Review Article

JRAD Journal of Research and Advancement in Dentistry

J Res Adv Dent 2019;10:1s:242-252.

Recent Advancement to Improve the Properties of Poly (Methyl Methacrylate) (PMMA) with Addition of Filler, Nanofiller and Fibers: A Review

Sourabh Khandelwal[1*] Rajeev Srivastava[2] Vivek Sharma[3] Garima Mukhopadhyay[4]

[1]PG Student, Department of Prosthodontics, Modern Dental College and Research Centre, Indore, Madhya Pradesh, India.
[2]Professor, Department of Prosthodontics, Modern Dental College and Research Centre, Indore, Madhya Pradesh, India.
[3]Professor, Department of Prosthodontics, Darshan Dental College and Hospital, Udaipur, Rajasthan, India.
[4]PG Student, Department of Prosthodontics, Modern Dental College and Research Centre, Indore, Madhya Pradesh, India.

ABSTRACT

Background: Poly (methymethacrylate) (PMMA) is still the most predominantly used denture base material because of its many characteristics such ease in processing, stability in oral environment, lightweight, excellent aesthetic properties, low cost, low water sorption and can easily be rechanged and repaired its shape. But, it has certain drawbacks like residual monomer allergy, low modulus of elasticity, low impact strength, low flexural strength, polymerisation shrinkage,porosity, crazing, warpage. This paper reviews reinforcement of poly(methyl methacrylate) (PMMA) acrylic denture base resin. The review is based on scientific reviews, papers, and abstracts, as well as studies concerning the effect of additives, fibers, fillers, and reinforcement materials on PMMA, published between 1974 and 2019. Many studies have reported improvement of PMMA denture base material with the addition of fillers, fibers, nanofiller, and hybrid reinforcement. However, , most of the studies, without bioactivity and clinical implications, were limited to in vitro work. There is no ideal denture base material, but with some modifications, especially with the addition of silanized nanoparticles and a hybrid reinforcement system, the properties of PMMA could be improved.

Keywords: Reinforcement, denture base, PMMA, nano particle, fibers, zirconia.

INTRODUCTION

History of complete dentures back to 700 BC, however complete dentures are constructed from several materials for instances wood, bone, rubber and ivory. The polymers such as cellulose plastics, poly(vinyl chloride) and vinyl acetate became used since 1900's. However, the Poly (methylmethacrylate) (PMMA) material used as denture base, material for the first time in 1937 by Walter Wright and Vernom Brothers in Philadelphia. PMMA became so prevalent in 1940's.[1,2] PMMA is still the most predominantly used denture base material because of its many characteristics such as ease in processing, stability in oral environment, lightweight, excellent aesthetics properties, low cost, low water sorption and can easily be rechanged and repaired its shape.[1,2] But, it has certain drawbacks like residual monomer allergy, low modulus of elasticity, low impact strength, low flexural strength[3], poor conductor of heat, high coefficient of thermal expansion, polymerisation shrinkage, porosity, crazing, warpage, poor adhesion to metal and porcelain and requirement of mechanical retention.[4] Thus, to overcome these drawbacks, there has been much new advancements to improve the properties of PMMA. PMMA have been reinforced using different materials to improve its physical and mechanical properties.

Received: Nov. 11, 2019: **Accepted**: Jan. 1, 2020
*__Correspondence Dr. Sourabh Khandelwal.__
Department of Prosthodontics, Modern Dental College and Research Centre, Indore, Madhya Pradesh, India.
Email: sourabh25193@gmail.com

pISSN 2278-0076
eISSN 2321-9270

Many materials such as fibers, fillers and nanofillers are incorporated into PMMA with the goal of enhancing the properties of PMMA. This paper reviews different types of fibers and fillers added to PMMA denture base resin and to evaluate their effect on the physical and mechanical properties.

DISCUSSION

Many materials are suggested to enhance the properties of denture base resin such as fillers, nano fillers and fibers (Table 1).

Table 1: List of filler, nanofillers and fibers used to reinforce poly (methylmethacrylate) (PMMA)

Additives	Modification
Fillers and nanofillers	
Metal oxides	Alumina (Al_2O_3, Al_2O_3 NPs, Silane treated Al_2O_3) Zirconia (Zro_2, Zro_2 NPs, Silane treated zirconia NPs) Titanium (TiO_2, TiO_2 NPs)
Noble metals	Silver (Ag) NPs Gold (Au) NPs Platinum (Pt) NPs Palladium (Pd) NPs
Silica based	Glass flake Mica Sio_2 Surface treated silica
Fiber	Glass fiber Silanized glass fiber Aramid Nylon Polyethylene Polypropylene
Hybrid reinforcement	Hybrid fibers Metal oxides and ceramics Fiber and fillers

