
UV LASER	**Mean**	109.300	2.462	0.115
	Std. Deviation	2.175	0.322	0.019
	Std. Error of Mean	0.888	0.131	0.008
Water Bath	**Mean**	88.300	1.462	0.098
	Std. Deviation	2.212	0.322	0.023
	Std. Error of Mean	0.903	0.131	0.009
p-value		0.000	0.000	0.187