EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 70, 1503:1513, April, 2024

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 23-12-2023 • Accept Date : 02-02-2024 • Available online: 10-04-2024 • DOI : 10.21608/EDJ.2024.257497.2844

# INFLUENCE OF REINFORCEMENT WITH SILICON DIOXIDE NANOPARTICLES ON THE FRACTURE STRENGTH AND SURFACE ROUGHNESS OF IMPLANT-RETAINED MANDIBULAR OVERDENTURE: AN IN VITRO COMPARATIVE STUDY

Safaa Salah Ali*, Sherief M. Abdelhamid*,
*and* Mostafa El-Sayed Abd El-haleem* Iman A El-asfahani*

## ABSTRACT

**Aim**: Evaluating the influence of adding silicon dioxide nanoparticles (SiO2 Nps) on fracture strength and surface roughness of implant-retained mandibular acrylic overdentures

**Materials and methods**: A mandibular epoxy resin model was constructed from a completely edentulous mold. Two implants were inserted at the canine areas bilaterally. Experimental overdentures were constructed with metal housings of ball and socket attachments. Overdentures for the SiO2 Nps group were constructed from heat-cured acrylic resin material with the incorporation of 1% silanized SiO2 Nps and overdentures for the control (conventional PMMA) group were constructed from heat-cured acrylic resin material. The fracture strength was measured in newtons (N) by a universal testing machine at a speed of 5 mm/min. The surface roughness of overdentures was measured in micrometers ($\mu$m) by using a stylus profilometer.

**Results**: Regarding fracture strength, the PMMA overdenture base group reinforced with 1% SiO2 Nps had significantly higher fracture strength compared to the control group. On the other hand, the surface roughness of the SiO2 Nps overdenture base group was significantly higher than the control group.

**Conclusion**: Within the limitations of this study, the incorporation of 1.0 % silanized SiO2 Nps to heat-cured PMMA may significantly increase the fracture strength and surface roughness of the denture base in implant-retained mandibular overdenture.

**KEYWORDS**: Implant-retained overdenture, PMMA, SiO2 Nps, fracture strength, surface roughness.

* Teaching Assistant In Prosthodontics Department, Minia University
** Lecturer of Prosthodontics Department, Pharos University
*** Lecturer of Prosthodontics Department, Minia University
**** Associate Professor, Prosthodontics Department, Faculty of Dentistry Minia University, Egypt

## INTRODUCTION

The standard treatment of completely edentulous individuals poses a significant problem to obtain straightforward, inexpensive procedures and ensure patients' wellbeing [1].

A complete denture prosthesis is the most popular method for improving patients' dental health and restoring masticatory skills. Several individuals have reported difficulty performing regular duties after wearing dentures for a period. Poor retention and stability of a complete denture can often result in patient discontent and lower quality of life. A complete denture prosthesis is the most popular method for improving patients' oral health and restoring masticatory ability [2, 3].

Implant overdentures can improve the stability and retention of traditional dentures, which increases patient satisfaction and improves masticatory function. Implant-retained overdentures are a good substitute for fixed prostheses or else traditional complete dentures held in place by implants in the edentulous jaw. It can offer a satisfactory treatment option when the fixed implant-supported prosthesis is too costly[4,5]. It is also applicable in a range of edentulous mandible situations; in cases with implant failures requiring further therapeutic options or compromised bone states requiring the distribution of occlusal load between the implants and mucosa [6].

The retention needed, jaw anatomy, inter-arch distance, the patient's submission to follow-up visits to perform necessary maintenance, and oral function play a great role in the selection of a certain attachment [7].

A ball and socket attachments are the most widely used overdenture attachments. Its advantages include easy manufacturing, a wide range of movement, cost-effectiveness, ease of use and maintenance, good retention, hygienic, and high patient satisfaction [8, 9].

Poly methyl methacrylate (PMMA) is a material that is broadly used for denture bases because of its numerous beneficial characteristics, such as its low price, lightweight, stability in the oral environment, and ease of repair. Additionally, it has a simple construction technique, low water absorption and solubility, high aesthetic outcomes, and color-matching capabilities [10].

On the other hand, PMMA has several drawbacks because of its reduced mechanical characteristics, which frequently lead to denture bases fracture. It is susceptible to fracture during function owing to dynamic masticatory force and handling [11]. The mechanical and surface characteristics of PMMA could be improved by using various fillers and reinforcing fibers. Recent advances have focused on using nanoparticles to produce nanocomposite materials with acceptable mechanical characteristics [12].

The previously investigated range of nanoparticle concentrations was 0.5% to 10% by weight (wgt). Regarding their effect on the mechanical properties of acrylic denture base, an enormous amount of variation was provided. High concentrations had adverse effects in most of the situations, while low levels had beneficial ones. Research which investigated addition of $SiO_2$ Nps to PMMA recommended addition of low concentration. It has been documented that adding $SiO_2$ Nps to PMMA improves its thermal conductivity and optical characteristics [13,14]. Low concentrations of $SiO_2$ Nps were added to acrylic resin denture base material with homogeneous nanoparticle distribution, thus reducing or preventing $SiO_2$ Nps aggregation which improved the mechanical characteristics eventually [15]. **Balos S et al, 2014** reported that the adding $SiO_2$ Nps to acrylic denture base allowed for thin, strong, and long-lasting denture base production without decreasing the mechanical and physical properties [16].