Fillers and Nano fillers

Several studies have been conducted on the use of fillers (Table 2) to reinforce denture base resin, and their properties have been significantly improved. Poly (methylmethacrylate) (PMMA) reinforced with metal oxides resulted in the improvement of the physical and mechanical properties of the denture base material. Patient's sensation of hot and cold stimuli was also improved.[5-7] Recently, it has been suggested to incorporate nanofillers (Table 2) to improve PMMA properties. The high surface area, fine size, and homogenous nanofillers distribution enhanced the thermal properties of PMMA.[6-8] The properties of resin reinforced by nanofillers depend on the size, shape, type, and concentration of the added particles.[8]

Metal oxides

Alumina (Al_2O_3)

Several studies found that, reinforcing PMMA with aluminum increased the flexural strength, impact strength, tensile strength, compressive strength, surface hardness, and thermal conductivity of the resin.[5-7,9-16] Significant decrease was seen in warpage after addition of aluminium to PMMA. On the other hand, several research, found that adding aluminium decreases PMMA's Impact and tensile strength.[11,17] Due to stress concentration around the embedded metal and its poor adhesion to the polymer, the resin was weakened.

However, several methods have been suggested to improve the bond between the acrylic resin and metal surface, such as sandblasting, silanization, and metal adhesive resins.[7] Treating aluminium particles with silane coupling agent [3-(Trimethoxysilyl) propyl methacrylate (TMSPM)] significantly increased the wear resistance and the compressive, flexural, and tensile strength of reinforced denture base resin.[5,18,19]

Surface roughness and water sorption were not significantly changed with aluminum-reinforced denture resin.[11,17] However, one study found a significant decrease in water sorption and solubility after addition of Al_2O_3[6] and an increase in water sorption was found by another study.[11]

The disadvantage of aluminium-reinforced PMMA is discoloration of the resin, which limits its use to areas where it is not visible.[20] Although thermal conductivity was significantly increased on addition of Al_2O_3 to PMMA, there was no significant change was seen in flexural strength values of PMMA.[13]

Zirconia (ZrO_2)

Several studies found that, there is significant increase in flexural strength of PMMA on incorporating zirconia (ZrO_2) fillers.[6-14,17-24] However, there has been a slight decrease in flexural strength; this may result from clustering of the particles within the resin, which weakened the material.[25] In addition, incorporating ZrO_2 significantly increased the impact strength, tensile strength, fracture toughness, and hardness of PMMA.[6,22,26,27] Also, addition of ZrO_2 significantly increased the thermal conductivity of PMMA.[13] It was found that adding ZrO_2 significantly decreased the water sorption and solubility of PMMA.[6] It was suggested that adding zirconia NPs improve the mechanical properties of PMMA.[28,29] PMMA reinforced with zirconia NPs increased its impact strength, flexural strength, compressive strength, fatigue strength, fracture toughness and hardness.[28,30-33] In addition, it may have an antifungal effect and may play a preventive role in patients susceptible to fungal infections.[34] Safi et al,[35] studied the effect of adding zirconia NP on the color properties of PMMA and found no noticeable changes in color.

A silane coupling agent was used to improve the bond strength between zirconia NPs and PMMA because poor wettability between fillers and the resin matrix reduced improvement of the physical and mechanical properties of PMMA. It resulted in increased flexural strength and impact strength of acrylic resin, but its tensile strength was not improved. However, silanized zirconia NPs improved the tensile strength, fatigue strength, hardness of PMMA. While, its porosity, water sorption, and solubility decreased.[27,35-38]

Titanium ($TiO2$)

Several studies found that adding TiO_2 particles could improve the flexure strength, impact strength, fracture toughness, hardness and thermal conductivity of PMMA.[6,13,22,39-41] In addition, a significant decrease in water sorption and solubility were found upon addition of TiO_2 to PMMA.[6] In comparison, some studies found that TiO2 did not improve PMMA's flexure strength, which could be due to particle clustering within the resin, resulting in its weakness.[22,39]

Safi[8] found that PMMA reinforced with TiO_2 NPs has an effect on its mechanical (decreased E-Modulus) and thermal (decrease in the thermal expansion coefficient and contraction) stability, while a reduction in flexural strength and toughness was reported.[41] A titanium coupling agent could be useful for improving the properties of titanium-reinforced PMMA because adhesion between the resin matrix and filler particles is very important in order to enhance the properties.[42] PMMA reinforced with silanized TiO2 NPs improved the transverse strength, impact strength, and surface hardness of the resin and decreased its water sorption and solubility.[43]

Noble metals

Silver (Ag)

Several studies found that addition of silver NPs (AgNPs) to denture base acrylic resin displayed antifungal properties,[44-47]especially at high concentrations,[48] and acted like a latent antifungal material with low-releasing Ag+.[49] On the contrary, Wady et al[50] found that incorporating silver NPs in PMMA did not affect the adhesion of *C. albicans* and biofilm accumulation.

