Original article | *International Journal of Dental Materials 2023;5(4)* | ISSN:2582-2209

Effect of silver nanoparticles incorporation on impact strength of Heat-cure denture base resins

Rama Krishna Alla[1,*], K N Raghavendra Swamy[2], Ritu Vyas[3], Vineeth Guduri[4], N B Prakash Tiruveedula[5], G Narasimha Rao[4]

[1]Professor, Department of Dental Materials, Vishnu Dental College, Bhimavaram, Andhra Pradesh, India.

[2]Professor, Department of Prosthodontics, JSS Dental College & Hospital, JSS University, Mysuru, Karnataka, India.

[3]Associate Professor, Department of Chemistry, Faculty of Science, PAHER University, Udaipur, Rajasthan, India.

[4]Reader, Department of Prosthodontics, Vishnu Dental College, Bhimavaram, Andhra Pradesh, India.

[5]Assistant Professor, Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research, Guntur, Andhra Pradesh, India.

Article History

Received *18th December 2023*

Accepted 30*th December 2023*

Available online 3*1st December 2023*

*Correspondence

Rama Krishna Alla

Professor,

Department of Dental Materials,

Vishnu Dental College, Bhimavaram,

Andhra Pradesh, India.

E-mail: rkdentalbiomaterials@gmail.com

DOI: *http://dx.doi.org/10.37983/IJDM.2023.5401*

Abstract

Background: Poly (Methyl methacrylic acid) based materials are widely used for the fabrication of removable complete and partial denture prostheses. these materials are prone to fractures when subjected to impact forces. While recent studies have explored the antimicrobial potential of denture base materials incorporating silver nanoparticles, their impact on the mechanical properties crucial for the prosthesis's durability has not been adequately established.

Aim: To evaluate the impact strength of the heat-cure denture base materials incorporated with various concentrations of silver nanoparticles.

Materials and Methods: Silver nanoparticles were incorporated at various concentrations (0.5, 1.0, 2.0 and 5.0 wt%) into three different heat-cure denture base materials. A total of 150 rectangular-shaped specimens (50 x 6 x 4), which comprises 50 samples from each of the three heat-cure acrylic resins were made using the compression molding technique. Ten specimens (n=10) were allocated for each concentration such as control, 0.5wt%, 1.0wt%, 2.0wt% and 5.0wt% concentrations of silver nanoparticles. A "V" notch was made exactly at the centre of each specimen to prevent the ductile fracture. The impact strength was evaluated using the Izod impact tester. The data were subjected to One-way ANOVA and Post hoc tests for statistical analyses.

Results: A decrease in the impact strength was observed in the modified groups compared to the control groups. One-way ANOVA showed significant differences (p=0.000) among the different concentrations of all three denture base materials.

Conclusion: Silver nanoparticles incorporation reduced the impact strength of the denture base materials.

Keywords: Denture base materials, PMMA, Silver nanoparticles, impact strength.

1. Introduction

Dentures remain the most popular choice of prosthetic devices with a high success rate for the treatment of edentulous conditions. Complete dentures are usually made with polymers, precious metal alloys and base metal alloys [1,2]. Among these, polymer-based materials, especially Poly (methyl methacrylate) resins are widely used for the fabrication of complete and partial dentures [3,4]. The reasons for using PMMA resin as the most common materials are due to its favourable working characteristics, accurate fit, and stability in the oral environment, superior aesthetics, and ease of processing with inexpensive equipment. However, it has a few shortcomings such as the frequent fracture of dentures due to mechanical fatigue and chemical degradation of the base material, low thermal conductivity [1-4] and ease of microbial adherence to the intaglio surface [5,6]. Numerous researchers have studied the effect of the incorporation of various fillers like metallic particles, fibres, nanoparticles, etc., on the mechanical properties of PMMA materials with varying success [4]. Further, attempts have been made to copolymerize PMMA with rubber materials to improve the impact strength [4].

