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Original Article

The Effect of Joint Surfaces Contours on The Mechanical Properties of The Repaired Denture Base Material Reinforced With Nanoparticles Material: An In-Vitro Comparative Study

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Abstract

Aim: This study aimed to evaluate the effect of different nanoparticles as reinforced materials used to repair midline fracture with different joint surface contours, on the denture base material's mechanical characteristics after repair.

Subjects and methods: 45 complete dentures were evaluated after repairing midline fractures having different joint contours with different nano-particle materials. In This in-vitro study, the complete dentures were divided into 3 groups, ***Group A*** includes fifteen complete dentures with rounded joint contours fracture line, and ***Group B*** includes fifteen complete dentures with rabbet-shaped fracture line contours. And ***Group C*** included complete dentures with butt fracture line contour. Samples of further groups were subdivided into 3 sub-groups accordingly, five dentures repaired with self-cured PMMA (group A1, group A2, group A3), Five dentures repaired with TiO_2 nanoparticles (groupB1, groupB2, groupB3), and five dentures repaired with ZnO nanoparticles respectively (group C1, group C2, group C3) 5% by weight. Independent sample t-tests were used to assess the findings ($p \leq 0.05$).

Results: Group A showed a significant difference in micro-hardness and surface roughness with round joint contour than Group B and Group C. For sub-groups, there was a non-significant difference in the repaired dentures treated with the addition of TiO_2 or ZnO_2 nanoparticles reinforced materials compared with the group treated with self-cured acrylic resin ($p \leq 0.001$)

46 Conclusion: Dental acrylic PMMA resin's mechanical properties in terms of micro-hardness and surface roughness have been improved by the addition of 5% weight TiO_2 nanoparticles and/or ZnO_2, in repairing the midline fracture of complete dentures, whether they are being rounded, rabbet, or butt-joint surface contours. Where the round joint contour showed the best contour for the repair of midline fracture.

Keywords: Micro-hardness, Surface roughness, Polymethyl methacrylate (PMMA); Titanium oxide nanoparticles; Zirconium oxide nanoparticles

I. INTRODUCTION

The widespread materials used in the dental field are polymers ***(Abdelraouf, 2018; Abdelraouf et al., 2021; Abdelraouf et al., 2019).*** One of the most popular materials for removable denture base constructions is acrylic resin.

methacrylate is the major component of heat-or self-cured acrylic resins (PMMA). Self-cured acrylic resin is used to repair dentures in order to prevent warping and/or destruction of the denture's broken components ***(Hadi et al., 2017; Hamouda, 2017).***

On a long-term service, High flexural stresses that occur during mastication are one of the leading causes of denture base fractures that may occur inside the mouth ***(Minami et al., 2005).*** Midline fracture due to fatigue of the acrylic resin is the commonest type of denture breakage ***(Shweta, 2019).***

Despite PMMA's desirable characteristics, there is a considerable need to improve its mechanical properties by including reinforcement materials or additives in the fillers that make up its composition ***(Choksi and Mody, 2016).*** An innovative method for improving the mechanical characteristics and structural 26 integrity of dental materials made of polymeric materials has been made possible by the inclusion of nanotechnology (nanofiller particles) ***(Naji et al., 2015; Meng and Latta, 2005; Gad et al., 2017; Zaki et al.,, 2014; Hamdy et al., 2015).***

While there are many different kinds of nano-metals, including silver and cobalt-chromium, titanium dioxide (TiO2) nanoparticles are particularly valuable because of their key characteristics, including non-toxicity, safety, chemical inertness, antimicrobial properties, high flexural strength, fracture toughness, and micro-hardness ***(Hamdy et al., 2019; Ashour et al., 2016; Nevarez-Rascon et al., 2021).*** Therefore, it is assumed that the most crucial criterion for successful denture base materials is a high mechanical strength property ***(Lee et al., 2012).*** As it influences the surface characteristics of the acrylic denture base, micro-hardness is a measure of how abrasive the denture base material is. This shows resistance to scratching either while in use or after cleaning dentures (Bahrani et al., 2012). Additionally, the PMMA denture base's surface imperfections and roughness encourage the buildup of stains and plaque, which over time have a negative impact on the appearance and biological characteristics of acrylic dentures ***(Bahrani et al.,2012).*** The patient accidentally drops the denture while cleaning it and/or receives a blow to the mouth. Whenever possible, the cause, or causes, of the fracture must be identified before the denture is repaired or replaced.

Until this is done and the cause is attended to, the denture is likely to fracture again within a short period of time ***(Alhareb et al., 2017).*** Self-cured (chemical- cured) acrylic resins are reported to be a viable method for repairing or rebasing a fractured denture base, saving both time and money if deciding to construct a new denture ***(Dar-Odeh et al., 2008).***

This study aimed to evaluate the effect of the incorporation of 5% weight of Titanium dioxide (TiO2) nanoparticles and zirconium oxide (ZnO2) on the mechanical properties of PMMA used for repairing a mid-line fracture with different joint surfaces contours (round, rabbet, and butt joints) regarding surface micro-hardness and surface roughness.