Incorporation of silver in PMMA could be beneficial for immune-compromised and geriatric patients because of its antimicrobial effect so it could reduce microbial adhesion and colonization.[44,45] In addition, PMMA resin reinforced with silver has increased flexural and fatigue strength and improved thermal conductivity.[12,13] It was suggested that the addition of silver could adversely affect the mechanical properties of the denture base resin, depending on its percentage.[44] Compressive strength of PMMA was significantly increased upon incorporating silane-treated silver particles. Also, tensile and flexural strength of PMMA were enhanced upon addition of 10wt% and 20wt% silane-treated silver fillers.[5] The flexural strength values of PMMA were not significantly changed on addition of silver powder to PMMA.[13]

PMMA reinforced with silver NPs resulted in the improvement of its physical and mechanical properties including improvement of thermal conductivity and compressive strength.[51,52] Therefore, it is recommended to be used in the palatal area of maxillary acrylic resin dentures.[51]

Also, it was found that PMMA-silver NPs are not cytotoxic.[21,46] However, tensile strength did not change significantly after incorporating 0.2% of AgNPs in comparison with unmodified PMMA, but it decreased significantly after incorporation of 2%.[53] The disadvantage of silver reinforced PMMA is its poor color stability.[49,54]

Nano-gold (Au), platinum (Pt), palladium (Pd)

Recently it has been proposed that nano-gold (Au) and platinum (Pt) NPs improve the properties of PMMA denture base. The available studies on the effect of adding nano-gold to PMMA are currently still limited. It has been observed that incorporating gold NPs considerably improved the flexural strength and thermal conductivity to almost double the value of pure PMMA, which could lead to more patient satisfaction.[55,56] Addition of Pt NPs could improve mechanical properties of PMMA and provide antimicrobial effect.[57] Platinum was found to significantly increase PMMA's bending deflection, and palladium increased bending strength when compared to silver and gold, which showed the lowest bending strength value. Addition of gold and palladium improved Vickers hardness of PMMA and was decreased with the addition of platinum.[58]

Silica-based filler

Addition of glass flakes to acrylic resin improved its fracture toughness, and silane coupling agent used resulted in further improvement of the acrylic resin properties.[22] Micas are a group of lamellar silicate minerals and these are characterized by their high aspect ratio. They improved the mechanical, thermal, as well as dimensional properties of PMMA.[59] Incorporation of mica increased the hardness of acrylic resin, but its flexural strength was reduced because of weak bond of mica with the acrylic resin.[60] Nanoclay is another material which is used to enhance the properties of acrylic polymers. Thermal conductivity of PMMA is improved upon the addition of Nanoclay particles to PMMA, while flexural strength was decreased.[61] Placing silicon carbide filler powders in the palatal region of dentures can improve PMMA's thermal conductivity without reducing strength or increasing weight.[13]

Carbon family fillers

Carbon fillers are not commonly used to reinforce PMMA because of biological problems, poor denture aesthetics, as well as difficulty in handling and polishing.[75]

Table 2: Classification of fillers and nanofillers

Additives	Filler (µm)	Nano-filler (nm)
Metal oxides	Aluminum oxide (Al_2O_3) Zirconium oxide (ZrO_2) Titanium oxide (TiO_2)	Al_2O_3 NPs ZrO_2 NPs TiO_2 NPs
Noble metals	Silver (Ag)	AgNPs Gold (Au) Platinum (Pt) Palladium (Pd)
Silica based	Glass flakes Mica	Nanoclay
Abbreviations: NPs-nanoparticles.		

Fibers

Several studies have been conducted on the use of fibers to reinforce denture base resin, and has been reported to improve the flexural and impact strength as well as the fatigue resistance of the resin.[62] Different types of fibers are used, such as nylon, polyethylene, polyamide fiber, and particularly glass fiber, due to their biocompatibility and superior aesthetics and mechanical properties.[62,63]

Glass fiber

It has been found that PMMA reinforced with Glass fiber significantly increased its flexural strength, impact strength, toughness, and Vickers hardness.[64-68] Also, a significant reduction in deformation of the denture base to less than 1% deformation was found.[64] Moreover, a recent study found that the position of glass fiber within the denture base affects its flexural properties. Improvement of flexural strength, toughness, and flexural modulus was obtained from placement of glass fiber close to the surface of the denture base on its tensile stress side. When glass fiber was placed in neutral stress area, only flexural toughness was improved, and when placed in the compressive side, surface flexural modulus was increased.[69]

Preimpregnated and silane treated glass fiber also increased the flexural strength[70] and impact strength[71,72] of acrylic resin. Silanized glass fiber was found to be biocompatible when added to heat-cured and light-cured resins.[64,73] Moreover, fiber-reinforced nanopigmented PMMA showed reduced porosity and *Candida albicans* adherence.[73]

Polyamide fiber

Polyamide fiber includes both Nylon and Aramid fiber. Denture base resin reinforced with aramid fiber was found biocompatible, and its flexural strength and flexural modulus were increased.[74] However, the hardness of the resin decreased with increasing fiber concentration. Also, its yellow color is considered a drawback.[75,76] Nylon increased the fracture resistance of PMMA, as it has high resistance to continual stress. Therefore, incorporating nylon fiber in PMMA increased its structural elasticity.[77]

