ORIGINAL RESEARCH

Effect of Adding Different Concentrations of Silver Nanoparticles on Flexural Strength and Microhardness of Different Denture Base Materials

Ibrahim Gamal El-Hussein

Received on: 29 April 2024; *Accepted on*: 31 May 2024; *Published on*: 05 August 2024

Abstract

Aim: This study aimed to evaluate the effect of adding different concentrations of silver nanoparticles (AgNPs) on the flexural strength and microhardness of various denture base materials.

Materials and methods: For this study, a total of 60 specimens were used and divided into equal groups. The first group consisted of heat-cured acrylic resin (Vertex-Germany), while the second group consisted of thermoplastic resin (Breflex 2nd edition, Germany). The samples were created using a split brass mold with dimensions of 65 × 10 × 2.5 mm, in accordance with the specifications of the American Dental Association (specifically No. 12 for flexural and microhardness). Following this, the samples were divided into three groups (A, B, and C) based on different concentrations of AgNPs (0, 2, and 5%). The flexural and microhardness of the samples were assessed using a universal testing machine and the Vickers hardness test, respectively. The data were gathered, organized, and analyzed using statistical methods.

Results: The flexural strength findings showed a significant difference between the two groups. Also, there was a considerable decrease in the average value of the acrylic group as the concentrations of AgNPs rose, while the flexural strength of the thermoplastic group notably improved. Regarding microhardness, the results showed a significant difference between the two groups. It showed that the mean value of both groups increased with increasing concentrations of AgNPs.

Conclusion: Within the limitations of laboratory testing conditions of this study, it was discovered that AgNPs negatively impact the flexural strength of acrylic resins. Furthermore, an increase in the concentration of AgNPs was found to be directly related to the flexural strength of thermoplastic resin and the microhardness of both groups.

Clinical significance: The concentration of AgNPs has a significant impact on certain mechanical properties of denture base materials, but it is important to consider their potential toxicity.

Keywords: Acrylic resin, Flexural strength, Mico hardness, Silver nanoparticles (AgNps) and Thermoplastic resin.

The Journal of Contemporary Dental Practice (2024): 10.5005/jp-journals-10024-3688

Introduction

Polymethyl methacrylate resin is frequently used for creating partial dentures due to its ease of use, affordability, esthetic appeal, and ability to retain its color. However, it has limitations, including poor heat conductivity, low resistance to bending and impact, and a tendency to attract microorganisms to the impression surface.[1–3]

Dentures may lead to suboptimal outcomes in certain patients due to the properties of traditional heat-cured acrylic resin, including initial base adaptation, bulk requirements, and allergy-inducing residual monomers.[4,5]

Studies showed that 68% of acrylic resin dentures break within a few years of fabrication.[6,7] The most common causes of denture breakage are accidental drops on hard surfaces and excessive chewing forces. Fractures typically result from ill-fitting dentures and imbalanced occlusions, with upper dentures being twice as likely to break as lower dentures.[8,9] Additionally, prominent undercuts in the patient's anatomy are a crucial consideration, as leaving them unblocked can cause significant pain and irritation to the tissue.

Flexible resin was presented as a substitute for traditional heat-cured acrylic resin in the production of partial dentures, complete dentures, and obturators. However, these materials lacked the necessary durability to withstand chewing forces. The flexibility enhanced comfort and impacted user satisfaction.[10–12]

Department of Removable Prosthodontics, Faculty of Dentistry, Sinai University (Kantara), Cairo, Egypt

Corresponding Author: Ibrahim Gamal El-Hussein, Department of Removable Prosthodontics, Faculty of Dentistry, Sinai University (Kantara), Cairo, Egypt, Phone: +01156674887, e-mail: ibrahimabdelhakm14@gmail.com

How to cite this article: El-Hussein IG. Effect of Adding Different Concentrations of Silver Nanoparticles on Flexural Strength and Microhardness of Different Denture Base Materials. J Contemp Dent Pract 2024;25(5):417–423.

