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EFFECT OF ADDING ZIRCONIUM DIOXIDE NANOPARTICLES ON SURFACE ROUGHNESS AND FRACTURE STRENGTH OF IMPLANT RETAINED MANDIBULAR ACRYLIC OVERDENTURE: AN IN VITRO COMPARATIVE STUDY

Shrouk A. Sharaf*, Hussein Abdelhady Hussein Taha** *and* Ahmad Fathalla Shawky***

ABSTRACT

Objectives: Investigate the impact of adding zirconia dioxide nanoparticles (ZrO_2 NPs) on the surface roughness and fracture strength of implant-retained acrylic mandibular overdentures.

Materials and method: An epoxy resin model of a completely edentulous mandibular arch was poured. Two implants were inserted in the canine regions. Two balls and a socket attachment were attached to these implants. Twelve casts were duplicated from the implant epoxy model and divided into two groups. Group I (Control Group): overdentures were made from heat-cured polymethyl methacrylate (PMMA). Group II (Test Group)**:** overdentures were made from heat-cured PMMA modified by 3% silanized ZrO_2 NPs. The surface roughness (Ra) was measured by a contact stylus profilometer in micrometers (µm). A universal testing machine was used to measure fracture strength.

Results: The results of this study revealed a significant increase in the surface roughness of the tested group, while the results demonstrated insignificant differences between the two groups in fracture strength.

Conclusion: The addition of 3% silanized ZrO_2 NPs to implant-retained acrylic overdentures enhances the mechanical properties of the denture base; however, the thickness of the denture base is to be considered.

KEYWORDS: Silanized ZrO_2 NPS, PMMA, implant retained overdenture, surface roughness, fracture strength**.**

* Instructor, Prosthetic Department, Nahda University, Bani-Swif, Egypt
** Associate Professor, Prosthodontics Department. Faculty of Dentistry, Minia University
*** Assistant Professor, Removable Prosthodontics Faculty of Dentistry Beni-Suef University

INTRODUCTION

Conventional complete dentures have many problems, especially mandibular ones, which may be attributed to residual ridge resorption, elevation of superficial muscle attachment, diminished support area, mobility of the floor of the mouth, and the presence of the tongue, which affect denture stability in addition to compromised retention [1].

Dental implants and attachments are widely used to address issues with traditional dentures, especially with ball and socket attachments offering a simple, inexpensive, and easy-to-clean solution for patients [2].

Heat-cured PMMA remains a widely used material for denture bases due to its affordability, ease of manipulation, low density, and esthetic properties. However, it has some drawbacks: it is relatively brittle and weak, making it prone to mechanical failure and increasing the risk of fracture. This risk is particularly concerning for implant overdentures, where the denture base thickness may not be sufficient to withstand loads at the abutment areas. Fortunately, there are now several alternatives available for the enhancement of acrylic denture base material [3]. Research has been interested in nanoparticles, which are widely used. These particles have advantageous characteristics such as their nanoscale size, homogenous shape, composition, and ability to enhance the mechanical properties of PMMA [4].

Recently, ZrO_2 nanoparticles have been applied as a reinforcing agent owing to their biocompatibility, white color, superior strength, resistance to physical corrosion, abrasion resistance, and antifungal activity. Well bonding between inorganic ZrO_2 NPs and organic PMMA is improved through surface modification with silane coupling agent [5]. Several studies concluded that the inclusion of salinized ZrO_2 NPs in acrylic resin led to a significant decrease in porosity and a slight improvement in surface roughness and hardness [6].

Candida albicans adherence and plaque formation are directly related to the roughness of the complete denture surface. Hence, it is quite important to pay attention to the surface roughness of denture base materials. A smooth denture surface means better aesthetics, fewer stains, and subsequent patient comfort [7].

Our study was accomplished to evaluate the effect of 3% silanized ZrO_2 NPs on the surface roughness and fracture strength of mandibular implant retained overdentures.

MATERIALS AND METHODS

Model fabrication and implant installation

The epoxy model was constructed according to manufacturer instructions by pouring a ready-made rubber mold (Trimould, Tokyo, Japan) with epoxy resin (Kemapoxy cast resin, CMB, Egypt) to simulate the modulus of elasticity of the bone [8, 9].

Two identical internal hex implants (3.5 mm in diameter and 12 mm in length, Vitronex Elite Implant System, Italy) were drilled in the canine region bilaterally using a milling machine with a surveyor table. The two implants were parallel to each other, perpendicular to the ridge, and at the same vertical level [10, 11]. Implants were fixed to the cast using a small amount of epoxy resin to simulate osseointegration. Ball abutments (FLW-MS01-MPI, Vitronex Elite, Italy) were attached to both implants (Fig. 1).