The composition and surface structure of biomaterials, as well as the physicochemical characteristics of the microbial cell surface, all may influence microbial adherence on their surfaces. As dental plaque adhesion is correlated with surface roughness and presence, smooth acrylic resin surfaces are less sticky to bacterial colonization and production. Accordingly, the lower surface roughness of acrylic resin dentures results in less biofilm production [17]. SiO2 Nps was incorporated into acrylic denture base resin by **Alzayyat et al, 2021** at low concentrations (0.25, 0.5, and 1.0%). This study's results showed an improvement in Candida albicans adherence, hardness, and contact angle [18].

Hence, a question arises whether the addition of 1.0 % silanized SiO2 Nps to acrylic resin denture base in implant-retained mandibular overdenture can improve the fracture strength and surface roughness of the denture base or not. The null hypothesis was that no difference in fracture strength and surface roughness of acrylic resin denture base in implant-retained mandibular overdenture with the incorporation of 1.0 % silanized SiO2 Nps in denture base material could be found.

## MATERIAL AND METHODS

### Model construction and implants' insertion

The research was performed on an epoxy mandibular model for the sake of standardization simulating the clinical situation. The mandibular resin model was obtained from epoxy resin poured into a rubber mold of a completely edentulous mandible (fig. 1a). A commercially available rubber mold (Trimould, Tokyo, Japan) for a completely edentulous mandible was used to obtain the working model. The Chem epoxy resin used for the construction of the model was presented in the form of two Mixings A and B. Mixing was done according to manufacturer instructions by proportion 3A to 1B and mixed using a wood stick used for the construction of the epoxy model. The mix of epoxy resin was poured into the rubber mold until setting to obtain the epoxy cast.

Another cast made from extra-hard dental stone (Dentstone KD, Saint-Gobain, Formula, Newark, UK) was made by pouring the same rubber mold to attain two identical models (epoxy resin and stone).

In the canine areas on both sides of the mandibular ridge, two identical implants with 10 mm length and 3.5 mm diameter (Neobiotech, Korea, Lot. Number: F010122) were inserted using AF30 universal milling machine (NOUVAG, AF30, CH-9403,Goldach, Switzerland) to ensure parallelism (fig. 1b).

Two identical ball and socket abutment systems (Neobiotech, Korea, Lot. Number: F010122) with a ball diameter of 3.5 and Hex 2.4mm were used (fig. 1c). Housings with a Diameter of 5.0 and Length of 4.0mm were placed on the ball abutments to be picked up later in base of denture (fig. 1d).

### Silica nanoparticles salinization

Toluene was first put in the container, and then silicon-dioxide nano particles filler (Nano gate, Egypt) was added and stirred. After that, the toluene and silica nanoparticles were homogeneously mixed for 20 minutes using an ultrasonic probe (fig. 2). To prevent particle agglomeration, propyl-trimethoxy-silane was added drop by drop while stirring the mixture. Later, toluene was removed using an evaporator after mixture was covered and left for 48 hours. After that, the nanofiller was dried up using a vacuum oven at 60 °C for 20 hours.

### Construction of the experimental overdentures and grouping

Two baseplate wax sheets (Cavex, Holand) with a thickness of 3.50 mm were shaped on the ridge in the stone cast afterwards an occlusal rim was made atop of denture base wax. Later, the mandibular anterior and posterior teeth (Artic 6M S7 shade A2, Metrodent Limited, Huddersfield) were arranged in the occlusion rim (fig. 3a). The area posterior to the second molar at the retromolar area in the