Source of support: Nil

Conflict of interest: None

Many methods have been studied to improve the strength of denture acrylic resin polymer. One method included adding metal powder fillers like silver, copper, and aluminum particles into the resin polymer.[13] This approach boosted strength but impacted the appearance of the dentures. Another method focused on adjusting the chemical makeup of acrylic resin by combining it with rubber through copolymerization. The rubber methacrylate graft copolymers resulted in improved impact strength but decreased transverse strength.[14,15]

Nanoparticles are a crucial component of nanotechnology and have a significant influence on the characteristics of modified dentures.[16,17] Silver nanoparticles (AgNPs) integrated into dentures offer potent antibacterial features, along with flexibility and electrical and thermal conductivity.[18] Silver nanoparticle-containing polymers are more efficient at releasing silver ions than polymers using silver in micrometers. This is attributed to enhanced processing, increased surface area, and smoother surfaces. The optimal concentration of AgNPs for antibacterial purposes depends on various factors such as the type of bacteria, the size and shape of the nanoparticles, and the duration of exposure.[19,20] Generally, lower concentrations of AgNPs are more effective in eradicating bacteria compared with higher concentrations.[21,22] Silver nanoparticles work by releasing silver ions that are detrimental to bacteria. However, high concentrations of AgNPs can cause them to aggregate, reducing the surface area available for silver ion release and potentially harming human cells. It is crucial to use the lowest effective concentration of AgNPs to mitigate these risks.[23] The levels and forms of AgNPs play a critical role in both their antibacterial effectiveness and their ability to enhance the mechanical properties of denture base materials. The research novelty revolves around the impact of different concentrations of AgNPs on thermoplastic resin therefore, this study aims to evaluate the influence of different concentrations of AgNPs on flexural strength and microhardness of different denture base materials.

Materials and Methods

The materials utilized in this research are cataloged in Table 1.

Study Design

This study was conducted as experimental research utilizing randomization and comparison. Ethical approval for this study was granted by the Ethics Committee of the Faculty of Dentistry at Minia University (Committee No. 105, Decision No. 901).

Table 1: Materials utilized in this research

Materials	*Commercial name*	*Manufacturer*
Heat-cured acrylic resin	Rapid Simplified Vertex	Germany
Thermoplastic resin	Nylon (Breflex 2nd Edition)	Bredent–Germany
Silver nanoparticles (AgNps) (Fig. 1)	Silver nanoparticles (AgNps)	NanoTech (Egypt)

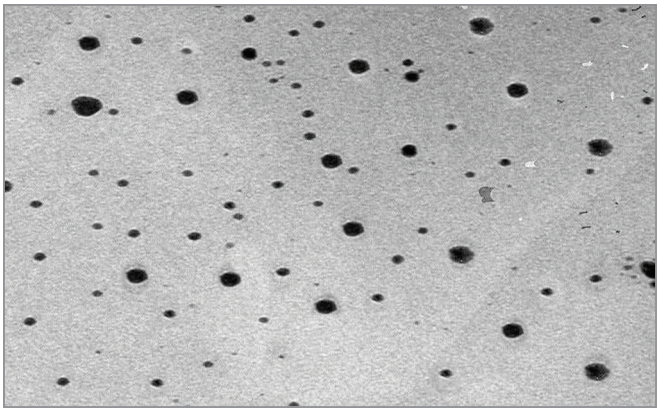

Fig. 1: Silver Nanoparticles AgNps

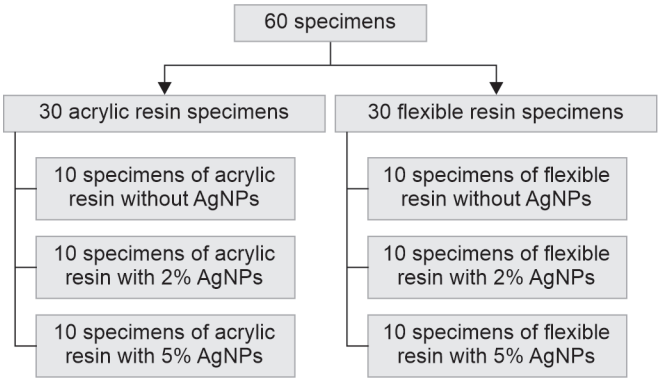

Fig. 2: Samples categorized into three groups (A, B, and C) based on the concentration of AgNPs present in each sample (0, 2, and 5)

Study Setting

Silver nanoparticles of different concentrations were created at a nanotechnology laboratory in Egypt. Subsequently, these AgNPs were integrated into various denture bases at the dental laboratory of Sinai University (Kantara branch).

Sample Size Calculation

The sample size was determined using version 3.3.1 of the R statistical package, which involved conducting *t*-test power calculations to establish the required sample size. This calculation was done with 90% power and 5% significance level, assuming an identical distribution.