Dentures, the preferred prosthetic devices for edentulous conditions, boast high success rates. Typically crafted from polymers, precious metal alloys, and base metal alloys [1,2], complete dentures often utilize Poly (methyl methacrylate) (PMMA) resins [3,4]. PMMA stands out due to its favourable attributes—easy workability, precise fit, stability in the oral environment, superior aesthetics, and cost-effective processing. Despite these advantages, PMMA dentures are prone to fractures, mechanical fatigue, base material degradation, low thermal conductivity [1-4], and microbial adherence to the intaglio surface [5,6]. Further, the accidental dropping of the denture prostheses during cleansing results in fractures due to impact forces. Researchers have explored enhancements, incorporating fillers like metallic particles and fibers to improve mechanical properties [4], and copolymerizing PMMA with rubber materials to enhance impact strength [4].

In recent investigations, several studies have elucidated the impact of incorporating nanoparticles on the antimicrobial properties of polymers. Among these nanoparticles, silver nanoparticles (AgNPs) have garnered particular attention from researchers due to their broad-spectrum antimicrobial activity. Alla RK et al. studied the antimicrobial efficacy against diverse microorganisms [8], the flexural strength [9] and the hardness [10] of heat-cured denture base materials were examined with varying concentrations of silver nanoparticles. The findings indicated that denture base materials incorporating AgNPs exhibited notable antimicrobial activity, particularly at lower concentrations, demonstrating effectiveness against C. *Albicans* and S. *Mutans* [8].

However, the effect of the incorporation of AgNPs on the mechanical properties of denture base materials has not been validated. The impact strength is an essential mechanical property as denture prosthesis should exhibit maximum resistance to the sudden application of the forces during mastication and accidental dropping during the cleansing. Hence, this study aimed to evaluate and compare the impact strength of heat-cure denture base resins modified with the incorporation of different concentrations of AgNPs.

2. Materials and methods

The materials used in the present study are detailed in Table 1.

Table 1. Materials used in the study

S.No.	Materials	Manufacturer's details
1.	Trevlon	Dentsply India Pvt Ltd., India.
2.	Lucitone199	Dentsply International Inc., USA.
3.	TriplexHot	Ivoclar Vivadent, USA.
4.	Silver nanoparticles (80–100 nm)	Nanolabs Pvt Ltd., India.

2.1 Preparation of Acrylic Specimen

A total of 150 specimens were fabricated using the compression molding technique. Acrylic specimens were made by investing rectangular metal strips of 50 x 6 x 4 mm according to ADA specification number 12. Metal strips were carefully removed after the investment material was set. A thin layer of separating medium was applied in the mold space and allowed to dry. Denture base acrylic powder with or without silver nanoparticles and monomer liquid was mixed as per the manufacturer's recommendations and packed into the mould when the mix reached the dough consistency. Then the flask was closed, and a pressure of 4 lbs was applied, and bench cured for 30 minutes in a hydraulic press apparatus (Silfradent, India). Then the flask was tightly secured in a clamp and transferred into a thermostatically controlled water bath (Acrylizer, Confident A-73, India) and cured as per the manufacturer's recommendations. The temperature of the water bath was increased to 73±1°C within 30 minutes and maintained at the same temperature for 90 minutes. Then the temperature of the water bath was increased to 100°C and maintained for 60 minutes. After completion of the polymerization cycle, the flask was allowed to cool in the water bath to room temperature, and the acrylic resin specimens were retrieved after deflasking. The specimens obtained were finished and polished conventionally [2]. Fifty specimens from each denture base material were made totalling 150 specimens. These 50 specimens from each denture base material were divided into five groups based on their concentration of silver nanoparticles (AgNPs), with ten specimens (n=10) in each group. These five groups included a control group (with no modification of denture base materials) and four modified groups with 0.5wt%, 1.0wt%, 2.0wt%, and 5.0wt% of AgNPs, respectively. The specimens were stored in distilled water at 37˚C for seven days.

2.2 Evaluation of Impact Strength

A "V" notch was made on each sample exactly at the midpoint of the sample with a depth of 1.2 mm using the carborundum disc to avoid ductile fracture. The sample was placed in a metal fixture of an Izod impact tester (KRYSTAL Industries, India) ensuring the middle of the sample coincided with the striking pendulum. The pendulum was released to strike the sample to fracture, and the energy required to break the sample was measured in Joules/mm^2.

