Research Article

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A Study of PMMA Reinforced with Titanium Dioxide Nanosized Particles on Transverse and Impact Strengths

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ABSTRACT

Aim: This study investigated PMMA [heat-polymerized acrylic resin] reinforced with titanium dioxide nanosized particles at concentrations (0.5%, 1%, 1.5%, and 2% wt%) on transverse and impact strengths.

Materials and Methods: Incorporated titanium dioxide (TiO_2) powders in various concentrations (0.5%, 1.5%, 1.5%, and 2% wt%) into PMMA and cured the samples at 95 °C for 2 hours using a water bath. The fabricated test specimens for transverse strength (65 x 10 x 2.5mm) and impact tests (60 x 7 x 4mm). As a test control, PMMA without additions was created.

The samples were subjected to two mechanical tests: transverse and impact strength. Transverse strength in (MPa) and impact strength in (kJ/m^2), the measurements were collected, tabulated, and statistically evaluated. The means-tested groups were compared by using Tukey's tests and analysis of variation [one-way (ANOVA)] that significant differences when P value ≤ 0.05 between them.

Results: Inclusion the titanium dioxide (TiO_2) nanosized to PMMA improved its transverse and impact strength substantially.

Conclusion: PMMA with nanofillers titanium dioxide (TiO_2) has ability to be a durable foundation of denture material with higher transverse and impact strength. According to the findings of this investigation, adding 2%wt TiO_2 concentration resulted in the best mechanical performance.

KEYWORDS: titanium dioxide (TiO_2); Polymethayl methacrylate; Impact strength

INTRODUCTION

A number of advantages have made acrylic resin polymethyl methacrylate (PMMA) the preferred material for design and implementation of dental restorations for many decades, including good aesthetics, proper fit, stability in the mouth, ease of use in laboratories and clinics, and low cost of materials [1]. Denture bases are commonly made from this material, but it does not meet all mechanical standards for dental applications, plaque accumulation and low fracture strength are primary reasons of this [2,3].

Examining study of 10 different types of prosthesis base resins revealed that approximately 70% of prostheses failed in the first three years of use [2]. According to a study on denture fractures, Broken/detached teeth accounted for 33% of repairs, midline fractures are more prevalent in upper dentures, accounted for 29%, and various forms of fracture serials accounted for the remainder. The mandibular partial denture was found to be repaired most frequently in another study [4]. Consequently, testing mechanical characteristics of base denture materials is crucial for evaluating influence of various reinforcing substances [5,6].

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In addition to incorporating rubber phases [7], metal scaffolds [8], oxides of metal [9], and fibers [10], numerous approaches are taken to enhance characteristics of materials denture base mechanically, as well as solutions by chemistry like crosslinking agents polyfunctional (polyethylene glycol Di methacrylate) [6]. Although PMMA fracture strength was improved by these efforts, few positive results were obtained [11,12]. The use of metal composite systems to reinforce polymers used in dentistry is an important focus [12].

Nanotechnology is an evolving field that will shape the scientific technology of the future. It centers on the concept of building functional structures through the structural regulation of molecules and the manipulation of matter at billionths of a meter or nanometer scale [13]. Nanotechnology is defined by National Nanotechnology Initiative as "the direct manipulation of materials at the nanoscale" [14]. The phrase of technology refers to enabling approximately full control of matter structure at the nanoscale. It will allow organized atoms as fit, so that we can effectively and completely control the structure of matter. Nanotechnology developments led to corresponding changes in dentistry, ranging from diagnosis to alternatives treatment [15]. Nanotechnology can be used in dentistry in a variety of ways, including medical applications, tissue regeneration, and incorporation into dental materials [16]. As already stated, use of nanoparticles in PMMA denture bases is through the modification and addendum of TiO_2 fillers to enhance the material's improvement. Nanomaterials come in various shapes and sizes, including particles, flowers, cubes, rods, and tubes [17].

The antimicrobial properties of titanium dioxide nanoparticles have already been demonstrated. Also nontoxic, corrosion-resistant, chemically stable, and low-cost, it is also a biocompatible, biodegradable material. As a reinforcing agent, titanium dioxide nanoparticles are added to a polymer material to improve its electrical, optical, chemical, and physical properties [18]. It has been reported that dentures can fracture due to flexural fatigue as well as impact fractures. Consequently, denture base materials' transverse strength can provide an indication of their performance. In light of the fact that few data have been reported on metal oxides' effects on heat cured PMMA, this work examined benefit of metal oxides on PMMA mechanical properties with nanosized titanium dioxide (TiO_2) particles.