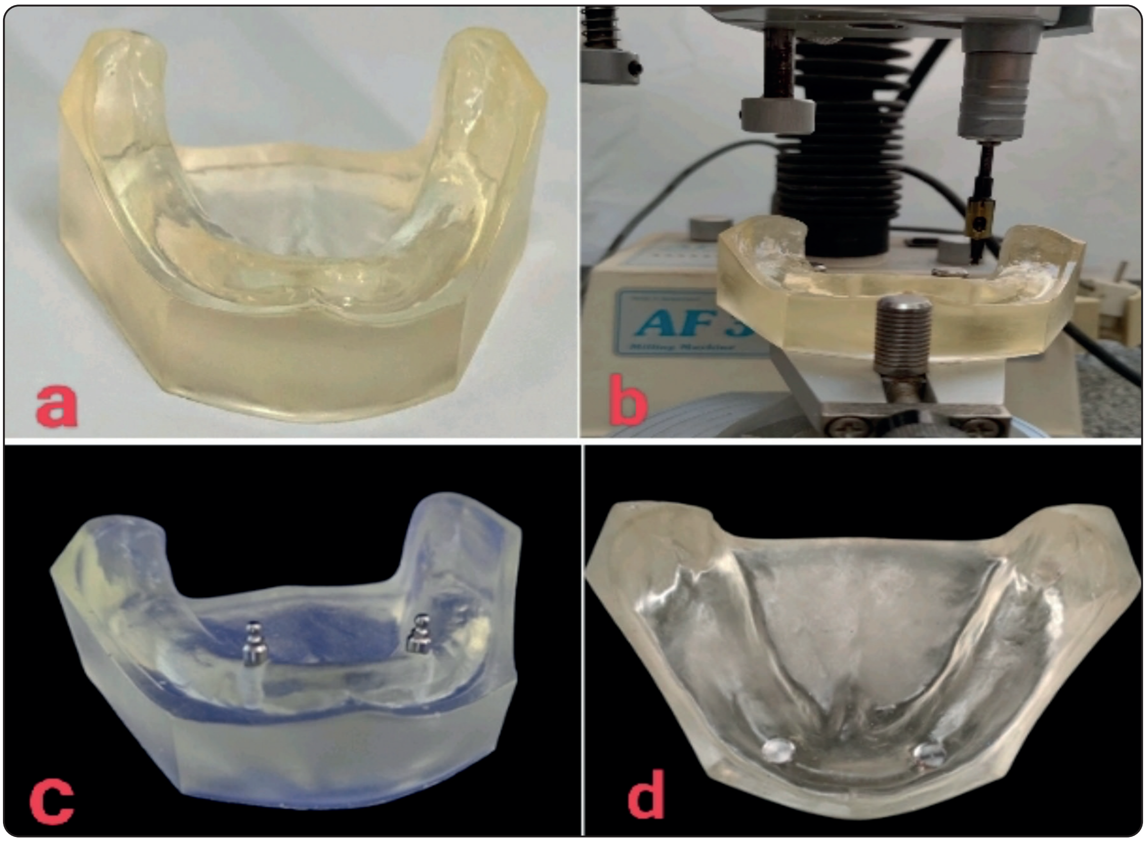


Fig. (1) a) Epoxy resin cast, b) Using milling machine for drilling of implants at canine areas, c) Ball Abutments on implants. d) Housings placed on the ball Abutments.

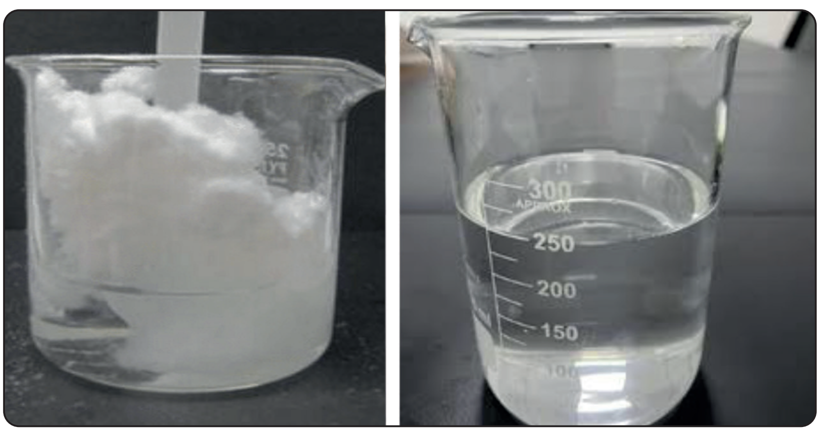


Fig. (2): Mixing nanoparticles and toluene denture polished surface of the wax forming the denture base was carved to be a flat rectangular area with 4 mm height and 3 mm width. This flat area was created to be used in the surface roughness measurement. The waxed denture was flasked then the waxing elimination process was done using the wax elimination unit. Two study groups were assigned.

***For the Silicon dioxide Nanoparticles (SiO2 Nps) group:*** An electronic balance (Shimadzu corporation, Tokyo, Japan) was used to weight the acrylic resin and SiO2 Nps powders and adjust the percentage of SiO2 Nps to acrylic resin to be 1.0 % by weight (wgt) (fig. 3b). The SiO2 Nps were added to the acrylic monomer to prepare monomer/ SiO2 Nps to produce a homogenous mix. Later, powder of acrylic resin was inserted into the mixture; the mixture was then accurately mixed sticking to the manufacturer's guidelines (tab. 1).

***For the control group*** **:** Acrylic resin monomer and powder of acrylic resin (Dentsply international inc., York, Pennsylvania) were mixed following manufacturer's guidelines until the mixture had been made uniformly.