Model duplication

The epoxy model with implants, a ball abutment, and their corresponding metal housing were duplicated by silicon duplicating material (ZHERMACK Elite Double 32, Italy) to produce 12 replicas on which dentures were constructed.

Preparation of zirconium dioxide nanoparticles

Coupling agent: 3-aminopropyltriethoxysilane (APTES) (Sigma-Aldrich, 102465057, China) Silane was used as a surface modification of

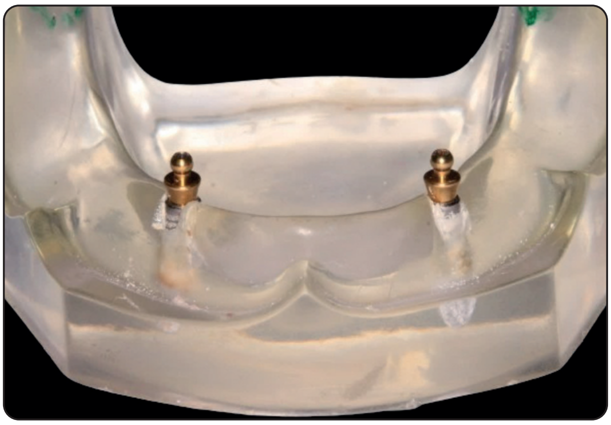

Fig. (1) Epoxy cast with implants and attachment.

inorganic ZrO_2 NPs to enhance their chemical bond with organic PMMA [12].

According to the tested concentration of ZrO_2 NPs, 25 g of PMMA powder needed 0.75 g of ZrO_2 NPs for each specimen. According to manufacturer instructions, the polymer/monomer ratio must be 2.5:1, which means using 10 ml of monomer [12].

Overdenture construction and sample grouping

A silicone mold of the epoxy model was poured to produce 12 casts on which overdentures were constructed. Two sheets of baseplate wax (Cavex, Holland BV Netherlands) were adapted onto the residual alveolar ridge of the Edentulous cast (12). Artificial teeth (Acrostone, crosslinked acrylic teeth, size 20, licensed by WHW, England, and Egypt) were arranged on the base plate wax. The occlusal plane was adjusted at the level of the junction between the superior and middle thirds of the retromolar pad. Waxing up of the dentures was completed.

Group I: Overdentures were constructed from conventional heat-cured PMMA (Acrostone, licensed by WHW, England, Egypt), which was mixed according to manufacturer instructions.

For group II, overdentures were constructed from PMMA reinforced with 3% silanized ZrO_2 NPs (Nano Gate, Egypt), which were added to the monomer and mixed by Homogenizer (DAIHAN-brand Homogenizer, HG-15D With Microprocessor Digital-Control) at 2500 rpm for 5 minutes, then the PMMA powder was added directly to the mixture [13].

Packing, processing using a long curing cycle, fishing, and polishing were standardized and accomplished in the same manner as in conventional dentures. On the epoxy model, ball abutments were covered by housing, followed by pick-up with self-cured resin (Acrostone, licensed by WHW, England, Egypt). Denture base thickness was measured by caliper to ensure even thickness, specifically in the canine regions, which was adjusted at 2 mm.

I-Surface Roughness (Ra) Test

A contact stylus profilometer (Mitutoyo Surface Test SJ-210, Stroke Length: 4mm, ISO 1997, Japan) was used to measure surface roughness with a diamond contact stylus. Dentures were positioned in such a way that the stylus was just in contact with their surfaces. The stylus was moved perpendicular for 4 mm at a speed of 0.5 mm/sec with 4 mN of force on the polished surface of dentures. Ra is defined as the average vertical deviation along the surface of the specimen measured in micrometers (μm) (Fig. 2).

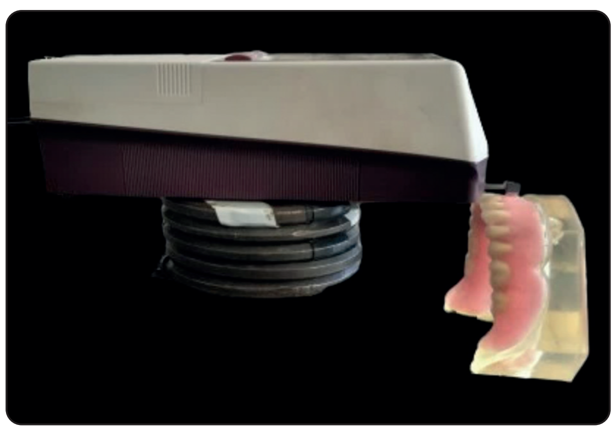

Fig. (2) Measuring surface roughness.