II. SUBJECTS AND METHODS

Forty-five complete dentures were constructed according to the manufacturer's instructions, where all dentures were fabricated from conventional heat-cured acrylic resin as follows: An investing plaster (Egypt Premix plaster market. Egypt) was used for the preparation of stone mold for conventional heat-cured acrylic resin samples, and the resultant mold cavities were filled with wax pattern in a conventional flask, each flask pour was allowed to set for 1 hour. A thin film of separating medium was applied to the surface of investing material.

Elimination of wax was done by placing the flask in boiling water for 5 minutes to soften the wax followed by ringing in lean boiling water. A mixture of PMMA resin was applied with a standard powder ratio as recommended by the manufacturer, where 4 ml of liquid: 10gm of powder were mixed in a small jar and then tapped the jar until the layer of excess liquid disappeared. When the resin had become doughy, it was placed into the flask and the two cavities were closed together and then placed in the bench press gradually. The curing cycle was done by flasks into the water at 74c and maintaining them for 1 hour. The flask was then cooled slowly to permit the release of stresses within the polymer. The investing plaster was removed carefully then the acrylic block was removed from the flask, finished and polished.

After the construction of the complete dentures, they all were fractured in the midline with a united universal testing machine, and the fracture line was widened to 6 mm and shaped into three different contours.

Denture grouping:

The forty-five complete dentures were divided equally into three groups according to the joint surface contours,

- **Group A:** Fifteen complete dentures with rounded joint contours midline fracture. ***(Figure 1)***

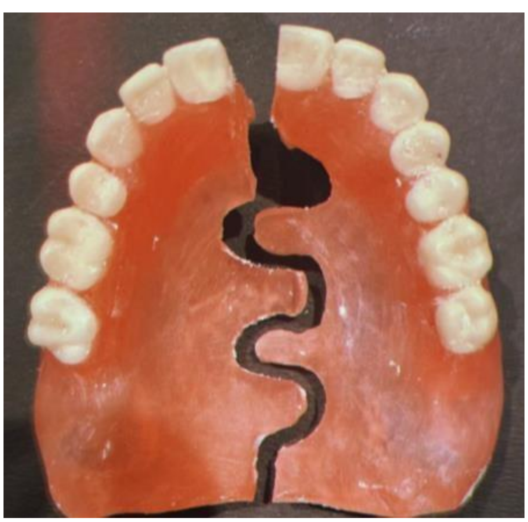

Fig. 1: Fracture with rounded joint contour

- ***Group B:*** Fifteen complete dentures with rabbet joint contours midline fracture. ***(Figure 2)***

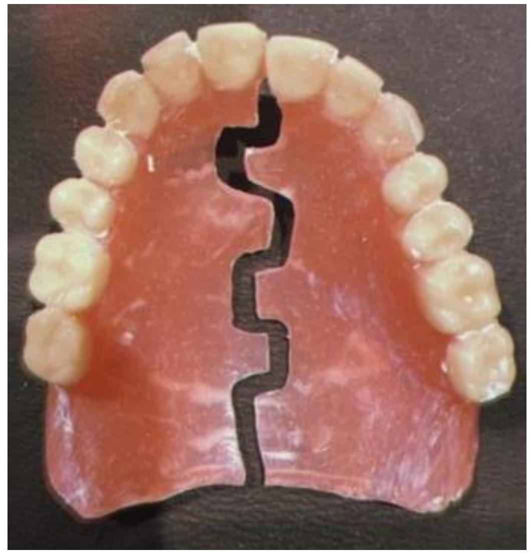

Fig. 2: Fracture with rabbet joint contour

- **Group C:** Fifteen complete dentures with butt joint contours midline fracture. ***(Figure 3)***

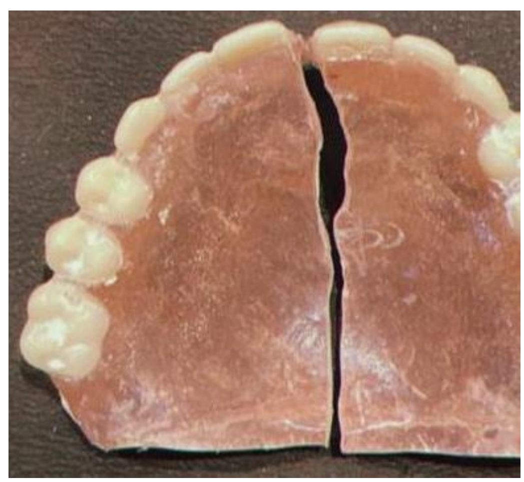

Fig. 3: Fracture with butt joint contour

Those groups were further subdivided into 3 subgroups according to the repaired material applied.

