Effect of addition of silver nanoparticles on flexural and impact strength of heat cure acrylic resin

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Background and objectives: Heat cure denture base material is the most commonly used material for fabrication of removable prosthesis since its introduction in 1937. The unresolved problem of frequent fracture is one of the main drawbacks when used in denture construction. The purpose of this study was to evaluate the influence of silver nanoparticles on flexural and impact strength of heat-polymerized resin.

Materials and methods: Silver nanoparticles were impregnated at 1%, 3% and 5% by weight to the monomer of methyl methacrylate with the aid of probe sonicator. Afterward, they were mixed with the acrylic powder. Sixty samples were prepared in total to observe its influence on flexural and impact strength.

Results: Flexural strength values revealed a statistically significant difference (p<0.05) among the three concentrations. The results indicated a 22% reduction in the mean value for 3% while 1% and 5% caused 20% and 21% decrease respectively when compared to control. Regarding impact test, it demonstrated a statistically significant difference only for 5% that caused a drastic drop in impact value by 41% in contrast to the control group.

Conclusion: Within the limitations of this study, it can be concluded that the addition of silver nanoparticles caused a reduction in mechanical strength of heat cure acrylic except for 3% which caused a minor non-significant increase in impact strength. Considering the negative effect on mechanical strength and jeopardizing the aesthetic value for acrylic, it can’t be considered as a suitable additive to enhance the properties tested.

Keywords: Acrylic resin, silver nanoparticles, flexural strength, impact strength.

Introduction

Complete and partial dentures that are made from acrylic considered the most popular method because it provides a much affordable option for reconstruction than other available prostheses.1 Throughout the years, researchers are trying to improve the quality of biomaterials for fabrication of denture base together with the increase in life expectancy of human beings and increasing demand of patients for better aesthetics, function, and comfort.2 Numerous materials with their modifications had been introduced to the market with enhanced mechanical and biological properties; despite this, there is still no single material that can fulfill the ideal requirement of denture base material.3 Polymethyl methacrylate (PMMA) is a derivative of acrylic acid, which is referred to as acrylic resin4 introduced in 1937, by Walter Bauer, which gradually took the place of the traditional metal base and became the most widely used material in clinical practice5,6 because of its good biocompatibility, dimensional stability, the absence of taste and odour, good tissue response and outstanding toxicity profile.7 Despite those excellent properties, PMMA demonstrates high porosity8 and frequent fracture under load due to fatigue and chemical degradation.9,10 Fracture resistance of PMMA does not show satisfactory results.11 According to a survey done in 1981, 68% of dentures had broken within three years of their
Due to their unsatisfactory properties, PMMA remains as an active material for research. Generally speaking, there are three methods manufacture can use to enhance mechanical properties of denture base: discovery or development of new material to PMMA; chemical alteration of PMMA to fabricate high impact resin; and reinforcement of PMMA by other materials (e.g., nanoparticles). Addition of nanoparticles (NPs) to the polymer matrix will result in alteration of mechanical properties by providing resistance against stress which may cause cracking. Depending on the way the material was enhanced; it was based on the size, shape, type, and concentration of the added material. Alveolar ridge resorption is a continuous and irregular operation that causes uneven prosthesis support with perpetual chewing cycles which will result in the generation of micro-cracks in the material and with the continual application of force will cause propagation of cracks and flexural fatigue that commonly manifest itself as midline fracture. Studies had tried to improve the flexural properties of the material to overcome the consequence of fracturing and enhancing patient’s satisfaction. In a study by Arora and his colleagues that added silver fillers at 25% to PMMA, the results showed a reduction in flexural mean when compared to control. Following this, silver filler was impregnated to the same material and showed an increase in flexural strength for 10% and 20% while the 30% had a reverse effect. Furthermore, AgNPs added at 0.3%, 0.8%, and 1.8% to heat-polymerized acrylic resin revealed a reduction in flexural value for all concentrations. Munikamaiah et al. evaluated the flexural strength of PMMA that was reinforced with 0.5% and 5% AgNPs that was cured with two different curing cycles; results revealed an increase in the flexural mean by 7.5% and 4.4% respectively. Moreover, the effect of 0.05% and 0.2% AgNPs on flexural strength of heat-polymerized acrylic resin was investigated by Oyar et al. where only low concentration showed an increase in the flexural strength of the acrylic.