2.3 Scanning electron microscopy (SEM) analysis

The dispersion of the nanoparticles in the acrylic resin specimens was evaluated using a Scanning Electron Microscope (SEM, JSM-610LV, JEOL, Japan). The specimens were vacuum-dried in a desiccator containing silica gel until a constant weight was obtained. The dried specimens were gold-sputtered and were subjected to scanning electron microscopy at 10 kV.

2.4. Statistical Analysis

The data were subjected to One-way ANOVA and Post-hoc tests for statistical analyses using SPSS for Windows, Version 12.0., SPSS Inc.

3. Results

The mean impact strength and standard deviation of different denture base materials incorporated with various concentrations of AgNPs are presented in Table 2. Among the control groups, Lucitone 199 demonstrated more impact strength followed by Trevlon and TriplexHot. The unmodified groups of the three denture base materials demonstrated more impact strength than the modified groups. Among the modified groups, the denture base materials incorporated with 0.5 wt% of AgNPs displayed more impact strength compared to the other modifications. As the concentration of NPS increased a decrease in the impact strength was observed among the modified groups. One-way ANOVA showed a significant difference in the impact strength (p=0.000) among the different concentrations of the AgNPs in different denture base materials.

In posthoc analysis, the control groups of Trevlon and TriplexHot denture base materials showed significant differences with the 2.0 wt% and 5.0 wt% of modified groups (Trevlon- 0.001, 0.000; TriplexHot – 0.004, 0.000, respectively). The controlled group of Lucitone199 displayed significant differences (0.000) with the modified groups. Among the modified groups, 0.5 wt% of 1.0 wt% of the Trevlon and the TriplexHot materials showed significant differences with the 2.0 wt% (Trevlon – 0.001, TriplexHot – 0.027) & 5.0 wt% (Trevlon – 0.000; TriplexHot – 0.000), and 1.0 wt% & 5.0wt% (p=0.001), respectively. Among the modified Lucitone199 denture base material, significant differences were observed between all the modified groups (Table 3).

The SEM analysis showed the agglomeration of the nanoparticles in the resin matrix. Nanoparticle agglomerations increased with an increase in the nanoparticle concentration (Figures 2 a-d).

Table 2. Comparison of impact strength of Denture base materials modified with various concentrations of AgNPs (One-Way ANOVA)

Groups	Trevlon		Lucitone 199		TriplexHot	
	Mean ± SD	Significance	Mean±SD	Significance	Mean ±SD	Significance
Control	4.630±0.383	0.000	5.560±0.254	0.000	4.400±0.391	0.000
0.5wt%	4.620±0.376		5.370±0.447		4.310±0.314	
1.0wt%	4.360±0.350		3.960±0.0843		4.180±0.304	
2.0wt%	4.010±0.242		3.460±0.195		3.900±0.149	
5.0wt%	3.720±0.252		3.110±0.490		3.620±0.269	