TABLE (1) The materials used in each group denture base.

| Groups | Silica (wgt. %) | Silica (g) | PMMA Powder (g) | MMA Monomer (ml) |
|---|---|---|---|---|
| **Control group** | 0 | 0 | 33.00 | 13 |
| **SiO2 Nps group** | 1.0 | 0.330 | 32.67 | 13 |

In both study groups, packing of the heat-cured acrylic resin and curing using long curing cycle were done according to the manufacturer's instructions. Ten overdentures were constructed for each group. for each overdenture, a long curing cycle (9h at 75°C) was selected for polymerization process. After that, the flask was transferred from the curing bath and allowed to cool for half an hour at room temperature. Denture was then removed after opening the flask. The denture was cleaned, finished, and polished using a polishing machinery (Tavom, Wigan, UK ) using the pumice powder (fig. 3c,d).

**Picking-up procedure:**

The ball attachment nylon caps and housings have been located over the ball abutment at each implant bilaterally. Relief in the intaglio surface of the denture at the sites facing metal housings. Two small holes had been created on the over denture at the lingual flange to permit the escape of extra lining acrylic resin were made. Chemically activated acrylic resin material (Dentsply international inc., York, Pennsylvania) was mixed and placed in the fitting surface of the over denture opposite the housing site. The over denture was then seated over the epoxy cast to pick-up the 2 housing. After complete setting of acrylic resin, the overdenture was removed from the cast, the excess resin was removed and finished (fig. 3e). A micrometer was used for measuring the denture base thickness at the area of loading (near canine zone). The average measurement was 2±0.1 mm (fig. 3f). The previously mentioned picking-up procedure was repeated for each overdenture using a different metal housing and nylon cap each time .

**Surface roughness test**

The surface roughness (Ra) values were measured using a digital profilometer (Mitutoyo Surf Test SJ 210, Mituto Corp., Japan), which uses a stylus to detect minute surface differences. The measurements were made at the flat retromolar area posterior to the second molar. Stylus moved in touch with this area in the overdenture polished surface which was seated on the epoxy resin cast. The surface variations were measured as the stylus vertical displacement over the denture surface occurred. The stylus height position was converted into a digital signal, which was then stored and shown at the screen of profilometer measured in micrometers ($\mu$m) (fig. 3g).