- **Groups A1:** Five dentures were repaired with self-cured acrylic resin.
- **Group A2:** Five dentures were repaired with TiO2nanoparticles (5% in weight) added to the PMMA.

- **Group A3:** Five dentures were repaired with zirconium oxide (5% by weight) added to the PMMA.
- **Group B1:** Five dentures were repaired with self-cured acrylic resin.
- **Group B2:** Five dentures were repaired with TiO_2 nanoparticles mixed with PMMA.(5% by weight).
- **Group B3:** Five dentures were repaired with ZnO_2 nanoparticles mixed with PMMA.(5% by weight).
- **Group C1:** Five dentures were repaired with self-cured acrylic resin.
- **Group C2:** Five dentures were repaired with TiO_2 nanoparticles mixed with PMMA. (5% by weight).
- **Group C3:** Five dentures were repaired with ZnO nanoparticles mixed with PMMA. (5% by weight).

Application of nanoparticle materials:

Using a spatula, manual mixing was done by blending powders of either titanium dioxide or zirconium with powders of PMMA acrylic resin for 10 minutes. Afterward, the mixture was shaken in a sealed container for an additional 10 minutes. Then, the blended powder was added as one unit to the liquid monomer in a ratio of 3:1 by volume as previously mentioned.

Parameters evaluation:

In this study, the micro-hardness and surface roughness were measured and evaluated. 15 dentures from each group were constructed for each test (Group A, Group B, and Group C). Five dentures for each sub- group were analyzed.

Micro-hardness test:

Surface micro-hardness was determined using Digital Vickers hardness tester (Otto Wolpert, Werke GmbH, Ludwigshafen, Germany). Square based pyramid is used where the length of diagonals of indentation was measured and the average value was used. The indentations were made within 30 s from the loading of 500 g at 20 magnifications. After the indentation was finished, the resulting indentation was analyzed optically to measure the length of the diagonals. The Vickers micro-hardness number (VHN) value was calculated automatically using the equation:

$$VHN = 1.8544\ P/d2$$

(P): is the applied force in kilogram

(d):is the mean of the two diagonals obtained from the indentation in mm.

Surface roughness test:

Using a profilometer (Surfcorder SE 1700, Kosaka, Japan) with a 0.01 mm resolution calibrated to a specimen length of 0.8 mm, 2.4 mm percussion of measure, and 0.5 mm/sec, the surface roughness roughness between groups dentures were measured. For each subgroup of the main groups, three readings were collected, and a mean value was calculated.

Statistical Analysis:

The Statistical Package for the Social Sciences was used to conduct the statistical analysis (IBM SPSS Statistics for Windows, Version 24, IBM Corporation, Armonk, NY, USA). The three sub-groups mean values were compared using an independent sample t-test (self-cured acrylic resin, reinforced PMMA with TiO_2, and reinforced PMMA with zirconium oxide). At P ? 0.05, the significance level was determined. The results of micro-hardness and surface roughness were also compared among the three groups using the same test.

III. RESULTS

Using the independent sample t-test and the data distribution, the numerical data were examined for normality.

Regarding the joint surface contours, a statistically significant difference was the result between group A, group B, and group C, where group A found lower surface roughness values than group B and group C.

<u>*For surface roughness within sub-groups*</u>

Regarding the material used for repair, a statistically significant difference was the result between subgroups, wheresubgroupsA1B1, and C1 showed higher values of surface roughness than subgroups A2,3B2,,and C2,3, while there was a non- significant difference between subgroups A2,3,B2,3 and C2,3. As shown in **(Table 1)**

Table (1): The mean, standard deviation (SD) values, and results of repeated measures ANOVA test for surface roughness of all Groups and the subgroups of repair materials.

Group	*subgroup*	*Before fracture*	*After fracture*	*M*	*S.D*	*P-Value*
A	*A1*	*15.8*	*17*	*17.27*	*±2.311*	*0.001**
	A2	*13.8*	*14.1*	*13.51*	*±1.51*	*1.789*
	A3	*13.7*	*13.9*	*13.08*	*±1.67*	*1.732*
B	*B1*	*17.2*	*18.7*	*18.68*	*±14.41*	*0.001**
	B2	*15.2*	*15.7*	*12.30*	*±1.89*	*1.823*
	B3	*14.9*	*15.2*	*20.65*	*±2.33*	*1.722*
C	*C1*	*16.8*	*17.5*	*11.94*	*±2.42*	*0.001**
	C2	*14.9*	*15.1*	*12.47*	*±1.93*	*1.345*
	C3	*14.8*	*15.2*	*11.40*	*±2.262*	*1.221*

M: mean SD: standard deviation * Significant difference as P < 0.05.