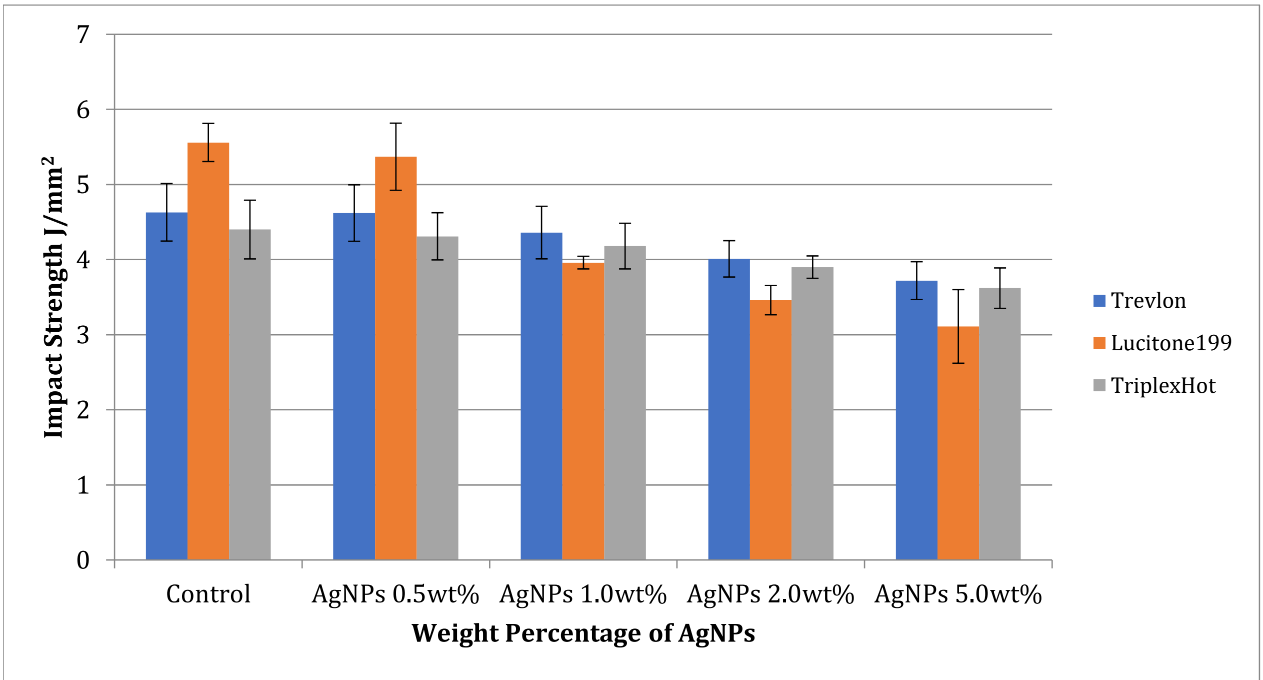

Figure 1. Impact strength of denture base materials incorporated with AgNPs

Table 3. Post-Hoc analysis (Tukey-HSD) of impact strength of three denture base materials modified with AgNPs

Groups		Trevlon		Lucitone199		TriplexHot	
		Mean Difference ± SE	Significance	Mean Difference ± SE	Significance	Mean Difference ± SE	Significance
Control	0.5 wt%	0.010±0.146	1.000	0.190±0.148	0.705	0.090±0.132	0.960
	1.0 wt%	0.270±0.146	0.360	1.600±0.148	0.000	0.220±0.132	0.469
	2.0 wt%	0.620±0.146	0.001	2.100±0.148	0.000	0.500±0.132	0.004
	5.0 wt%	0.910±0.146	0.000	2.450±0.148	0.000	0.780±0.132	0.000
0.5 wt%	1.0 wt%	0.260±0.146	0.398	1.410±0.148	0.000	0.130±0.132	0.863
	2.0 wt%	0.610±0.146	0.001	1.910±0.148	0.000	0.410±0.132	0.027
	5.0 wt%	0.900±0.146	0.000	2.260±0.148	0.000	0.690±0.132	0.000
1.0 wt%	2.0 wt%	0.350±0.146	0.135	0.500±0.148	0.013	0.280±0.132	0.234
	5.0 wt%	0.640±0.146	0.001	0.850±0.148	0.000	0.560±0.132	0.001
2.0 wt%	5.0 wt%	0.290±0.146	0.290	0.350±0.148	0.146	0.280±0.132	0.234