Samples Distribution

Sixty specimens were used in this study and divided into two equal groups. The first group consisted of heat-cured acrylic resin (control group), while the second group consisted of thermoplastic resin (study group). Samples were categorized into three groups (A, B, and C) based on the concentration of AgNPs present in each sample. The concentrations used for grouping were 0, 2, and 5% (Fig. 2).

Criteria of Mold Construction

The samples were manufactured in accordance with specific guidelines set by the American Dental Association (ADA) Specification No. 12 and the British Standard Institute (BSI) Specification No. 771.

In order to meet the necessary dimensions for testing, a split brass mold was utilized. The mold came in different sizes but followed the ADA and BSI guidelines. For the assessment of the samples' transverse strength and microhardness, a split brass mold measuring 65 mm in length, 10 mm in width, and 2.5 mm in thickness was used (Fig. 3). Following the manufacturing instructions provided by the respective manufacturers ensures consistency and accuracy in the fabrication of the samples, which is crucial for conducting reliable tests and obtaining meaningful results in the research.

Group I: Samples Preparation

The samples were created using a standard dental compression molding method with gypsum investment. Metal bars sized

Fig. 3: Split brass mold measuring 65 mm in length, 10 mm in width, and 2.5 mm in thickness was used

65 × 10 × 2.5 mm were made and covered with a release agent before being positioned in dental stone. After the stone hardened, the bars were removed, leaving molds with identical dimensions. The AgNPs were gauged using a precision electrical balance with a 0.000 lgm accuracy, combined with resin monomer at levels of 2% and 5%, and then sonicated in a solicitor (Masonic S 60 H, Germany) for 15 minutes. The material was mixed according to the manufacturer's instructions at a ratio of 3 parts polymer to 1 part monomer by volume or 2.5 parts to 1 by weight until it reached the dough stage. The mixture was then placed into molds and cured by submerging the flasks in boiling water. Following removal from the molds, the specimens were finished and polished before being soaked in a 2% glutaraldehyde solution for 2 minutes and rinsed with sterile water for disinfection.

Group II: Samples Preparation

The process began by emptying the thermoplastic flexible granules from the cartridges and weighing them using an electrical balance with a precision of 0.000 lgm. After weighing, the granules were returned to the cartridges. Plastic tubes were used to hold specific quantities of silver nanoparticle powder (2 and 5% of the granules' weight). Afterward, the tube was placed on a vibrator (Vibrational Sieve Shaker, D-3162, Kottermann Labortechnik Co., Germany), and the nanoparticle powder was slowly added while the tube was manually shaken and rolled to achieve uniform distribution. The substance was injected using specific tools. Metal disks, matching the size of the acrylic samples, were covered in gypsum to form molds. These disks were linked and secured to the flask's exterior with waxed sprues. Once the flask was soaked in hot water to remove the sprues, followed by cooling, the metal disks were taken out, resulting in molds identical to the metal patterns. The thermopress 400 injection molding system from Bredent company in Germany was operated according to the manufacturer's guidelines (265°C for 15 minutes) to liquefy the granules in the cartridge. The two flask halves were firmly secured using four screws and positioned vertically in the injection unit. The molten granules were then injected into the flask. Following the injection process, the flask was detached and left to cool down to room temperature. The flask was opened, and the samples were taken out of the molds. Afterward, the samples were smoothed and polished with blue rubber wheels and pumice. They were then disinfected by soaking them in 2% glutaraldehyde for 2 minutes and washed with sterile water.

Testing Flexural Strength

The Lloyd testing machine was employed to assess the toughness, deflection, transverse strength, and modulus of elasticity of various specimens. The three-point bend test assembly was used to mount individual samples horizontally. The specimens were supported by two parallel stainless steel rods measuring 50 mm in length. It was in a central location on the tensile side. The testing machine used was a computer-controlled materials testing machine (Model LRX-plus, Lloyd Instruments Ltd., Fareham, UK) with 650 kN of a load cell. Nexygen-MT, a computer software developed by Lloyd Instruments was used to capture data from the tests. The machine was set to zero degree to begin the test. The load was applied at the center of the specimen, with a gradual increase in strength until it fractured. The process's crosshead speed was established at 5 mm/min. The Nexygen-MT software recorded the maximum load before fracture and the curves for deflection. The load–deflection curve could be used to calculate the flexural strength (FS), flexion modulus (E), maximum deflation at fracture, and elastic strength.