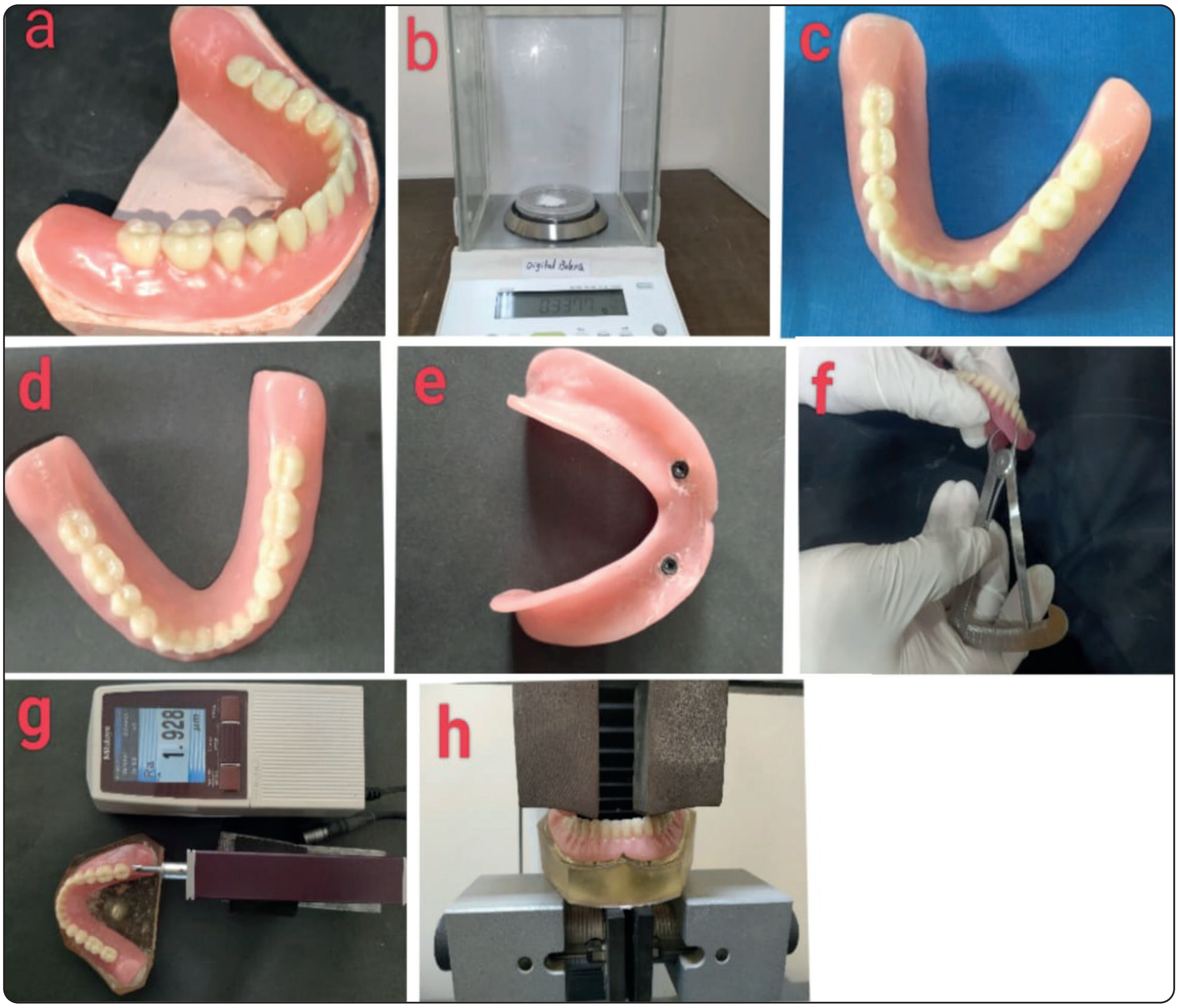


Fig. (3) a) Arrangement of acrylic teeth on denture base wax, b) Electronic balance for weighting acrylic and Nanoparticle powder, c) the control group overdenture, d) the nanoparticle group overdenture, e) Micrometer measuring denture base thickness, f) Picking up of the housings, g) Stylus profilometer measuring surface roughness. h) Universal testing machine applying load at canine areas.

**Fracture strength test**

To avoid dislodgement of epoxy model while performing the fracture strength test , a lead pin was embedded at middle of epoxy model, this pin was then clamped in the jig of a universal testing machine (Model LRX Plus, Ametek Instrume, Fareham, England). The model with the overdenture specimen was mounted horizontally using the jig in a specially built loading fixture in the testing equipment with a load cell of 5 KN. A static load was applied at the canine regions bilaterally. This load was originally set to zero then was increased gradually at a crosshead speed of 5 mm/min until the overdenture base was fractured. At this event , force was registered and measured in newtons (N). This force was assigned to be the maximum force needed to fracture this overdenture specimen and was as an indication of the fracture strength of the overdenture base (fig. 3h).

### Statistical analysis

Raw data were registered, presented in tables, and statistically analyzed using Statistical Package for Social Sciences (SPSS, Version 23.0, IBM Corp., Armonk, New York). The data distribution was evaluated for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. The distribution of all data was normal (parametric). The mean and standard deviation (SD) values of the data were displayed. The two groups were compared using the student's t-test. The relationship between surface roughness and fracture strength was determined using Pearson's correlation coefficient. The criteria for significance were chosen at $P \leq 0.05$.

## RESULTS

### Fracture strength (N)

Comparing the mean ± standard deviation (SD) of fracture strength (N) SiO2 Nps group and the control group is presented in Table 2. The SiO2 Nps group compared to the control group displayed a statistically significant higher fracture strength ($P \leq 0.05$). (fig. 4a).

### Surface roughness ($\mu$m)

Comparing the mean ± standard deviation (SD) of surface roughness ($\mu$m) SiO2 Nps group and the control group is presented in Table 3. The SiO2 Nps group in comparison to the control group displayed a statistically significant higher surface roughness (fig. 4b).

TABLE (2) Student's t-test results and descriptive statistics for comparing the fracture strengths (N) in SiO2 Nps and Control groups.

| SiO2 Nps Group (n = 10) | Control Group (n = 10) | *P*-value | *Effect size (d)* |
|---|---|---|---|
| **Mean+ SD** | **Mean+ SD** | | |
| 1227.3+7.1 | 1051.2+8 | ≤ 0.001* | 23.374 |

***Any P-value ≤ 0.05 is judged significant.***

TABLE (3) Student's t-test results and descriptive statistics for comparing the surface roughness ($\mu$m) in SiO2 Nps and Control groups.

| SiO2 Nps Group (n = 10) | Control Group (n = 10) | *P*-value | *Effect size (d)* |
|---|---|---|---|
| **Mean+ SD** | **Mean+ SD** | | |
| 1.768+0.0884 | 0.8401+0.0638 | 0.001* | 12.034 |