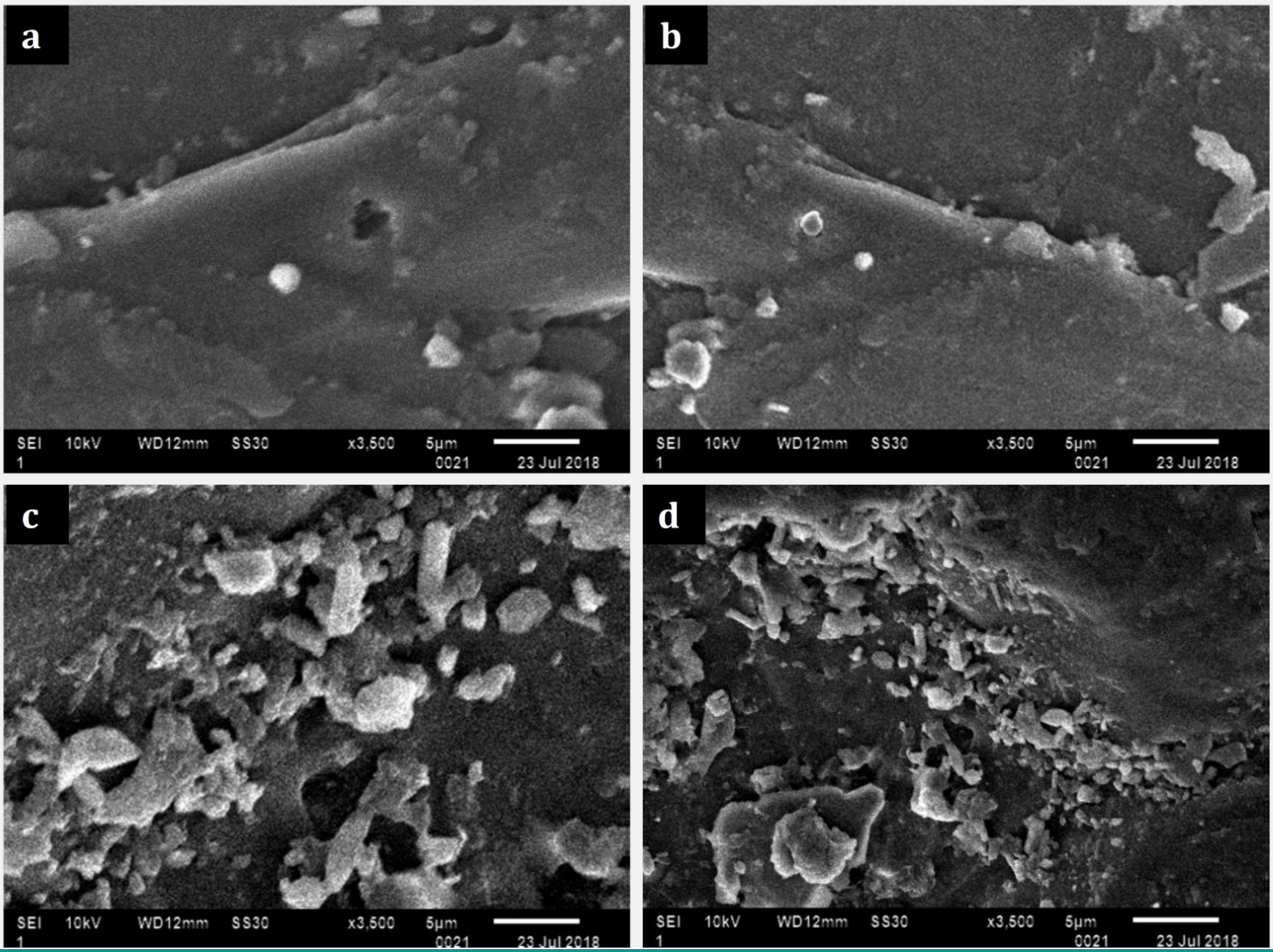

Figure 2 a-d. Dispersion of Silver nanoparticles in acrylic resin denture base material. Where a, b, c and d are denture base resin specimens incorporated with 0.5wt%, 1.0wt%, 2.0wt% and 5.0wt% of Silver nanoparticles, respectively.

4. Discussion

The denture prostheses are prone to fracture due to sudden application of forces, a risk heightened during routine cleaning practices [2-4]. Hence, the impact resistance of polymers employed in the production of prostheses is crucial for predicting their clinical performance. This consideration has prompted extensive research efforts to explore strategies for improving the mechanical strength of PMMA during its clinical utilization.