MATERIALS AND METHODS

This study investigated PMMA [heat-polymerized acrylic resin] fortified with titanium dioxide nanosized particles at concentrations (0.5%, 1%, 1.5%, and 2% wt%) on transverse and impact strengths.

A type PMMA [heat-polymerized acrylic resin] was used as a control (DPI Heat Cure, the Bombay burmah trading corporation ltd, India), nanoscale (TiO_2) particles [Sigma-Aldrich, St. Louis, MO, USA] at different concentrations (0.5%, 1%, 1.5% and 2% wt%) were added to the (PMMA) and processed under optimum conditions powder/monomer ratio (2.5:1), conventional packaging technique and water bath about 2 hours at 95 ^{o}C for curing. For this study, 100 rod mould specimens were prepared. Every test [transverse strength (Group A) and impact strength (Group B)], 50 specimens were used.

Grouping of the Specimens

As indicated in Table 1, every group was furthermore subdivided into five subgroups (1, 2, 3, 4, and 5) of ten specimens each.

Table 1: Specimens description and grouping.

Groups	Subgroups	Description	No. of Specimens
Group A	Group A1	Test control, PMMA without additions	10
	Group A2	PMMA with 0.5% nano-sized titanium dioxide (TiO_2) particles.	10
	Group A3	PMMA with 1% TiO_2	10
	Group A4	PMMA with 1.5% TiO_2	10
	Group A5	PMMA with 2% TiO_2	10
Group B	Group B1	Test control, PMMA without additions	10
	Group B2	PMMA with 0.5% nano-sized titanium dioxide (TiO_2) particles.	10
	Group B3	PMMA with 1% TiO_2	10
	Group B4	PMMA with 1.5% TiO_2	10
	Group B5	PMMA with 2% TiO_2	10
Total			100

Transverse Strength Testing

Transverse strength testing (TS) for denture base polymers was carried out in conformity with International Standards Organization standard 1567 [19]. Rectangular Specimens shape (65 x 10 x 2.5mm) were prepared. The test was forced upon Lloyd universal testing machine (model LRX plus II, Fareham, England) under 3-point loading and a crosshead speed of 5 mm/min (model LRX plus II, Fareham, England); (Figure 1).

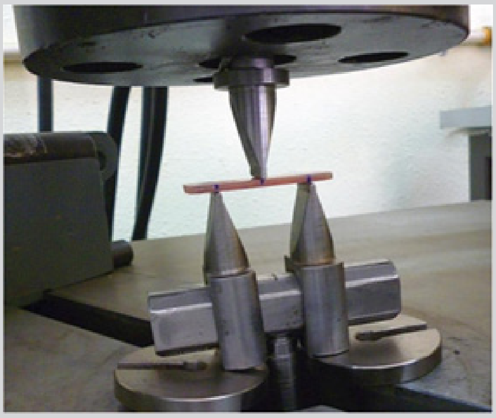

Figure 1: Transverse strength testing on universal testing machine.

Impact Strength Testing

The specimens are rectangular for impact strength (IS) (60 x 7 x 4 mm) was tested. Uzun et al. [20]. Employed a comparable specimen size and strength test procedure. A notch cutter was used to make a 3.5 mm notch per specimen (Figure 2); (Hounsfield notching machine, Tensometer Ltd., Croydon, U.K.). To exert force on the sample from the unnotched side, a Charpy-type notch impact tester (Hounsfield plastic impact machine, Tensometer Ltd.) was employed (Figure 3). Specimens that do not fracture in initial experiment were removed from the research.

Figure 2: Impact strength specimens.

Figure 3: Charpy-type impact tester.