Polyethylene and polypropylene fibers

Addition of Polyethylene fiber to PMMA significantly increase its impact strength, and a further increase was observed with fiber surface treatment.[65,78] Woven polyethylene fiber reinforcement can significantly increase the elastic modulus and toughness of PMMA. However, the procedures of woven fiber etching, preparing, and positioning were found impractical.[78] Addition of Polypropylene fiber to PMMA significantly increase its impact strength, and a further increase was observed with fiber surface treatment.[72] The highest impact strength was obtained with polypropylene fibers treated with plasma, which can be used to strengthen acrylic resin and reduce fracturing. A study suggested that incorporating silanized polypropylene fiber in PMMA resin significantly improved its transverse, tensile, and impact strengths, but its wear resistance was highly decreased.[79]

Hybrid reinforcement

In 1997, Vallittu first suggested reinforcement of PMMA by more than one type of filler or fiber.[80] The combination may be between different fibers, fillers (metal oxides) and ceramics, [81-85] and fibers with metal oxides,[86,87] or ceramic materials[32,88-90] (Table 3).

Hybrid fiber reinforcement of PMMA significantly increased its flexural strength and toughness.[71] Similar results were also obtained by incorporating metal oxides and ceramics, in PMMA, particularly NPs.[90] In addition, improvement in surface roughness,[83] tensile strength, flexural modulus,[88] hardness, thermal conductivity,[90] and radiopacity[85] as well as reducing shrinkage. It has antibacterial properties. It is not cytotoxic.[82]

In addition, a combination of fibers and other fillers increased impact strength, hardness,[86] surface roughness, and thermal conductivity,[87] as well as compressive and fatigue strengths.[49]

Table 3: Different hybrid reinforcement materials

Hybrid type	Hybrid materials
Fillers	– Al_2O_3 + ZrO_2[83,88] – ZrO_2-TiO_2[90]
Fibers	Glass fiber + polyethylene fibers[65]
Fibers + fillers	– Polyester fiber reinforced PMMA + (clay, glass powder, SiO_2, or ZrO_2)[86] – Al_2O_3 + plasma-treated polypropylene fiber[87] nHA particles, micro-zirconia, glass fiber, and Kevlar fiber (PMMA-nHA and glass fiber), (PMMA-ZrO2 and glass fiber), (PMMA-nHA and Kevlar fiber), (PMMA-ZrO2 and Kevlar fiber).[32]
Abbreviations: nHA, nano-hydroxyapatite; PMMA, poly(methyl methacrylate).	

CONCLUSION

It can be concluded based on this comprehensive review that:

- Obvious enhancement in the properties of denture base resin material properties was found with the addition of fillers, nanofillers.

- Glass fiber reinforcement significantly increases the mechanical properties of PMMA, but further investigations are needed.

- Silane coupling agents play a central role in improving bonding between fillers, nanofillers and the resin matrix, and they subsequently improved the properties of poly (methylmethacrylate) (PMMA) resin.

- The hybrid system is the newest reinforcement system. Hybrid fiber, hybrid fillers, or hybrid fiber and filler may significantly enhance the properties of poly (methylmethacrylate) (PMMA).

- Multiple studies were conducted in vitro, so further studies in vivo are needed, as well as clinical studies.

SUMMARY

To improve quality of life of edentulous patients PMMA acrylic dental prosthesis has been used for years. PMMA is most predominantly used denture base material because of its many characteristics such ease in processing, stability in oral environment, lightweight, excellent aesthetics properties, low cost, low water sorption and can easily be rechanged and repaired its shape. But, it has certain drawbacks like residual monomer allergy, low modulus of elasticity, low impact strength, low flexural strength, poor conductor of heat, high coefficient of thermal expansion, polymerisation shrinkage, porosity, crazing, warpage, poor adhesion to metal and porcelain and requirement of mechanical retention. Thus, to overcome these drawbacks, there has been much new advancements including addition of reinforcing material as, fillers, fibers, fillers-fiber hybrid reinforcement and, recently, NPs to improve the properties of PMMA. PMMA have been reinforced using different materials to improve its physical and mechanical properties. However, the most effective reinforcement is not apparent, and clinicians are confused about designing such reinforcement. Currently, reinforcement has two important purposes on a prosthesis. The first purpose is to improve the strength and prevent fracture, and the second purpose is to improve the stiffness and prevent residual ridge resorption and overloading to residual teeth or structures. To summarize this review, Undoubtedly, reinforcement of denture base acrylic resins had some efficacy in improving the physical and mechanical properties. The properties of denture base acrylic resin reinforced by fillers, nanofillers, fibers and NPs depend on the size, shape, type, and concentration, surface treatment, and position of the of the added particles for reinforcement.