***Any P-value ≤ 0.05 is judged significant.***

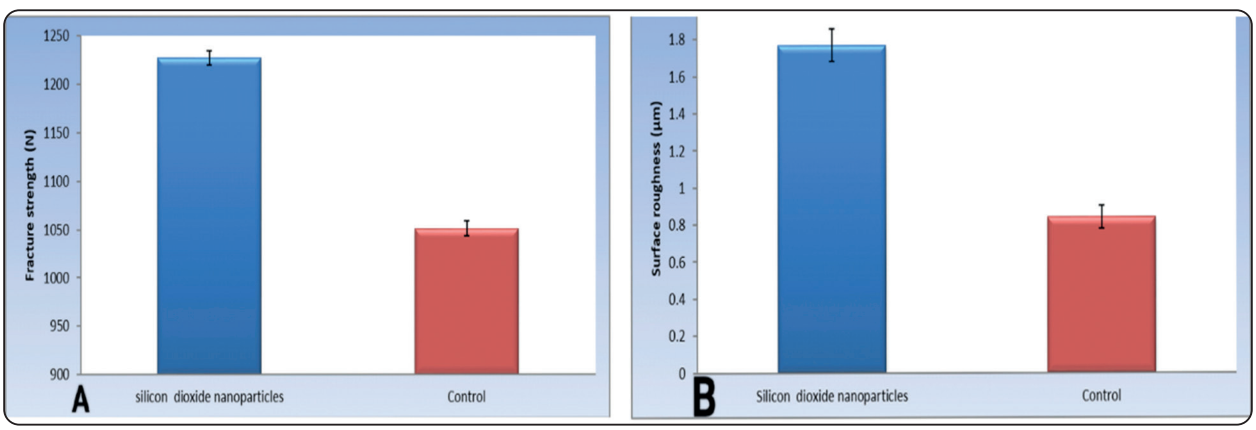


Fig. (4) a) Bar chart showing mean and standard deviation values for the fracture strength of both groups. b) Bar chart showing mean and standard deviation values for the surface roughness of both groups.

Surface roughness and fracture strength were directly correlated in a statistically significant manner. Surface roughness increase was linked to higher fracture strengths (tab 4).

TABLE (4) Results of the correlation between surface roughness and fracture resistance using Pearson's correlation coefficient.

| Correlation coefficient (*r*) | *P*-value |
|---|---|
| 0.990 | <0.001* |

***Any P-value ≤ 0.05 is judged significant.**

## DISCUSSION

This study was performed on a cast of an edentulous mandible. The attachment system was supported by two implants that were positioned bilaterally in the canine regions. To evaluate the fracture strength and surface roughness of two different denture base materials (heat-cured PMMA and heat-cured PMMA reinforced with 1.0 % silicon dioxide nanoparticles).

The cast material was epoxy resin which was selected as its modulus of elasticity (20GpA) which closely resembles the human mandibular bone Furthermore, the epoxy resin material's high mechanical characteristics might protect against the model breaking down mechanically when exerting force on the assembly [19].

For edentulous patients, an implant-retained overdenture system is a standard of care treatment choice. Chewing ability, stability, support, and overdenture retention can be improved compared to conventional complete dentures. Additionally, it might preserve the surrounding bone and improve patient satisfaction [20].

Two identical implants (10 mm in length and 3.5 mm in width) were placed in the canine region bilaterally using a universal milling machine to ensure that the implants were perpendicular to the residual ridge of the epoxy cast and parallel to each other [21]. Ball attachments were used because they are inexpensive, simple to handle, and can be utilized with both implant- and root-retained prostheses [8]. Ball attachment may offer a sufficient retention mechanism, reduce stress on implant bodies, and improve denture stability. Additionally, it was demonstrated that when a ball attachment is employed, the force is not transferred to the implant body but rather is absorbed by the plastic matrix component causing denture deformation[22,23].

Salinized SiO2 Nps were used in this investigation, and the salinization process produced a siloxane layer on the nanoparticle surface, this process This layer is created because of silane's interaction with the hydroxyl group (OH) on the external surface of the nanoparticles inducing the formation of a bond which subsequently causes the organic PMMA polymer and inorganic filler be strongly attached. Propyl-trimethoxy-silane is advised since it has been shown to offer excellent bonding, more homogenous filler scattering with superior mechanical properties of PMMA, and enhanced surface alteration impact with several kinds of nanoparticles [24].

The most used denture base material is acrylic resin owing to its beneficial working qualities, processing simplicity, precise fit, stability in the oral environment, good color stability, and superior benefits, it has some poor mechanical qualities [25]. Acrylic resin's inadequate fracture strength, impact strength, and fatigue resistance might result in fractures during use. Resin fatigue is primarily responsible for denture fractures inside the patient's mouth [26].

SiO2 Nps are widely used as reinforcing nanomaterial owing to its unique properties. It could be employed in reinforcing denture base polymer because of its stiffness and antibacterial qualities. A previous study stated that adding low SiO2 Nps

(1.0 % by weight) to PMMA resin in interim fixed prostheses has markedly increased their fracture toughness [27].

On comparing heat-cured PMMA and heat-cured PMMA reinforced with SiO2 Nps, the reinforced PMMA denture base had a higher fracture strength. This finding agrees with another study which concluded that the addition of lower concentrations of SiO2 Nps (0.25, 0.5, and 1.0 wgt %) into the heat-cured resin denture base increased the flexural strength (FS) [28]. Additionally, in previous research, 1% and 3% of SiO2 Nps were added to denture base material and the FS significantly increased in the 1% concentration [29].

The current study results also coincide with another study that compared the silanized SiO2 Nps to PMMA and concluded that there was a significant increase in FS in the 1.0 % concentration[30]. Moreover, an in vitro study investigated the influence of adding various concentrations of silanized SiO2 Nps (0.25, 0.5, 1, 5, and 10%) and their impact on the acrylic denture base material's mechanical properties, and the results showed that the 1% amount of silanized nanoparticles had the highest FS among the other groups. Advancement in the FS might be caused by the homogeneous distribution of nanofillers and their capacity to infiltrate gaps in the inter-polymeric chain, which interrupts fracture propagation [31].