Before IS testing, the designed specimens were kept in a humidifier for 24 hours at 37 °C. When the notched specimen was broken, IS was estimated as the loss of momentum in the pendulum. Air force due to pendulum friction against air (-0.1 J) was removed to reach the true value. The prepared specimens were held horizontally as a supported beam. The pendulum struck specimens in the same plane as the notch but on the other side in the center. After testing specimens, IS was calculated using equation

$IS = E/bnd \times 10^3$

where E is the energy absorbed by the tested material when impact, bn is the specimen's wide (mm), and d is the specimen's thickness (mm)

The gathered transverse and impact strength data was assembled and statistically evaluated. Tukey's tests and analysis of variation [one-way (ANOVA)] were performed to identify the statistically significance of the variables between the means of analyzed groups when the *P* value is ≤ 0.05.

RESULTS

Transverse strength

Table 2 & Figure 4 compare PMMA-tested groups' mean transverse strength in (MPa). The ANOVA test revealed that there was difference among the groups that significant statistically. PMMA specimens with 2% nano-sized titanium dioxide (TiO_2) particles (group A5) had the largest mean transverse strength, then PMMA specimens with 1.5% (TiO_2, group A4), 1% (TiO_2, group A3), and 0.5% (TiO_2, group A2). There were significant variances. ($P \leq 0.05$) between the investigated groups. The mean transverse strength of control group [PMMA specimen without any additions] was substantially lower.

Table 2: The mean transverse strength (MPa) of the PMMA testing groups.

Group A1 Control Group		Group A2 (0.5% TiO_2)		Group A3 (1% TiO_2)		Group A4 (1.5% TiO_2)		Group A5 (2% TiO_2)		*P*-value
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
78.1^{e}	1.129	84.57^{d}	3.62	96.03^{c}	3.67	98.8^{b}	3.076	129.6^{a}	1.96	0.000*

*Significant at $P \leq 0.05$

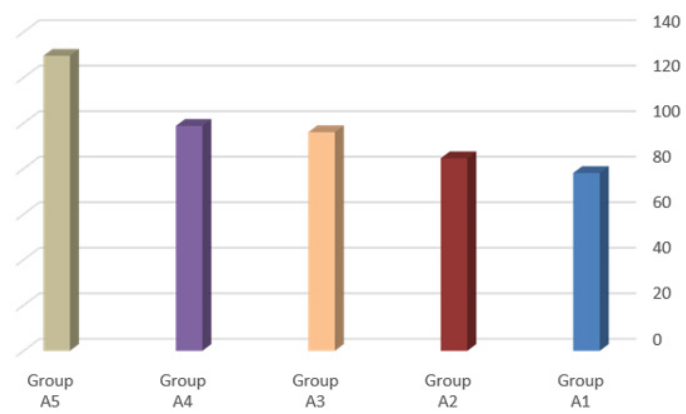

Figure 4: Bar chart of PMMA-tested groups' mean transverse strength (MPa).

Impact strength

The impact strength results revealed that tested groups were strengthened with nano-sized titanium dioxide (TiO_2) particles improved significantly (Table 3); (Figure 5) when emulating to the control group, there was raise in impact strength in the groups fortified with (0.5%, 1%, 1.5%, and 2% TiO_2) significantly.

Table 3: Comparison of PMMA testing groups' mean impact strength (kJ/m^2).

Group B1 Control Group		Group B2 (0.5% TiO_2)		Group B3 (1% TiO_2)		Group B4 (1.5% TiO_2)		Group B5 (2% TiO_2)		*P*-value
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1.62^{e}	0.96	1.97^{d}	0.63	2.45^{c}	1.07	2.83^{b}	0.56	3.85^{a}	1.05	0.000*

*Significant at $P \leq 0.05$

DISCUSSION

Due to its numerous positive properties, PMMA is often used for the fabrication of prosthetic bases. Nevertheless, it is deficient physical and mechanical strength to withstand masticatory forces [21]. According to literature by Johnston et al. [22]. On of ten regularly base of denture to assess flexural strength, 68% of dentures fracture during clinical use in first year. Several other studies yielded different results on denture fractures, with fatigue and impact leading to midline fractures of maxillary dentures and impact leading to 80% fractures of mandibular dentures [23]. Due to the above factors, many novel interventions have been made in PMMA through the introduction of nanofillers, and new processing techniques have also been introduced as an alternative to current methods. TiO_2 nanofillers have been shown to have better mechanical and antibacterial properties compared to other nanofillers [24]. In this work, PMMA reinforced with titanium dioxide nanosized and compared acrylic resins with and without TiO_2 nanofillers to evaluate possible enhancements in PMMA mechanical characteristics, especially transverse and impact strengths. PMMA mechanical characteristics can improved by three approaches: replacement with another component, by chemical modification, or by reinforcement with other materials [25,26]. One of the mechanical strength tests, the transverse strength test, is very useful for the evaluation of denture base materials when the denture is loaded with such a force during mastication [27]. Transverse and flexural strengths are an integration of compressive, tensile, and shear strengths, all representing stiffness and fracture strength of a material [28].