Clinical significance

Poly (methylmethacrylate) (PMMA) resin with improved properties obtained by addition of fillers, nanofillers, fiber, filler-fiber hybrid reinforcement and NPs can serve in prosthodontic applications.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

REFERENCES

1. Engelmeier RL. The history and development of posterior denture teeth-introduction, part II: Artificial tooth development in America through the nineteenth century. J Prosthodont. 2003;12(4):288-301.

2. Alla RK, Sajjan S, Alluri VR, Ginjupalli K, and Upadhya N. Influence of fiber reinforcement on the properties of denture base resins. J Biomater Nanobiotechnol. 2012;4:91-97.

3. Stsiak ZD. Allergy as a cause of denture sore mouth. J Prosthet Dent. 1971 Jan;25(1):16-20.

4. Nandal S, Ghalaut P, Shekhawat H, Gulati MS. New era in denture base resins: A review. Dent. J. Adv. Stud. 2013;1(3):136-143.

5. Yadav P, Mittal R, Sood VK, Garg R. Effect of incorporation of silane-treated silver and aluminum microparticles on strength and thermal conductivity of PMMA. J Prosthodont. 2012;21:546–551.

6. Asar NV, Albayrak H, Korkmaz T, Turkyilmaz I. Influence of various metal oxides on mechanical and physical properties of heat-cured

polymethylmethacrylate denture base resins. J Adv Prosthodont. 2013;5:241–247.

7. Sehajpal SB. Effect of metal fillers on some physical properties of acrylic resin. J Prosthet Dent. 1989;61:746–751.

8. Safi I N. Evaluation the effect of nano-fillers (TiO2, AL2O3, SiO2) addition on glass transition temperature, E-Modulus and coefficient of thermal expansion of acrylic denture base material. J Bagh Coll Dent. 2014;26:37–41.

9. Arora P, Singh SP, Arora V. Effect of alumina addition on properties of polymethylmethacrylate – a comprehensive review. Int J Biotech Trends Technol. 2015;9:1–7.

10. Ellakwa AE, Morsy MA, El-Sheikh AM. Effect of aluminum oxide addition on the flexural strength and thermal diffusivity of heat-polymerized acrylic resin. J Prosthodont. 2008;17:439–444.

11. Abdulhamed AN, Mohammed AM. Evaluation of thermal conductivity of alumina reinforced heat cure acrylic resin and some other properties. J Bagh Coll Dent. 2010;22:1–7.

12. Arora N, Jain V, Chawla A, Mathur VP. Effect of addition of sapphire (Aluminum oxide) or silver fillers on the flexural strength, thermal diffusivity and water sorption of heat-polymerized acrylic resins. Int J Prosthodont Restorat Dent. 2011;1:21–27.

13. Kul E, Aladag LI, Yesildal R. Evaluation of thermal conductivity and flexural strength properties of poly (methyl methacrylate denture) base material reinforced with different fillers. J Prosthet Dent. 2016;116:803–810.

14. Zhang X, Zhang X, Zhu B, Lin K, Chang J. Mechanical and thermal properties of denture PMMA reinforced with silanized aluminum borate whiskers. Dent Mater J. 2012;31:903–908.

15. Dhole RI, G. Srivatsa2, Shetty R, Huddar D, Sankeshwari B, Chopade S. Reinforcement of aluminum oxide filler on the flexural strength of different types of denture base resins: An in vitro study. J Clin Diagn Res. 2017 Apr;11(4): 101-104

16. Pentapati L, Srinivas K, Shankar YR, Swetha V, Hari Krishna M. Effects of addition of aluminum oxide on flexural strength and hardness of acrylic resins. IOSR-JDMS. 2017;16(3):1-6

17. Vojdani M, Bagheri R, Khaledi AR. Effects of aluminum oxide addition on the flexural strength, surface hardness, and roughness of heat-polymerized acrylic resin. J Dent Sci. 2012;7:238–244.

18. Yadav NS, Elkawash H. Flexural strength of denture base resin reinforced with aluminum oxide and processed by different processing techniques. J Advan Dent Res. 2011;2:33–36.

19. Chaijareenont P, Takahashi H, Nishiyama N, Arksornnukit M. Effect of different amounts of 3-methacryloxypropyltrimethoxy silane on the flexural properties and wear resistance of alumina reinforced PMMA. Dent Mater J. 2012;31:623–628.

20. Jasim BS, Ismail IJ. The effect of silanized alumina nano-fillers addition on some physical and mechanical properties of heat cured polymethylmethacrylate denture base material. J Bagh Coll Dent. 2014;26:18–23.

21. Abdulkareem MM, Hatim NA. Evaluation the biological effect of adding Aluminum Oxide, Silver nanoparticles into microwave treated PMMA powder. Int J Enhanc Res Sci Technol Eng. 2015;4:172–178.

22. Franklin P, Wood DJ, Bubb NL. Reinforcement of poly (methyl methacrylate) denture base with glass flake. Dent Mater. 2005;21:365–370.

23. 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. 2008;4:145–151.