The current study results demonstrated that there was a statistically significant increase of the surface roughness of acrylic resin material by adding 1.0% silanized SiO2 Nps compared to the control group. This finding might be accredited to the different particle size of nano fillers compared to that of acrylic resin, which may have led to the creation of filler aggregates on the surface that might separate during finishing and polishing, creating spaces and trenches in the surface[32].

This finding agrees with a study which evaluated the surface roughness of reinforced acrylic resin using scanning electron microscope. The latter study stated that reinforcing with 1% silica showed the greatest surface roughness as compared with the other groups [30]. Moreover, in a study which investigated the properties of PMMA after adding (0.25, 0.5, and 1%) SiO2 Nps the results displayed a significant increase in surface roughness in all concentrations [29]. Furthermore , another study concluded that the addition of higher than 0.5% SiO2 Nps to PMMA increased its surface irregularities [33]. Based on the current study results, the null hypothesis was rejected.

Preventing denture base fracture at weak and thin areas, such as the area around the attachment housing can be a chief requirement in implant-retained mandibular overdentures. Hence a better fracture resistance would be significantly beneficial. On the other hand, materials used within the mouth must have a smooth surface to have a superior biocompatible effect in the oral cavity, especially in preventing bacterial and fungal adhesion.

This in vitro study had some limitations; a single type of PMMA used several material restrictions, and the investigation was done in a laboratory environment which may not exactly replicate circumstances orally. Therefore, further studies are required to determine the influence of various nanofiller concentrations and other types of denture resins under diverse circumstances that replicate the oral environment.

## CONCLUSION

Within the limitations of this study, the incorporation of 1.0 % silanized SiO2 Nps to heat-cured PMMA may significantly increase the fracture strength and surface roughness of the denture base in implant-retained mandibular overdenture.

## REFERENCES


1. Srisilapanan P, Korwanich N, Jienmaneechotchai S, Dalodom S, Veerachai N, Vejvitee W, et al. Estimate of impact on the oral health-related quality of life of older Thai people by the provision of dentures through the royal project. Int J Dent 2016;2016:1976013.
2. Limpuangthip N, Somkotra T, Arksornnukit M. Modified retention and stability criteria for complete denture wearers: A risk assessment tool for impaired masticatory ability and oral health-related quality of life. J Prosthet Dent. 2018;120(1):43-49.
3. Melas F, Marcenes W, Wright PS. Oral health impact on daily performance in patients with implant-stabilized overdentures and patients with conventional complete dentures. Int J Oral Maxillofac Implants 2001;16:700-12.
4. Awad MA, Lund JP, Shapiro SH, Locker D, Klemetti E Chehade A, Savard A, Feine JS. Oral health status and treatment satisfaction with mandibular implant overdentures and conventional dentures: a randomized clinical trial in a senior population. Int J Prosthodont. 2003;16:390-6.
5. Ekfeldt A, Johansson LA, Isaksson S. Implant-supported overdenture therapy: a retrospective study. Int J Prosthodont. 1997;10(4):366-374.
6. Engquist B, Bergendal T, Kailus T, Linden U. A retrospective multicenter evaluation of osseointegrated implants supporting overdentures. IntJ Oral Maxillofac Implants 1988;3:129-134.
7. Rutkunas V, Mizutani H, Takahashi H, Iwasaki N. Wear simulation effects on overdenture stud attachments. Dent Mater J. 2011;30:845–53.
8. De Albuquerque, R.F., Jr.; Fromentin, O.; Lassauzay, C.;Conceição Pereira Saraiva, M.D. Patient satisfaction versus retention of implant overdentures with two attachment systems: A randomized trial. Clin. Implant. Dent. Relat. Res. 2019, 21, 21–31.
9. Evtimovska E, Masri R, Driscoll CF, Romberg E. The change in retention values of locator attachments and hader clips over time. J Prosthodont. 2009;18:479–83.
10. Rajul, V. & Romesh, S. (2015). Denture Base Materials: Some Relevant Properties and their Determination. International Journal of Dentistry and Oral Health, 1(4), 1-3.31.
11. Nejatian, T.; Pezeshki, S.; Yaqin Syed, A.U. Acrylic denture base materials. In 5 Advanced Dental Biomaterials; Khurshid, Z., Najeeb, S., Zafar, M.S., Sefat, F., Eds.; Woodhead Publishing: Cambridge, UK, 2019; pp. 79–104.
12. Balos S, Pilic B, Markovic D, et al: Poly (methyl-methacrylate) nanocomposites with low silica addition. J Prosthet Dent.2014.;111:327-334.
13. Cannon RD, Firth NA. Fungi and fungal infections of the oral cavity. In: Lamont RJ, Hajishengallis GN, Jerkinson HF, editors.Oral microbiology and immunology. 2nd ed. Washington DC:ASM Press; 2014. pp. 343–59.
14. Cevik P, Yildirim-Bicer AZ. The effect of silica and prepolymer nanoparticles on the mechanical properties of denture base acrylic resin. J Prosthodont 2018;27(8):763–770.
15. Aldegheishem A, AlDeeb M, Al-Ahdal K, Helmi M, and Alsagob EI. Influence of Reinforcing Agents on the Mechanical Properties of Denture Base Resin: A Systematic Review. Polymers (Basel). 2021; 13(18):3083.
16. Balos S, Pilic B, and Markovic D. Poly (methyl-methacrylate) nanocomposites with low silica addition. J Prosthet Dent. 2014; 111:327-334.
17. Altarawneh S., Bencharit L., and Mendoza. Clinical and histological findings of denture stomatitis as related to intraoral colonization patterns of Candida albicans, salivary flow, and dry mouth. Journal of Prosthodontics. 2013; 22(1):13-22.
18. Alzayyat ST, Almutiri GA, Aljandan JK, et al. Antifungal Efficacy and Physical Properties of Poly(methylmethacrylate) Denture Base Material Reinforced with SiO2 Nanoparticles. J Prosthodont. 2021; 30(6):500-508.
19. Stefos S, Kourtis S, Sarafianou A, and Zoidis P: The Influence of Impression Material on the Accuracy of the Master Cast In Implant Restorations. The Open Dentistry Journal. 2018 Dec 31;12(1).
20. Singh S, Mishra SK, and Chowdhary R. Patient satisfaction and crestal bone changes with one-piece and two-piece single implant-retained mandibular overdenture: A randomized controlled clinical study. J Prosthodont Res. 2023;67(1):112-120. Doi:10.2186/jpr.JPR_D_20_00315.
21. Tabatabaian F, Alaie F, and Seyedan K. Comparison of three attachments in implant-tissue supported overdentures: an in vitro study. J Dent (Tehran). 2010;7(3): 113-118.
22. Chacón, M. A. Caminero, E. García-Plaza, and P. J. Núñez. Effect of process parameters on mechanical properties and their optimal selection. Materials and Design. 2017; 124-143.