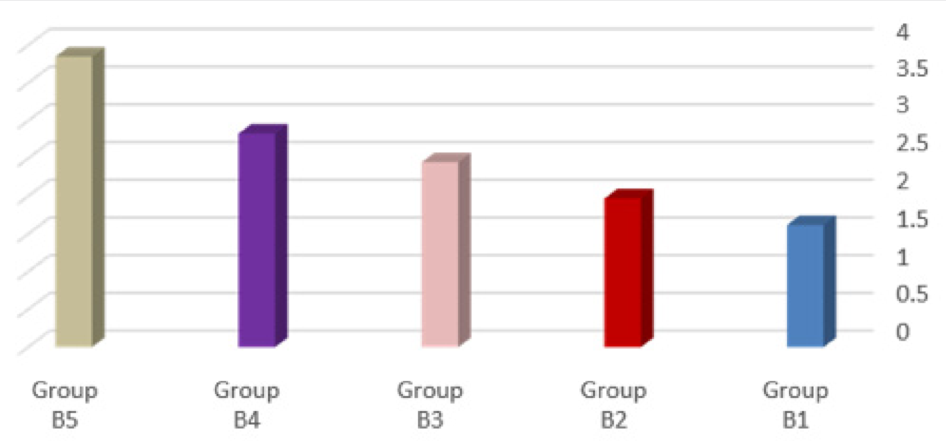

Figure 5: Bar chart of PMMA-tested groups' mean impact strength (kJ/m²).

Dropping acrylic resin dentures causes them to shatter, and research continues to this day to develop a denture base material with higher impact resistance. Impact strength is a significant characteristic because it might indicate the force necessary to shatter a denture in instances such as accidental falling [29]. The TiO_2 concentration was limited to 2 wt% in the present study because incorporation of TiO_2 into PMMA improved the mechanical properties in literature carried out by Shirkavand et al. [30] on the influence of different weight (0.5, 1, and 2 wt%) of nanomaterials TiO_2 on the tensile strength of PMMA. Higher concentrations of TiO_2 (5%) lead to reduction of impact strength of resin material. If filler is increased above the maximum level, the resin cannot absorb any additional filler particles, leads to fulness and degradation of the material. Moreover, attempts to add filler particles above the saturation threshold will result in fracture of the resin matrix and lower strength of the specimen [31]. The alternative assumption is that the nanoparticles in PMMA absorb the applied force, while the resin matrix distributes the load as well as structural stability [30].

The present study's findings revealed a considerable increase in transverse and impact strengths with increasing TiO_2 filler content. This amelioration in mechanical characteristics owing to strong shear strength between nanofillers and the resin matrix interfacially, that constructing of cross-linking or supramolecular bonds that cover or shield the nanofillers, preventing development of cracks; moreover, the resin completely wets the nanofillers resulted in an increase resist of scratching, fracture toughness, and flexural strength when raise filler amount [32]. These results are in agreement with many researchers [30-33] that investigate the influence of nanotechnology to enhanced conventional acrylic prosthetic resins, Acosta-Torres et al. [34] demonstrated that TiO_2 nanofillers gotten better mechanical properties of conventional acrylic prosthetic resins.

This Study was Examined Two Characteristics Impact and transverse strengths. When these amounts of titanium nanoparticles are added, other properties of the material must be evaluated. Because this was *in vitro* research, the outcomes could not be used in a clinical setting.

CONCLUSION

Within the scope of this investigation, adding nano-sized titanium dioxide (TiO_2) particles to PMMA boosted transverse and impact strengths of PMMA. According to this investigation, the greatest outcomes were obtained while employing a concentration of 2%wt. It is necessary to conduct more research to assess mechanical and physical characteristics various concentrations.

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