24. Asopa V, Suresh S, Khandelwal M, Sharma V, Asopa SS, Kairal LS. A comparative evaluation of properties of zirconia reinforced high impact

acrylic resin with that of high impact acrylic resin. Saudi J Dent Res. 2015;6:146–151.

25. Al-Rais RY, Al-Nakkash WA, Al-Bakri AK. Filler reinforced acrylic denture base material. Part 2-Effect of water sorption on dimensional changes and transverse strength. J Baghdad Coll Dent. 2005;17:6–10.

26. Fahmi M K, Ebrahim M I, Arora P.Enhancement of Mechanical Properties of Polymethylmetha-crylate Denture Base Material by Zirconium Oxide Nanofiller. World J. Dent. 2019;10(2):114-118.

27. Gad MM, Abualsaud R, Rahoma A, Al-Thobity AM, Al-Abidi KS, Akhtar S. Effect of zirconium oxide nanoparticles addition on the optical and tensile properties of polymethyl methacrylate denture base material. Int J Nanomedicine. 2018:13 283–292.

28. Safi IN, Moudhaffar M. Evaluation the effect of modified nano fillers addition on some properties of heat cured acrylic denture base material. J Bagh Coll Dent. 2011;23:23–29.

29. Gad MM, Rahoma A, Al-Thobity AM, ArRejaie AS. Influence of incorporation of ZrO2 nanoparticles on the repair strength of polymethyl methacrylate denture bases. Int J Nanomed. 2016;11:5633–5643.

30. Zhang XJ, Zhang XY, Zhu BS, Qian C. Effect of nano ZrO2 on flexural strength and surface hardness of polymethylmethacrylate. Shanghai Kou Qiang Yi Xue. 2011;20:358–363.

31. Gad M, ArRejaie AS, Abdel-Halim MS, Rahoma A. The reinforcement effect of nano-zirconia on the transverse strength of repaired acrylic denture base. Int J Dent. 2016;2016:7094056.

32. Salih SI, Oleiwi JK, Hamad QA. Investigation of fatigue and compression strength for the PMMA reinforced by different system for denture applications. Int J Biomed Mat Res. 2015;3:5–13.

33. Ahmed MA, Ebrahim MI. Effect of zirconium oxide nano-fillers addition on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin. World J Nano Sci Eng. 2014;4:50–57.

34. Cierech M, Kolenda A, Grudniak AM, et al. Significance of polymethylmethacrylate (PMMA) modification by zinc oxide nanoparticles for fungal biofilm formation. Int J Pharm. 2016;510(1):323–335.

35. Safi IN, Hassanen KA, Ali NA. Assessment of zirconium oxide nano-fillers incorporation and silanation on impact, tensile strength and color alteration of heat polymerized acrylic resin. J Bagh Coll Dent. 2012;24:36–42.

36. Bian YM, Zhang XY, Zhu BS, Yu WQ, Ruan DP, Min M. Influence of different amount of silane coupling agent on the flexural strength of PMMA/nanometer ZrO2 composites. Shanghai Kou Qiang Yi Xue. 2007;16:319–323.

37. Zhang XY, Wu WL, Bian YM, Zhu BS, Yu WQ. The effect of different dispersive methods on flexural strength nano-ZrO2 reinforced denture polymethylmethacrylate. Shanghai Kou Qiang Yi Xue. 2009;18:313–316.

38. Hameed HK, Abdul Rahman H. The effect of addition nano particle ZrO2 on some properties of autoclave processed heat cures acrylic denture base material. J Bagh Coll Dent. 2015;27:32–39.

39. Nejatian T, Johnson A, Noort RV. Reinforcement of denture base resin. Adv Sci Technol. 2006;49:124–129.

40. Harini P, Mohamed K, Padmanabhan TV. Effect of Titanium dioxide nanoparticles on the flexural strength of polymethylmethacrylate: An in vitro study. Indian J Dent Res. 2014;25:459–463.

41. Ahmed MA, El-Shennawy M, Althomali YM, Omar AA. Effect of titanium dioxide nano particles incorporation on mechanical and physical properties on two different types of acrylic resin denture base. World J Nano Sci Eng. 2016;6:111–1119.

42. Elshereksi NW, Ghazali MJ, Muchtar A, Azhari CH. Perspectives for Titanium-derived fillers

usage on denture base composite construction: a review article. Adv Mat Sci Eng. 2014;1:1–14.

43. Moslehifard E, Anarak M R, Shirkavand SEffect of adding TiO2 nanoparticles on the SEM morphology and mechanical properties of conventional heat-cured acrylic resin. J Dent Res Dent. Clin Dent Prospect. 2019;13(3):234-240

44. Casemiro LA, Gomes Martins CH, Pires-de-Souza Fde C, Panzeri H. Antimicrobial and mechanical properties of acrylic resins with incorporated silver–zinc zeolite – part I. Gerodontology. 2007;25: 187–194.