II- Fracture strength test

Fracture strength for both groups was tested by universal testing machines (INSTRON and SATEC, CAT.NO. 2710.115, CHINA). The epoxy cast was fixed in the lower compartment of the machine by a lead pin screwed in the middle of the cast, then clamped in the jig of a universal testing machine. Compressive load was applied by an inverted T-shaped metallic load applicator (Fig. 3) [14], traveling at a crosshead speed of 0.5 mm/sec. To ensure even load distribution, it was applied occlusally and bilaterally in the central bicuspids. The fracture pattern of both groups was observed and recorded. An audible crack sound was observed as a manifestation of a fracture, in addition to a sharp drop at the load deflection curve, which was recorded by computer software. All the data were collected, tabulated, and statistically analyzed.

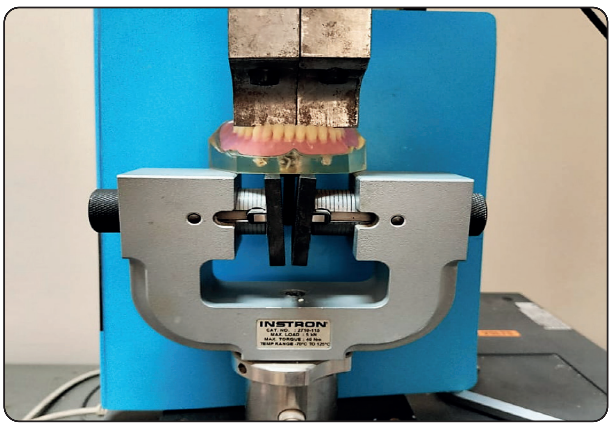

Fig. (3) Dentures mounted in universal testing machine.

Statistical analysis

Numerical data were presented as mean and standard deviation (SD) values. They were tested for normality and variance homogeneity by viewing the distribution and using Shapiro-Wilk's and Levene's tests, respectively. They were found to be normally distributed, yet the homogeneity assumption was violated. They were tested using an independent Welch t-test. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.4.1 for Windows (R Core Team 2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria)

RESULTS

Surface roughness (µm)

The comparison of the mean ± SD of surface roughness (µm) between the test group (ZrO_2 Nps) and the control group is presented in (Table 1). There was a statistically significant difference between both groups where reinforced acrylic resin with ZrO_2 showed high surface roughness ($p<0.001$). (Fig. 4).

TABLE (1) Comparison of surface roughness results for both groups.

Measurements	*(Mean±SD)*		*t-value*	*p-value*
	Test	*Control*		
Surface roughness (Ra)	1.26±0.07	0.85±0.10	**10.97**	**<0.001***

Significant (p<0.05).

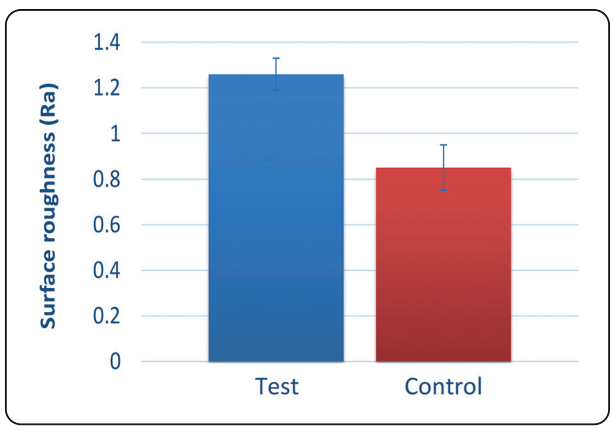

Fig. (4) Bar chart showing mean and standard deviation values (error bars) of surface roughness (Ra).

Fracture Strength (N)

Comparing the mean ± standard deviation (SD) of fracture strength (N) between the test group (ZrO_2 Nps) and the control group is presented in Table 2. There was a statistically insignificant difference between both groups (p = 0.755). Which are presented in (Fig. 5)

TABLE (2) Comparison of fracture strength results of two groups.

Measurement	*(Mean±SD)*		*t-value*	*p-value*
	Test	*Control*		
Fracture resistance (N)	1746.95 ±256.31	1774.18 ±80.66	**0.32**	**0.755**

Significant (p<0.05).

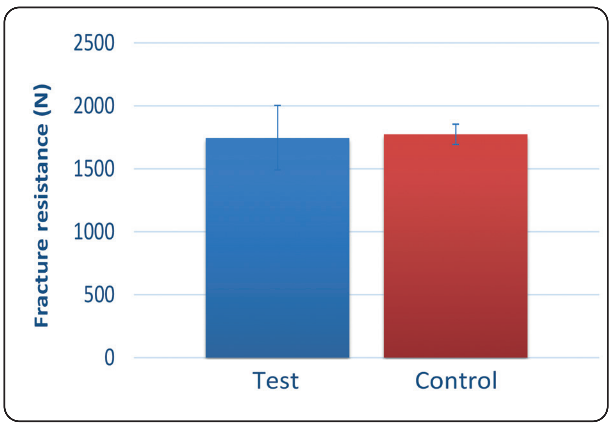

Fig. (5) Bar chart showing mean and standard deviation values (error bars) of fracture resistance (N).