The second most common scenario that the denture experiences during their lifespan is when it falls and is exposed to a sudden impact. This is a common finding in clinical practice since removable prosthesis is usually used by geriatric patients. Enhancing the impact strength of denture base is of great concern with only a few studies available that evaluated the effect of silver particles on impact strength. In a study by Gaffariani and his colleagues where they added AgNPs to acrylic, the results revealed a decrease in impact strength when added at 25% making it more susceptible to breakage by an impact force. While, in a recent study that impregnated the same filler at 0.3%, 0.8%, and 1.8% to heat-polymerized resin, it showed no effect on impact strength for all concentrations. Finally, Oyar et al. incorporated AgNPs into PMMA at two concentrations. The results recorded enhancement in impact strength at 0.05% while 0.2% had an opposite effect. This study was carried out to assess the impact of silver nanoparticles on flexural and impact strength of heat cure PMMA to discover a material that can stay in service to the desired time without a need for repair.

### Materials and Methods
Considering the addition of NPs into acrylic resin polymers is to enhance its properties, this has been gained by using low filler content between 1% to 5% because increasing the content above this level can have a significant impact on mechanical properties. As a result, AgNPs were added at 1%, 3% and 5% by weight to heat polymerized polymer. The NPs used in the study was bought from Richest Group Company in China with 50nm in size and were treated with a saline coupling agent. The saline agent will provide a better bond between particles and acrylic and minimizes agglomeration. The NPs used in the study was bought from Richest Group Company in China with 50nm in size and were treated with a saline coupling agent. The saline agent will provide a better bond between particles and acrylic and minimizes agglomeration. To reduce agglomeration of NPs, they were added to acrylic monomer first and then mixed with powder with the aid of probe sonicator (Biosafer 900-02). According to a pilot study that was performed, the below setting was chosen:

- **Power Rate**: 80%
- **Power**: 900w
- **Probe size**: 12 F
- **Processing time**: 1-minute
- **Pulse on**: 8s
Pulse off: 2s
Temperature warning: 37 °C.
Sonication was started with 8s on and 3s off to keep the temperature within the set range. After the sonication time was over, polymer powder was added immediately to the suspension (within 10s) to prevent re-agglomeration of NPs. The mix was polymerized using conventional flasking and pressure packing technique. After the polymerization was over, de-flasking was done, and samples with gross porosity were excluded according to revised ADA specification number 12 for denture base polymer.

**Flexural strength test.** For flexure strength test 5 samples were prepared for each concentration of AgNPs, making a total of 20 samples, including the unmodified group. Each sample had a dimension of 65 mm length x 10mm width x 3mm thickness and was stored in distilled water at 37 ± 1 °C for 50 ± 2 hours, in compliance with International Standard Organization (ISO) 1567:1999 Denture Base Polymers. The flexural value was obtained by doing a three-point bending test using a universal testing machine. The samples were placed on circular supports (3.2mm in diameter and 10.5mm in length) that are 50 mm apart (Figure 1). Then force was applied perpendicular to the center of the specimen using the loading nose at a cross-head speed of 5.00 ± 1 mm/ min until it breaks. The maximum load required to fracture the specimen was recorded. The flexural strength was calculated using the formula:

Where: F: is the maximum load, in Newton, exerted on the specimen; l: is the distance, in millimeter, between the supports, accurate to ±0.01; b: is the width, in millimetre, of the specimen measured immediately prior to water storage where h: is the height, in millimeter, of the specimen measured immediately prior to water storage.

**Impact strength test.** For this test, ten samples for each concentration were prepared to make a total of 40 samples, including the control group. The samples had dimensions of 80 ± 2 x 10 ± 0.2 x 4 ± 0.2 mm according to ISO 179-1: 2010 (34) and were conditioned for 16 hours at 23 ± 2 °C and 50 ± 5 % relative humidity according to ISO 291:2008. A Charpy type of digital impact tester (Figure 2) was used to determine the impact strength. A pendulum of one joule was installed on the impact tester. Before starting the procedure, a test was performed without the sample to check for air friction. The air friction value was subtracted from the impact strength value for each sample. The procedure was followed according to ISO 179-1:2010 for the unnotched specimen. After the samples were fractured, the Charpy’s impact strength for unnotched specimens was calculated in KJ/m² using the...
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\[ \alpha_{\text{corr}} = \frac{E_c}{h \cdot b} \times 10^3 \]

Where: \( E_c \) is the corrected energy, in joules, absorbed by breaking the test specimen; \( h \) is the thickness, in millimetres, of the test specimen and \( b \) is the width, in millimetres, of the test specimen.

Statistical Package for Social Sciences (SPSS, version 23) was used for data analysis and entry. One-way ANOVA with Tukey’s Honest Significant Difference (HSD) was performed to determine if there is a statistically significant difference between each concentration of AgNPs when compared to control. For statistical analysis, significant level \( \alpha = 0.05 \) was considered.