45. Suganya S, Ahila SC, Kumar BM, Kumar MV. Evaluation and comparison of anti-Candida effect of heat cure polymethylmethacrylate resin enforced with silver nanoparticles and conventional heat cure resins: An in vitro study. Indian J Dent Res. 2014;25:204–207.

46. Acosta-Torres LS, Mendieta I, Nuñez-Anita RE, Cajero-Juárez M, Castaño VM. Cytocompatible antifungal acrylic resin containing silver nanoparticles for dentures. Int J Nanomed. 2012;7:1–10.

47. Monteiro DR, Gorup LF, Takamiya AS, de Camargo ER, Filho AC, Barbosa DB. Silver distribution and release from an antimicrobial denture base resin containing silver colloidal nanoparticles. J Prosthodont. 2012;21:7–15.

48. Li Z, Sun J, Lan J, Qingguo Q. Effect of a denture base acrylic resin containing silver nanoparticles on Candida albicans adhesion and biofilm formation. Gerodontology. 2014;28:1–8.

49. Oei JD, Zhao WW, Chu L, et al. Antimicrobial acrylic materials with in situ generated silver nanoparticles. J Biomed Mater Res. 2012;100:409–415.

50. Wady AF, Machado AL, Zucolotto V, Zamperini CA, Berni E, Vergani CE. Evaluation of Candida albicans adhesion and biofilm formation on a denture base acrylic resin containing silver nanoparticles. J Appl Microbiol. 2012;112:1163–1172.

51. Hamedi-Rad F, Ghaffari T, Rezaii F, Ramazani A. Effect of nanosilver on thermal and mechanical properties of acrylic base complete dentures. J Dent (Tehran). 2014;11:495–505.

52. Ghafari T, Hamedi-Rad F, Ezzati B. Does addition of silver nanoparticles to denture base resin increase its thermal conductivity. J Dent Sch. 2014;32:139–144.

53. Ghaffari T, Hamedi-rad F, Ezzati B. In Vitro comparison of compressive and tensile strengths of acrylic resins reinforced by silver nanoparticles at 2% and 0.2% concentrations. J Dent Res Dent Clin Dent Prospect. 2014;8:204–209.

54. Nam KY, Lee CH, Lee CJ. Antifungal and physical characteristics of modified denture base acrylic incorporated with silver nanoparticles. Gerodontology. 2012;29:413–419.

55. Morsy MA, Al-Daous MA. Mechanical properties evaluation of new AuNP-PMMA Composite. Int Rev Chem Eng. 2013;5:65–70.

56. Morsy MA, Al-Daous MA. Gold nanoparticles-PMMA composite for denture base: Synthesis, mechanical and thermal characteristics. AKU J Sci Eng. 2014;14:369–374.

57. Nam KY. Characterization and bacterial anti-adherent effect on modified PMMA denture acrylic resin containing platinum nanoparticles. J Adv Prosthodont. 2014;6(3):207–214.

58. Aoyagi Y, Miyasaka T, Ando N. Application of noble metal cluster to PMMA resin and influence on mechanical properties and color. Dent Mater J. 2015;34(6):781–788.

59. Maine FW, Shepherd PD. Mica reinforced plastics: a review. Composites. 1974;5(5):193–200.

60. Mansour MM, Wagner WC, Chu TM. Effect of mica reinforcement on the flexural strength and microhardness of polymethylmethacrylate denture resin. J Prosthodont. 2013;22:179–183.

61. Ghaffari T, Barzegar A, Hamedi Rad F, Moslehifard E. Effect of nanoclay on thermal conductivity and flexural strength of

polymethyl methacrylate acrylic resin. J Dent (Shiraz). 2016;17(2):121–127.

62. Alla R, Sajjan S, Alluri V, Ginjupalli K, Padhya NU. Influence of fiber reinforcement on the properties of denture base resins. J Biomat Nano-Biotechnol. 2013;4:91–97.

63. Tacir IH, Kama JD, Zortuk M, Eskimez S. Flexural properties of glass fiber reinforced acrylic resin polymers. Aust Dent J. 2006;51:52–56.

64. Moreno MV, Acosta-Torres LS, Barcel O-Santana FH, Vanegas-Lanc RD, Plata-Rodrı´guez ME, Casta VM. Fiber-reinforced nano-pigmented poly (methyl methacrylate) as improved denture base. J Appl Polym Sci. 2012;126:289–296.

65. Sang-Hui YU, Yoon LE, Seunghan OH, Hye-Won CH, Yutaka OD, Ji-Myung BA. Reinforcing effects of different fibers on denture base resin based on the fiber type, concentration, and combination. Dent Mater J. 2012;3:1039–1046.

66. Farina AP, Cecchin D, Soares RG, et al. Evaluation of vickers hardness of different types of acrylic denture base resins with and without glass fiber reinforcement. Gerodontol. 2012;29:155–160.

67. Hamouda IM, Beyari MM. Addition of glass fibers and titanium dioxide nanoparticles to the acrylic resin denture base material: comparative study with the conventional and high impact types. Oral Health Dent Manag. 2014;13:107–112.