For micro-hardness between groups

Regarding joint surface contours, a statistically significant difference was the result between group A, group B, and group C. where group A showed a lower micro-hardness value than group B and group C.

For micro-hardness within sub-groups

Regarding the material used for repair, a statistically significant difference was the between subgroups, where subgroup A1, B1, and C1 showed lower values of micro-hardness than subgroups A2,3,B2,3,and C2,3, while there was a non-significant difference between subgroups A2,3,B2.3,and C2,3. As shown in **(Table 2).**

Table (2): The mean, standard deviation (SD) values, and results of repeated measures ANOVA test for micro-hardness of all Groups and the subgroups of repair materials.

Group	*subgroup*	*Before fracture*	*After fracture*	*M*	*S.D*	*P-Value*
A	*A1*	*10.2*	*12*	*17.07*	*±2.397*	*0.001**
	A2	*13.8*	*14.1*	*16.51*	*±8.042*	*1.789*
	A3	*13.7*	*13.9*	*19.08*	*±3.02*	*1.732*
B	*B1*	*10.2*	*11.7*	*13.68*	*±2.30*	*0.001**
	B2	*15.2*	*15.7*	*7.86*	*±1.62*	*1.823*
	B3	*14.9*	*15.2*	*7.165*	*±1.58*	*1.542*
C	*C1*	*10.8*	*11.5*	*25.46*	*±2.628*	*0.001**
	C2	*14.9*	*15.1*	*15.45*	*±1.710*	*1.388*
	C3	*14.8*	*15.2*	*15.14*	*±3.126*	*1.256*

M: mean SD: standard deviation * Significant difference as P < 0.05.

IV. DISCUSSION

The effect of the addition of TiO2 nano-particles and ZnO2 nanoparticles of PMMA depends on both concentration of 6 nanoparticles and their interaction with the acrylic resin polymer. The ideal concentration of the fillers is still under investigation ***(Gad et al., 2019).***

A fact attributed that the joint surface contour being a round joint contour was superior to other joint contours, where, there should be trails to prevent reoccurring structural failure by means of micro-surface hardness, by distributing the stresses as evenly as possible. Sharp-angled surfaces promote stress concentration, which is directly related to the degree and abruptness of surface changes ***(Li et al., 2021).***

Surface hardness and roughness of the denture are two crucial factors to avoid scratching the denture on service or collection of food, bacterial and fungal to avoid their adhesion to the denture surface with subsequent candidiasis and inflammation ***(Koruervne et al., 2019).***

Recent studies suggested in order to significantly increase the surface hardness of standard and high-impact heat-cured acrylic resin advised to add 5% TiO2 nanoparticles and/or ZnO2 nanoparticles ***(Ashour et al., 2016; Hashem et al., 2017).***

Regarding the surface roughness results, this study showed a statistically significant difference between the subgroups A1,B1,and C1 (round joint contour repaired with self-cured acrylic resin),where it showed higher values of surface roughness than the other subgroups A2,3,B2,3, and C2,3 repaired with nanoparticles. This may be attributed to the irregular and porous structure of PMMA and the presence of pre-polymerized PMMA beads regions as a major component of PMMA powder surrounded by in-situ PMMA formed by the polymerization reaction of methyl methacrylate monomer liquid. While there was a non-significant difference between subgroups A2,3, B2,3, and C2,3, where they found a homogenous less porous structure and this can be explained by the uniform which may help to lessen the likelihood of stains and plaque accumulation ***(Rasha et al., 2022).***

Regarding micro-hardness results, this study showed a statistically significant difference between subgroups A1,B1, and C1(round surface contour repaired with self- cured acrylic resin). While there was a non- significant difference between the subgroups A2,3.B2,3, and C2,3. And these may be due to the interaction between the nanoparticles filler of TiO2 and ZnO2 with PMMA was chemical through their interaction with the ester functional group COOR, Moreover, loading of TiO2 and/or ZnO2 nanoparticles within the resinous matrix hinders polymer chain movements due to strong bond between them and PMMA providing a cross-linking action as investigated by several studies ***(Chatterjee, 2018).***

V. CONCLUSION:

The addition of 5% weight TiO2 nanoparticles and/or Zno2 to dental acrylic PMMA resin improved its mechanical properties in terms of surface roughness and micro-hardness for repairing midline fracture of complete dentures with a round joint contour surface.

Conflict of Interest:
The authors declare no conflict of interest.

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Ethics:
This study protocol was approved by the ethical committee of the faculty of dentistry- Cairo university on: October 2022.

Data Availability:
Data will be available upon request

CRediT statement:

Author 1: Data curation, Writing - review & editing, Writing - original draft, Methodology, Conceptualization, Resources.

Author 2: Data curation, Conceptualization, Project administration, Supervision, Methodology, Writing - review & editing, Writing - original draft.

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