**Results**

The data that was obtained from flexural and impact strength test were calculated using one way ANOVA with HSD to find out the effect of addition of NPs at the three concentrations (1, 3, and 5\%) The flexural strength results revealed statistically significant differences (p< 0.05) between each concentration of AgNPs in reference to control. The results indicate 20\%, 22\% and 21\% reduction in mean value for 1\%, 3\% and 5\% AgNPs respectively. Despite the reduction in strength value for all concentrations but none of them compromised the strength beyond the minimal flexural strength value (65 MPa) that is set for Type I denture base polymer.\(^{33}\) Table 1 and Figure 3 illustrates the mean flexural strength value. As can be seen from the table, the highest mean 87.205 MPa, which was recorded for the control group.

Regarding the impact strength test, it demonstrated statistically significant difference only for 5\% that caused a drastic drop

<table>
<thead>
<tr>
<th>Nanoparticle</th>
<th>Concentration %</th>
<th>Mean (MPa)</th>
<th>SD</th>
<th>ANOVA P-value of concentration with control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>1</td>
<td>69.669</td>
<td>2.486</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>68.447</td>
<td>2.410</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>69.329</td>
<td>3.065</td>
<td>0.00</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>87.205</td>
<td>2.499</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Descriptive statistics and multiple comparisons of each concentration of AgNPs with a control group for flexural strength**

![Figure 3: Flexural strength mean for AgNPs concentration for heat cure acrylic](image-url)
in impact value by 41% in contrast to control. Also, the negative effect of 1% AgNPs on the impact strength was observed, which caused 0.8% reduction; while 3% AgNPs showed a non-significant increase in impact strength. Table 2 and Figure 4 shows the summary for impact values where the highest mean value was for 3% (24.733 KJ/m²) while 5% (14.190) showed the lowest value among the group.

**Discussion**
PMMA has been considered as the main material for denture base fabrication due to its pleasing appearance, good tissue response, and ease of manipulation, but it is mechanical properties not satisfactory. This reflects the high percentage of denture fracture that has been reported in the literature which compromises the longevity of the prosthesis. The masticatory process will result in movement and distortion of the denture, in turn, will impact on supporting tissue and the denture itself. The denture base is subjected to different types of stress in the mouth. Flexural fatigue from intraoral forces and extraoral impact are the two most common culprits responsible for fracturing dentures. As a result, impact and flexural strength test were conducted to closely resemble clinical conditions the removable prosthesis goes through during their functional use.

The results for this study showed when AgNPs were dispersed in acrylic at 1%, 3% and 5% causing a drastic reduction in flexural strength by 20%, 22%, and 21% respectively. These findings were in agreement with Arora et al.'s and Köroğlu et al.'s research were a reduction was displayed in flexural value for different concentrations of silver. This can be correlated to less silver content per unit area of the matrix of PMMA.
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PMMA which induces moister incorporation. This backs up the study that was performed by Yadav et al. that added 10% and 20% silver and resulted in an increase in flexural value. Regarding impact strength, 5% silver caused a 41% reduction in impact value that was statistically significant at p (0.00< 0.05).

As can be seen, the concentration of the NPs certainly played a significant role in compromising the mechanical strength of acrylic. This turn is in agreement with Gaffariani et al.’s research that revealed a reduction in strength with an increasing concentration of NPs. Also, other researchers had determined an inverse relationship between the increase in NPs concentration and strength.

There are several concepts regarding this inverse relation. Dispersion of NPs which had shown to play an important role in reinforcing the material. Such as increasing in filler content in addition to poor dispersion will result in suspending resin matrix continuity and creating a defect in the material which weakens it in the outcome. Improper dispersion of NPs will also interfere with the reaction of methyl methacrylate, which causes an increase in uncreative monomer that behaves as a plasticizer. The plasticizer capable of getting into polymer chains which induce the separate chains to become more tenuous and reduce the attraction force between molecules, as a consequence the acrylic will be more flexible but brittle. In addition to this, NPs might have acted as impurities within the PMMA which led to an unfavorable decrease in mechanical strength. The most probable cause of reduction for the mechanical strength of resin could be attributed to the low concentration of filler which results in poor interaction between PMMA and AgNPs. It is a well-known fact that NPs lacks chemical bond that results in poor adhesion between the particle and acrylic resin. Agglomeration within the matrix will result in a reduction in strength since too many fillers will act as a stress concentrating point that will change the modulus of elasticity of the resin and mode of crack propagation through the polymerized specimen and also perform as an interfering factor in the integrity of polymer matrix. Furthermore, agglomeration will bring about micro-cracks and micro-pores as a structural defect which endangers mechanical properties of the polymer.

Conclusion
Within the limitations of this in vitro study, it can be concluded that the addition of silver nanoparticles caused a reduction in mechanical strength of heat cure acrylic except for 3% which caused a minor non-significant increase in impact strength only. Considering it is negative effect on mechanical strength and jeopardizing the aesthetic value for acrylic in the result, it won’t be a suitable additive to enhance the properties tested.

Conflicts of interest
The author reported no conflict of interests.

References
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33. ISO 1567:1999 Denture Base Polymers.