68. Singh K, Sharma SK, Negi P, Kumar M, Rajpurohit D, Khobre P. Comparative evaluation of flexural strength of heat polymerized denture base resins after reinforcement with glass fibers and nylon fibers: An in vitro Study. Adv Hum Biol. 2016;6:91–94.

69. Agha H, Flinton R, Vaidyanathan T. Optimization of fracture resistance and stiffness of heat-polymerized high impact acrylic resin with localized e-glass fiber reinforcement at different stress points. J Prosthodont. 2016;25(8):647–655.

70. Fonseca RB, Favarão IN, Kasuya VB, Abrão M, Da Luz N FM, Naves LZ. Influence of glass fiber wt% and silanization on mechanical flexural strength of reinforced acrylics. J Mat Sci Chem Eng. 2014;2:11–15.

71. Hari Prasad A, Kalavathy, Mohammed HS. Effect of glass fiber and silane treated glass fiber reinforcement on impact strength of maxillary complete denture. Ann Essen Dent. 2011;4:7–12.

72. Mowade TK, Dange SP, Thakre MB, Kamble VD. Effect of fiber reinforcement on impact strength of heat polymerized polymethylmethacrylate denture base resin: in vitro study and SEM analysis. J Adv Prosthodont. 2012;4:30–36.

73. Jassim RK, Radhi AA. Evaluation the biological effect of two types of denture base materials reinforced with silanated glass fiber. J Bagh Coll Dent. 2011;23:26–30.

74. Yu SH, Ahn DH, Park JS, et al. Comparison of denture base resin reinforced with polyaromatic polyamide fibers of different orientations. Dental Mater J. 2013;32:332–340.

75. Jagger DC, Harrison A, Jandt KD. The reinforcement of dentures. J Oral Rehab. 1999;26:185–194.

76. Chen SY, Liang WM, Yen PS. Reinforcement of acrylic denture base resin by incorporation of various fibers. J Biomed Mater Res. 2001;58:203–208.

77. Soygun K, Bolayir G, Boztug A. Mechanical and thermal properties of polyamide versus reinforced PMMA denture base materials. J Adv Prosthodont. 2013;5:153–160.

78. Uzun G, Hersek N, Tinçer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. J Prosthet Dent. 1999;81:616–620.

79. Ismaeel IJ, Alalwan HA, Mustafa MJ. The effect of the addition of silanated polypropylene fiber to polymethylmethacrylate denture base material on some of its mechanical properties. J Bagh Coll Dent. 2015;27:40–47.

80. Vallittu PK, Narva K. Impact strength of a modified continuous glass fiber polymethylmethacrylate. Int J Prosthodont. 1997;10:142–148.

81. Safarabadia M, Khansarib NM, Rezaeic A. An experimental investigation of HA/AL2O3 nanoparticles on mechanical properties of restoration materials. Eng Solid Mech. 2014;2:173–182.

82. Han Z, Zhu B, Chen R, Huang Z, Zhu C, Zhang X. Effect of silver-supported materials on the mechanical and antibacterial properties of reinforced acrylic resin composites. Mat Design. 2015;65:1245–1252.

83. Aljafery MA, Basima MA. Effect of addition ZrO2-Al2O3 nanoparticles mixture on some properties and denture base adaptation of heat cured acrylic resin denture base material. J Bagh Coll Dent. 2015;27:15–21.

84. Alhareb AO, Akil HM, Ahmad ZA. Mechanical properties of pmma denture base reinforced by nitrile rubber particles with Al2O3/YSZ fillers. Procedia Manufact. 2015;2:301–306.

85. Alhareb AO, Akil HM, Ahmad ZA. Influence of Al2O3/Y-TSZ mixture as filler loading on the radiopacity of PMMA denture base composites. Procedia Chem. 2016;19:646–650.

86. Chen S, Liang W. Effects of fillers on fiber reinforced acrylic denture base resins. Mid Taiwan J Med. 2004;9:203–210.

87. Muklif OR, Ismail IJ. Studying the effect of addition a composite of silanized Nano-Al2O3 and plasma treated polypropylene fibers on some physical and mechanical properties of heat cured PMMA denture base material. J Bagh Coll Dent. 2015;27:22–27.

88. Alhareb AO, Ahmad ZA. Effect of Al2O3/ZrO2 reinforcement on the mechanical properties of PMMA denture base. J Reinf Plast Compos. 2011;30:1–8.

89. Zhang XY, Zhang XJ, Huang ZL, Zhu BS, Chen RR. Hybrid effects of zirconia nanoparticles with aluminum borate whiskers on mechanical properties of denture base resin PMMA. Dent Mater J. 2014;33:141–146.

90. Salman TA, Khalaf HA. The influence of adding of modified ZrO_2-TiO_2 nanoparticles on certain physical and mechanical properties of heat polymerized acrylic resin. J Bagh Coll Dent. 2015;27:33–39.