According to the ADA specification, FS = 3F(L)/2wh2 E = L3/4 wh3 (P/Y) for both FS and E are calculated using formulas. The data curves' displacement at fracture is the proximate cause of the greatest deflection. To measure the toughness, one needs to calculate the area under the load–deflection curve, which represents the amount of energy absorbed to break a specimen. The limit of strength a material can maintain without permanent deformation is called elastic.

Microhardness Test

The hardness tests were conducted on samples that were similar to those used for transverse strength testing. Before examination, the specimens were split into two equal parts and immersed in distilled water for 24 hours. The specimens were sanded with a variety of thicknesses (360 m, 600 м, and 1200 r), and then polished with ammonium oxide. A Vickers microhardness tester (Mitutoyo hardness testing machine, Japan) was utilized for conducting the microhardness test. A load of 500 gm was applied for 15 minutes for each sample, 10 measurements were taken, including five vertical and five horizontal diagonals, and the average was computed. The microhardness test proceeded as follows: (1) Each sample was individually mounted horizontally in the specified area of the testing apparatus. (2) The polished surface of the sample was examined, with the sample number indicated on the unpolished side. (3) The testing apparatus was calibrated, and a designated load was applied to the sample using a standard indenter. (4) A 500 gm load was exerted on the sample for 15 seconds. (5) Following the specified duration, the load was removed, and the vertical and horizontal diagonals of the indentation were gauged using a magnifying micrometer microscope. (6) The resultant hardness value was calculated by dividing the applied load by the square of the indentation created. (7) The microhardness was determined utilizing a specialized chart tailored for this equipment and load.

Statistical Analysis

The FS and microhardness data were arranged in tables and analyzed within and between groups. A significance level of

$p \leq 0.05$ was applied, and the analysis was conducted using SPSS version 21 from IBM Inc. in Armonk, New York, USA.

Results

Comparison of FS in Each Group

Descriptive statistics mean value, standard deviation (SD) for FS measured in MPa recorded for each group for both denture base materials groups as a function of silver (Ag) nanoparticles modification and concentration are summarized in Table 2 and graphically represented in Figure 4.

The control subgroup showed that the acrylic resin group had a significantly higher mean value (89.063 MPa) compared with the flexible group (72.308 MPa) as per the unpaired *t*-test ($p = <0.0001 < 0.05$). In the 2% Ag-modified subgroup, the acrylic resin group exhibited a statistically significant decrease in mean FS (80.208 MPa) but still higher than the flexible group (74.508 MPa) as indicated by unpaired *t*-test ($p = 0.04 < 0.05$). In the 5% Ag-modified subgroup, the flexible group had a significantly higher mean value (80.208 MPa) than the acrylic group (75.264 MPa) as indicated by unpaired *t*-test ($p = 0.04 < 0.05$).

Comparison of Microhardness in Each Group

Descriptive statistics mean value, and SD, for FS measured in HV recorded for each group for both denture base materials groups as a function of silver (Ag) nanoparticles modification and concentration are summarized in Table 3 and graphically represented in Figure 5.

The control subgroup showed that the flexible resin group had a significantly higher mean value (20.4HV) compared with the acrylic group (17.5HV) as per the unpaired *t*-test ($p = <0.0001 < 0.05$). In the 2% Ag-modified subgroup, the flexible resin group exhibited a statistically significant higher mean value (23.3HV) than the acrylic group (20.1HV) as indicated by unpaired *t*-test ($p = 0.0001 < 0.05$). In the 5% Ag-modified subgroup, the flexible group had a significantly higher mean value (26.3HV) than the acrylic group (23.1 HV) as indicated by unpaired *t*-test ($p = 0.002 < 0.05$).

Total Effect of Materials

The FS findings show that the acrylic group performs better than the flexible group with 0 and 2% Ag, but the flexible group outperforms the acrylic group with 5% Ag. Regarding microhardness, the flexible resin surpasses the acrylic group at 0, 2, and 5%.

Effect of Increasing Concentration of AgNPs on FS and Microhardness

The strength of acrylic resin has decreased significantly, whereas the strength of flexible resin has increased significantly. Additionally, there has been a noticeable rise in microhardness in both the acrylic and flexible groups.