This research assessed the impact strength of heat-cure acrylic resins following the introduction of antimicrobial nanoparticles, AgNPs. The findings indicated that the unmodified denture base materials exhibited greater impact strength compared to the modified specimens (Figure 1). Within the unmodified groups, Lucitone199 specimens demonstrated superior impact strength in comparison to other denture base materials. Nevertheless, post-hoc analysis revealed no statistically significant differences among the unmodified specimens. The impact strength results for unmodified Lucitone199 specimens in this investigation align with those reported by Meng TR *et al.* (2005) [11]. Existing literature suggests that the impact strength of polymers can be notably enhanced through the graft copolymerization of certain rubbers with the polymer [12]. The increased impact strength of Lucintone199 denture base material may be attributed to the incorporation of rubber-modified polymer, conferring the ability to withstand fractures when subjected to sudden forces [11].

In this investigation, a decline in impact strength was observed among the modified groups as the concentration of nanoparticles increased. However, statistically significant differences ($p < 0.05$) were evident only at concentrations of 2.0wt% and 5.0 wt% of AgNPs in the Trevlon group, and at 5.0wt% of nanoparticles in the TriplexHot group. Lucitone199 denture base material, among all the tested materials, exhibited a more pronounced impact on its strength with increasing concentrations of various nanoparticles (refer to Tables 2 and 3). Specifically, Lucitone199 modified with 5.0wt% of AgNPs demonstrated an approximate 44% decrease in impact strength, whereas other modified denture base materials exhibited reductions in impact strength ranging from 20% to 25%.

The decrease in impact strength observed in the modified specimens can be attributed to the agglomeration of nanoparticles, wherein these clusters of nanoparticles may disrupt the crosslinking process of polymer chains. Additionally, inadequate wetting of these agglomerates by the resin materials may lead to the formation of voids, acting as stress concentrations [13]. This phenomenon was evident in the SEM analysis of acrylic specimens modified with nanoparticles (Figures 2. a-d). Moreover, these agglomerations could have impeded the copolymerization of rubber material with the resin matrix, particularly in the case of Lucitone199 modified specimens. This interference may explain the significant decrease in impact strength observed in the Modified Lucitone199 groups compared to the unmodified counterparts. These findings align with previous studies [14-16].

The outcomes of this study align with the research conducted by D.T. de Castro *et al.* (2016) [17], where a decrease in the impact strength of denture base materials was noted with an increase in the weight percentage of nanoparticles. This phenomenon was attributed to challenges in achieving homogeneity of nanoparticles within the polymeric matrix. The existence of clusters acted as stress centers, compromising the strength of the resin.

Based on the findings of this study, it is advisable to incorporate nanoparticles into denture base materials up to a concentration of 1.0wt%, as no significant differences were observed between the control group and those modified with 1.0wt% of nanoparticles, except for the Lucitone199 group. This suggests that the impact strength may be influenced by the composition of denture base materials. Future research endeavours could focus on enhancing the dispersion of nanoparticles within the resin matrix.

6. Conclusion

This study concludes that the introduction of AgNPs leads to a reduction in the impact strength of the tested denture base materials. While the antimicrobial properties of silver nanoparticles are evident, their incorporation into denture base materials is viable up to specific concentrations, namely 0.5wt% and 1.0wt%, excluding Lucitone 199. However, higher concentrations of AgNPs result in undesirable black discolouration of the denture bases. Further investigations are needed to address issues related to biocompatibility, nanoparticle dispersion within the resin matrix, and the colour stability of denture base materials incorporating silver nanoparticles.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