23. Gotfredsen K, and Holm B. Implant-supported mandibular overdentures retained with ball or bar attachments: a randomized prospective 5-year study. Int J Prosthodont. 2000; 13:25-30.

24. Sabri A, B., Satgunam, M., Abreeza, N. M., and N. Abed, A. A review on enhancements of PMMA denture base material with different nano-fillers. Cogent Engineering. 2021, 8(1), 1875968.

25. Meng T. R. and Latta M. A. Physical Properties of Four Acrylic Denture Base Resins. Journal of Contemporary Dental Practice. 2005; 4(6): 93-100.

26. Bilhan H, Geckili O, Ergin S, Erdogan O, and Ates G. Evaluation of satisfaction and complications in patients with existing complete dentures. J Oral Sci. 2013; 55(1):29-37.

27. Topouzi M, Kontonasaki E, Bikiaris D, Papadopoulou L, Paraskevopoulos KM, Koidis P. Reinforcement of a PMMA resin for interim fixed prostheses with silica nanoparticles. Journal of the mechanical behavior of biomedical materials. 2017 May 1;69:213-22

28. Alzayyat ST, Almutiri GA, Aljandan JK, Algarzai RM, Khan SQ, Akhtar S, Ateeq IS, Gad MM. Effects of SiO2 incorporation on the flexural properties of a denture base resin: an in vitro study. European Journal of Dentistry. 2021 Aug 24;16(01):188-94.

29. Karci M., Demir N., and Yazman S. Evaluation of Flexural Strength of Different Denture Base Materials Reinforced with Different Nanoparticles. J. Prosthodont. 2019; 28 (5):572–579.

30. Cevik P, and Yildirim-Bicer AZ. The effect of silica and prepolymer nanoparticles on the mechanical properties of denture base acrylic resin. J Prosthodont. 2018; 27:763-770.

31. Jiangkongkho P, Arksornnukit M, Takahashi H. The synthesis, modification, and application of nanosilica in polymethyl methacrylate denture base. Dental materials journal. 2018 Jul 26;37(4):582-91.

32. Azmy E, Al-Kholy MRZ, Al-Thobity AM, Gad MM, and Helal MA. Comparative Effect of Incorporation of ZrO2, TiO2, and SiO2 Nanoparticles on the Strength and Surface Properties of PMMA Denture Base Material: An In Vitro Study. Int J Biomater. 2022; 2022:585-6545.

33. Gad MM, Abualsaud R, Al-Thobity AM, Baba NZ, and Al-Harbi FA. Influence of Addition of Different Nanoparticles on the Surface Properties of Poly (methylmethacrylate) Denture Base Material. J Prosthodont. 2020; 29(5):422-428.