Table 2: Flexural strength result (mean value ± SD) for both and acrylic resin and thermoplastic with different concentration of AgNPs

Type of denture base	*Acrylic resin (vertex)*		*Thermoplastic resin (Breflex)*		
Concentration of Ag nanoparticles	*Mean*	*SD*	*Mean*	*SD*	*p-value*
Control group (0% Ag)	89.063	1.12	72.308	0.92	0.0001*
With 2% Ag	80.208	0.85	74.508	1.34	0.04*
With 5% Ag	75.264	1.3	80.208	1.65	0.02*
p-value	0.02*				

*Significant of $p \leq 0.05$

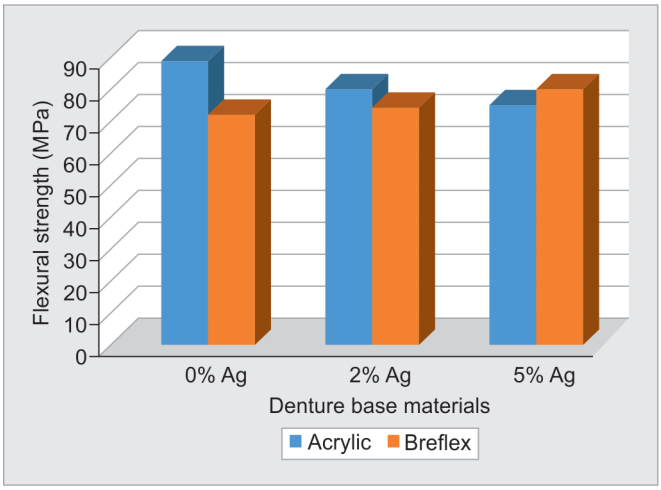

Fig. 4: Column chart showing the flexural strength mean value of acrylic and Breflex denture base groups with different concentrations of AgNPs

Table 3: μ-Hardness result (mean value ± SD) for both and acrylic resin and thermoplastic with different concentration of AgNPs

Type of denture base	*Acrylic resin (vertex)*		*Thermoplastic resin (Breflex)*		
Concentration of Ag nanoparticles	*Mean*	*SD*	*Mean*	*SD*	*p-value*
Control group (0% Ag)	17.5	1.12	20.4	0.92	0.0001*
With 2% Ag	20.1	0.85	23.3	1.34	0.0001*
With 5% Ag	23.1	1.3	26.3	1.65	0.0001*
p-value	0.0001*				

*Significant of $p \leq 0.05$

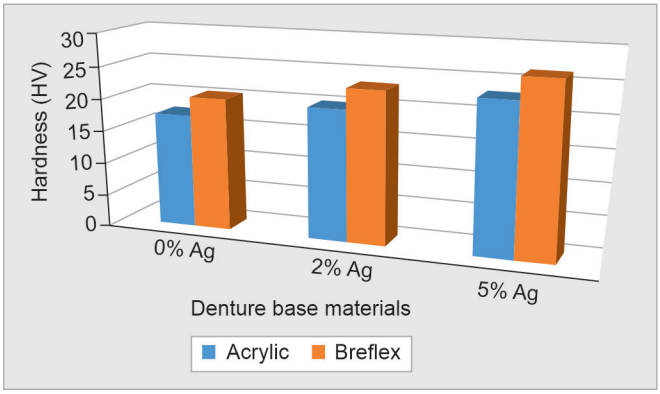

Fig. 5: Column chart showing the μ-hardness mean value of acrylic and Breflex denture base groups with different concentrations of AgNPs

Discussion

Acrylic resins are often used as base materials for removable prostheses, but their frequent fracture can cause discomfort for patients and may lead to canker sores,[24,25] no matter what kind of lining materials are used. Soft lining materials should also be regularly replaced.[26] Thermoplastic dentures provide a lightweight and flexible structure as an alternative to acrylics in removable prostheses.[27]

Silver nanoparticles were chosen for their capacity to inhibit *Candida albicans*, potentially lowering the prevalence of oral diseases in edentulous patients at minimal levels.[28] The aim of this study was to evaluate the effect of the addition of varying concentrations of AgNPs on the FS and microhardness of different denture base materials.

The three-point bending test is useful for comparing denture base materials because it mimics the stress that occurs during chewing.[29] In this study, the Vickers hardness test was chosen because of its ease of use compared with other hardness tests.[30] The calculations needed are not based on the indenter's size, and they can be utilized for all materials irrespective of their hardness. The key principle, like all conventional hardness measures, is to evaluate the material's ability to withstand plastic deformation from a standard source.