DISCUSSION

The main goal of this study is to evaluate the impact of silanized ZrO_2 NPs on the surface roughness and fracture strength of heat-cured acrylic resin in an attempt to decrease its drawbacks and improve the fracture strength of acrylic resin surrounding the ball attachment in implant-retained overdentures.

Contact Stylus profilometers have been used to measure surface roughness because of their merits, which include their surface independence, precision, adaptability, and direct approach, which eliminates the need for modeling. Often Contacting the surface is beneficial in unclean conditions, where non-contact technology may assess surface contaminants instead of the surface itself. Stylus profilometers are insensitive to color or reflection. As thin as 20 nanometers can be achieved for the stylus tip radius, making it a significant improvement over white-light optical profiling. Furthermore, vertical resolution frequently falls below the nanometer [(7)].

The universal testing machine (UTM) was used to determine fracture strength. It is the most often used equipment due to the variety of tests it can conduct on many types of materials. The control system and the software that goes with it record the specimen's load, extension, and compression during the test, as well as any changes to the gauge length [(15)].

The results of the present study have shown that the addition of ZrO2 NPs has an influence on the surface roughness and fracture strength of heat-cured acrylic resin. There was a significant increase in the surface roughness in the zirconia group; on the contrary, its effect on the fracture strength improved.

Results of the present study show that dentures with ZrO_2 nanoparticles have a more irregular surface texture, which can be explained by the fact that nanoparticle agglomeration and cluster formation occur on the surface in addition to reducing the homogeneity of the resin matrix. Their very small size allows particles to enter between the linear polymer chains, resulting in increased surface roughness [(16)].

Another study attributed the increase in the roughness of the denture base to the surface porosities owing to a number of agents such as air entrapment that occurs during the mixing of acrylic resin, the existence of residual monomers, and monomer evaporation as a result of the exothermic polymerization reaction [7].

The results of the present study agreed with Hamid et al., who reported that adding ZrO_2 NPs to heat-cured PMMA increased surface roughness, which was related to NP concentration [17].

The results are in accordance with Ergun et al., who stated that an increase in nano-ZrO_2 concentration was directly proportional to surface roughness (18). Another study showed that adding ZrO_2 NPs and TiO_2 NPs had a significant increase in the surface roughness of acrylic resin [19].

On the other hand, the result of surface roughness was in disagreement with Al-Hiloh et al., who suggested that there was no variance in surface roughness when adding 3% silanized ZrO_2 NPs to high-impact heat-cured acrylic resin [13].

Depending on the results of the fracture strength study, the modification of ZrO_2 NPs yielded that the difference was statistically insignificant. This finding confirmed the hypothesis of Elkafrawy et al., who found that the flexural strength increased at 0.5% and 1% zirconia but was insignificant at high concentrations, and they attributed that to the formation of impurities that disturbed the consistent matrix of PMMA, leading to the deterioration of the mechanical properties of the zirconia-modified acrylic resin. Moreover, the difference in density between PMMA (1.18 g/cm3) and zirconia (6.15 g/cm3) suggests that PMMA prefers zirconia to be settled down during mixing, resulting in an inhomogeneous composite [20].

The present findings contradict with some previous studies that supposed Reinforcement with nano-ZrO_2 increased the flexural strength of PMMA resin, even with decreased denture base thickness [21]. In one of these studies, Azmy et al. found that the incorporation of different concentrations of different NPs into PMMA, including 3% ZO2, significantly increased the flexural strength [22]. On the contrary, increasing the nano-zirconia ratio from 7% to above had a weakening effect on the flexural strength [23].

Study performed by Tokgoz et al reported that Fracture strength increased significantly when the denture base thickness was increased which explained this study findings [24].

There were certain limitations to this in vitro study: it was conducted in a laboratory, the sample size was limited to only one type of acrylic, NPs, and single percentages, along with many material restrictions. Other types of denture bases exist in diverse circumstances, mimicking the oral environment.

CONCLUSION

Within the limitations of this in vitro study, the surface roughness is increased by the addition of 3% silanized ZrO_2 NPs to the implant-retained overdenture. The fracture strength could be enhanced by PMMA with a precautionary measure of the percentage of nanoparticles and denture base thickness.

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