References

1. Anusavice KJ. Denture Base Resisns (in) Philips' Science of Dental Materials. 11th edition, India, Elsevier, 2010. p. 721-758.
2. Alla RK. Denture Base Resins (in) Dental Materials Science. 1st edition, India, Jaypee Medical Publishers Pvt. Ltd. 2013, p.248-284. https://doi.org/10.5005/jp/books/12018_11
3. Alla RK, Raghavendra Swamy KN, Ritu Vyas, Konakanchi A. Conventional and Contemporary polymers for the fabrication of denture prosthesis: part I – Overview, composition and properties. Int J App Dent Sci. 2015;1(4):82-89.
4. Alla RK, Suresh Sajjan MC, Ramaraju AV, Ginjupalli K, Upadhya NP. Influence of fiber reinforcement on the properties of denture base resins. J Biomater Nanobiotech. 2013;4(1):91-97. https://doi.org/10.4236/jbnb.2013.41012
5. Najla S. Dar-Odeh, Mohammad Al-Beyari, Osama A. Abu-Hammad, The role of antifungal drugs in the management of denture-associated stomatitis. Int Arabic J Antimicrob Agents. 2012;2(1):1-5.
6. Swamy KNR, Alla RK, Shammas Mohammed, Konakanchi A. The Role of Antifungal Agents in Treating Denture Stomatitis. Res J Pharm Tech. 2018;11(4):1365-1369. https://doi.org/10.5958/0974-360X.2018.00254.8
7. Pachava KR, Shenoy KK, Nadendla LK, Reddy MR, Denture Stomatitis – A Review, Ind J Dent Adv. 2013;5 (1): 1107-1112.
8. Alla RK, Vineeth G, Kandi V, Swamy KNR, Vyas R, Narasimha Rao G. Evaluation of the antimicrobial activity of heat-cure denture base resin materials incorporated with silver nanoparticles. Int J Dent Mater 2019;1(2):40-47. https://doi.org/10.37983/IJDM.2019.1201
9. Alla RK, Swamy KNR, Vyas R, Konakanchi A, Vineeth G, Gadde P. Influence of Silver Nanoparticles Incorporation on Flexural Strength of Heat-cure Acrylic Denture Base Resin Materials. Annu Res Rev Biol. 2017;17(4):1-8. https://doi.org/10.9734/ARRB/2017/36581
10. Alla RK, Guduri V, Tiruveedula NBP, Narasimha Rao G, Swamy KNR, Vyas R. Effect of silver nanoparticles incorporation on microhardness of Heat-cure denture base resins. Int J Dent Mater. 2020 ;2(4):103-10. https://doi.org/10.37983/IJDM.2020.2401
11. Meng TR, Latta MA. Physical properties of four acrylic denture base resins. J Contemp Dent Pract. 2005;6:93–100. https://doi.org/10.5005/jcdp-6-4-93
12. Sehgal B, Kunde G. Structure Property Relationship of Polymer Blends: Effect of Grafting on Mechanical Properties. Asian J Res Chem. 2010;3:637–9.
13. Dhir G, Berzins DW, Dhuru VB, Periathamby AR, Dentino A. Physical properties of denture base resins potentially resistant to Candida adhesion. J Prosthodont. 2007;16:465–472. https://doi.org/10.1111/j.1532-849X.2007.00219.x
14. Ayad NM, Badawi MF, Fatah AA. Effect Of Reinforcement Of High-Impact Acrylic Resin With Zirconia On Some Physical And Mechanical Properties. Rev Clín Pesq Odontol Curitiba. 2008;4:145–51.
15. Hameed HK, Rahman HA. The effect of addition nano particle ZrO2 on some properties of autoclave processed heat cure acrylic denture base material. J Baghdad Coll Dent. 2015;27:32–9. https://doi.org/10.12816/0015262
16. Hussain WA, Hashim FS, Effect of Additives on Impact Strength of Denture Base Resin. Iraqi J Sci. 2017;58:860–7.
17. de Castro DT, Valente ML, Agnelli JAM, da Silva CHL, Watanabe E, Siqueira RL, et al. In vitro study of the antibacterial properties and impact strength of dental acrylic resins modified with a nanomaterial. J Prosthet Dent. 2016;115:238–246. https://doi.org/10.1016/j.prosdent.2015.09.003

How to cite this article: Alla RK, Swamy KNR, Vyas R, Guduri V, Tiruveedula NBP, Rao GN. Effect of silver nanoparticles incorporation on impact strength of Heat-cure denture base resins. Int J Dent Mater. 2023;5(4):99-103. DOI:*http://dx.doi.org/10.37983/IJDM.2023.5401*