The study showed that the acrylic resin control group displayed significantly higher FS than the thermoplastic resin, which was attributed to factors such as high molecular weight, crosslinking agent concentration, and amorphous structure.[31]

The research also revealed a significant decline in FS as the concentration of AgNPs (2% and 5% AgNps) increased. This discovery aligns with that of Sodagar et al.,[32] who demonstrated that the aggregation of AgNPs diminished the FS. Similarly, Ghaffari et al.[33] observed a decline in the FS and elasticity modulus caused by the disruption of the PMMA matrix by AgNPs. Additionally, Omer et al.[34] concluded that the addition of AgNPs to acrylic resin resulted in reduced flexural and impact strengths owing to the creation of voids and cracks in the material.

However, the strength of the thermoplastic resin increased as more AgNPs (2% and 5% Ag) were added. This is because the AgNPs act as nucleating agents, encouraging the creation of smaller and more consistent crystalline structures in the polymer matrix.[35] Additionally, the dimensional stability of the thermoplastic resin coupled with the processing technique, along with the AgNPs, aids in absorbing and dispersing energy upon impact, thus decreasing the chances of cracking or breaking.[36]

This finding was in accordance with that of Zhang et al.[37] found that increasing the concentration of AgNPs in PA6 from 0.5 to 2 wt.% increased the FS of the composite by 25% and Wu et al.[38] found that increasing the concentration of AgNPs in PA66 from 1 wt.% to 3 wt.% increased the FS of the composite by 30%.

The microhardness findings suggest that higher levels of AgNPs enhance the microhardness of the acrylic and thermoplastic materials. As the AgNP concentration increased, the microhardness of both materials increased. This improvement is linked to various factors, such as increased crosslinking density, dispersion strengthening, and nanograining.[15,39] Researchers and studies have agreed that the impact of AgNPs (AgNPs) on microhardness is more pronounced in thermoplastic materials than in acrylic materials because of differences in composition, processing techniques, and the absence of the monomer. For instance, Alla et al.[40] discovered that thermoplastic denture base materials exhibited a greater increase in microhardness when incorporating AgNPs than acrylic resin. They attributed this to the unique properties and processing methods of thermoplastic materials. Smith et al.[41] also supported these findings by noting that the composition and molecular structure of thermoplastic denture base materials play a more significant role in the impact of AgNPs on microhardness, emphasizing the importance of material properties in nanoparticle interactions. Similarly, Lee et al.[42] observed a considerable increase in microhardness in thermoplastic denture base materials with the addition of AgNPs, whereas acrylic materials showed less improvement.

The study's limitations included being conducted *in vitro* to solely evaluate the FS and microhardness, with a relatively small sample size. Moreover, this study examined only three distinct concentrations of AgNPs. Future research should explore various concentrations and shapes of AgNPs. Moreover, upcoming studies could concentrate on evaluating the water sorption and impact strength of acrylic and thermoplastic resins.

Conclusion

Within the limitations of laboratory testing conditions of this study, it was discovered that AgNPs negatively impact the FS of acrylic resins. Furthermore, an increase in the concentration of AgNPs was found to be directly related to the FS of thermoplastic resin and the microhardness of both groups.

References

1. Alqutaibi AY, Baik A, Almuzaini SA, et al. Polymeric denture base materials: a review. Polymers (Basel) 2023;15(15):3258. DOI: 10.3390/polym15153258.
2. Gad MM, Fouda SM, Al-Harbi FA, et al. PMMA denture base material enhancement: A review of fiber, filler, and nanofiller addition. Int J Nanomedicine 2017;12:3801–3812. DOI: 10.2147/IJN.S130722.
3. Zol SM, Alauddin MS, Said Z, et al. Description of poly(aryl-ether-ketone) materials (PAEKS), polyetheretherketone (peek) and polyetherketoneketone (PEKK) for application as a dental material: A materials science review. Polymers 2023;15(9):2170. DOI: 10.3390/polym15092170.
4. Rashid H, Sheikh Z, Vohra F. Allergic effects of the residual monomer used in denture base acrylic resins. Eur J Dent 2015;9(4):614–619. DOI: 10.4103/1305-7456.172621.
5. Le Bars P, Bandiaky ON, Le Guéhennec L, et al. Different polymers for the base of removable dentures? Part I: A narrative review of mechanical and physical properties. Polymers (Basel) 2023;15(17):3495. DOI: 10.3390/polym15173495.
6. Ardelean LC, Rusu LC, Tigmeanu VC. Alternative denture base materials for allergic patients. Dentistry. Intech Open 2022. DOI: 10.5772/intechopen.101956.
7. Yu SH, Lee Y, Oh S, et al. Reinforcing effects of different fibers on denture base resin based on the fiber type, concentration, and combination. Dent Mater J 2012;31(6):1039–1046. DOI: 10.4012/dmj.2012-020.
8. Kumari R, Bala S. Assessment of cases of complete denture fracture. J Pharm Bioallied Sci 2021;13:1558–1560. DOI: 10.4103/jpbs.jpbs_284_21.
9. Kamble VS, Mangalvedhekar MS, Desai RG, et al. A clinical survey based study for assessment of removable denture. J Clin Diagn Res 2021;15(11): 6–10. DOI: 10.7860/JCDR/2021/48087.15614.
10. Hamouda IM, Lamfon HA. "Micro-hardness and fracture toughness of thermosens thermoplastic material versus the conventional heat-cured acrylic resin after one year of water storage". Acta Scientific Dent Sci 2023;7(4):03–07. DOI: 10.31080/ASDS.2023.07.1595.
11. Singh R, Chawla PS, Shaw E, et al. Comparison of flexural strength and surface roughness of two different flexible and heat cure denture base material: An in vitro study. The Journal of Contemporary Dental Practice 2018;19(10):1214-1220. PMID: 30498176.
12. Hatim NA, Taqa AA, Yassin SA. Modification of heat cured acrylic resin by using additives to make a flexible acrylic resin denture base material: A pilot study. Edorium J Dent 2016;3:1–11. DOI: 10.5348/D01-2016-14-OA-1.
13. Ravindranath, Sabarigirinathan C, Vinayagavel K, et al. A comparative study to evaluate the mechanical properties of zirconium oxide added polymethyl methacrylate by two different methods at two different concentrations – In vitro study. Ann Int Med Den Res 2015;1(3):161–165.
14. Sahin O, Ozdemir AK, Turgut M, et al. Investigation of flexural strength and cytotoxicity of acrylic resin copolymers by using different polymerization methods. J Adv Prosthodont 2015;7(2):98–107. DOI: 10.4047/jap.2015.7.2.98.
15. Khan AA, Fareed MA, Alshehri AH, et al. Mechanical properties of the modified denture base materials and polymerization methods: A systematic review. Int J Mol Sci 2022;23(10):5737. DOI: 10.3390/ijms23105737.
16. Ozak ST, Ozkan P. Nanotechnology and dentistry. Eur J Dent 2013;7(1):145–151. PMID: 23408486.
17. Glowacka-Sobotta A, Ziental D, Czarczynska-Goslinska B, et al. Nanotechnology for dentistry: Prospects and applications. Nanomaterials (Basel) 2023;13(14):2130. DOI: 10.3390/nano13142130.
18. Mohammed MR, Hadi AN. Enhancing the mechanical behaviour and antibacterial activity of bioepoxy using hybrid nanoparticles for dental applications. Int J Biomater 2022;2022:2124070. DOI: 10.1155/2022/2124070.
19. Sabarees G, Velmurugan V, Tamilarasi GP, et al. Recent advances in silver nanoparticles containing nanofibers for chronic wound management. Polymers (Basel) 2022;14(19):3994. DOI: 10.3390/polym14193994.
20. Yin IX, Zhang J, Zhao IS, et al. The antibacterial mechanism of silver nanoparticles and its application in dentistry. Int J Nanomedicine 2020;15:2555–2562. DOI: 10.2147/IJN.S246764.
21. Bruna T, Maldonado-Bravo F, Jara P, et al. Silver nanoparticles and their antibacterial applications. Int J Mol Sci 2021;22(13):7202. DOI: 10.3390/ijms22137202.
22. Menichetti A, Mavridi-Printezi A, Mordini D, et al. Effect of size, shape and surface functionalization on the antibacterial activity of silver nanoparticles. J Funct Biomater 2023;14(5):244. DOI: 10.3390/jfb14050244.
23. Köroğlu A, Şahin O, Kürkçüoğlu I, et al. Silver nanoparticle incorporation effect on mechanical and thermal properties of denture base acrylic resins. J Appl Oral Sci 2016;24(6):590–596. DOI: 10.1590/1678-775720160185.
24. Moosa R, Ghani F. Effect of curing methods and temperature on porosity in acrylic resin denture bases. J Pak DentAssoc 2012;21(03):127–135.
25. Scully C, Shotts R. Mouth ulcers and other causes of orofacial soreness and pain. West J Med 2001;174(6):421–424. PMCID: PMC1071433.
26. Panda SK, Reddy N, Manual L, et al. An in vitro evaluation of tensile bond strength of soft liners bonded to different denture base resins. Ann Afr Med 2021;20(2):116–120. DOI: 10.4103/aam.aam_30_20.
27. Selvaraj A, Palanivel S, Arumugam EM, et al. Knowledge attitude and awareness about flexible dentures among nonprosthodontist and general dentists in chennai city: A cross-sectional study. World J Dent 2023;14(8):677–682. DOI: 10.5005/jp-journals-10015-2292.
28. Corrêa JM, Mori M, Sanches HL, et al. Silver nanoparticles in dental biomaterials. Int J Biomater 2015;2015:485275. DOI: 10.1155/2015/485275.
29. Patankar RC, More V, Jadhav R, et al. Comparative evaluation of flexural strength of denture base resin materials processed using compression molding technique, injection molding technique, and computer-aided design CAM technique: An in vitro study. Dent Res J 2022;19:100. PMID: 36605146.
30. Cheng W-S, Chen G-Y, Shih X-Y, et al. Vickers hardness value test via multi-task learning convolutional neural networks and image augmentation. Appl Sci 2022;12(21):10820. DOI: 10.3390/app122110820.
31. Ceylan G, Emik S, Yalcinyuva T, et al. The effects of cross-linking agents on the mechanical properties of poly (methyl methacrylate) resin. Polymers 2023; 15(10):2387. DOI: 10.3390/polym15102387.
32. Sodagar A, Kassaee MZ, Akhavan A, et al. Effect of silver nano particles on flexural strength of acrylic resins. J Prosthodont Res 2012;56(2):120–124. DOI: 10.1016/j.jpor.2011.06.002.
33. Ghaffari T, Hamedi-Rad F. Effect of silver nano-particles on tensile strength of acrylic resins. J Dent Res Dent Clin Dent Prospects 2015;9(1):40–43. DOI: 10.15171/joddd.2015.008.
34. Omer RA, Ikram FS. Effect of addition of silver nanoparticles on flexural and impact strength of heat cure acrylic resin. EDJ 2023;2(2):243–250. DOI: 10.15218/edj.2019.16.
35. Zeng Y, Liu Y, Wang L, et al. Effect of silver nanoparticles on the microstructure, non-isothermal crystallization behavior and

antibacterial activity of polyoxymethylene. Polymers 2020;12(2):424. DOI: 10.3390/polym12020424.
36. Zhang M, Song W, Tang Y, et al. Polymer-based nanofiber–nanoparticle hybrids and their medical applications. Polymers 2022;14(2):351. DOI: 10.3390/polym14020351.
37. Zhang XF, Liu ZG, Shen W, et al. Silver nanoparticles: Synthesis, characterization, properties, applications, and therapeutic approaches. Int J Mol Sci 2016;17(9):1534. DOI: 10.3390/ijms17091534.
38. Wu P, Huang X, Li S. Preparation and characterization of polyamide 66 (PA66)/silver nanoparticles (AgNPs) composite with enhanced mechanical properties. J Appl Polym Sci 2018;135(22):e46598. DOI: 10.1515/pjct-2017-0065.
39. Li Z, Sun J, Lan J, et al. Effect of a denture base acrylic resin containing silver nanoparticles on Candida albicans adhesion and biofilm formation. Gerodontology 2016;33(2):209–216. DOI: 10.1111/ger.12142.
40. Alla RK, Guduri V, Tiruveedula NBP, et al. Effect of silver nanoparticles incorporation on microhardness of heat-cure denture base resins. Int J Dent Mater 2020;2(4):103–110. DOI: 10.37983/IJDM.2020.2401.
41. Smith A, Jones B, Johnson C, et al. Impact of silver nanoparticles on the mechanical properties of denture base materials. J Dent Res 2023;102(2):123–130.
42. Lee X, Kim Y, Park Z, et al. Impact of silver nanoparticles on microhardness in thermoplastic versus acrylic denture base materials. J Dent Mater 2021;30(5):234–245.