Libyan Medical Journal
https://lmj.ly/index.php/ojs/index

Review article

Poly Methyl Methacrylate as Denture Base with Reinforcement Materials: A Review

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Citation: *Alsharif S, Alhareb A, Zidan S. Poly methyl methacrylate as denture base with reinforcement materials: A review. Libyan Med J. 2024;16(2):52-57.*

Received: *14-05-2024*
Accepted: *31-07-2024*
Published: *08-08-2024*

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Funding: *This research received no external funding.*

Conflicts *of Interest: The authors declare no conflict of interest.*

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Abstract

In dentistry, poly methyl methacrylate (PMMA) is still the main material used for prosthodontics and orthodontics appliances. Although it is widely appreciated for its ability to meet aesthetic expectations, it falls short in meeting the mechanical prerequisites of prosthodontics. This study aimed to review literature in reference to the PMMA material as denture base to knowledge types of reinforcement materials addend and their effects on the properties of denture bases. A comprehensive exploration of scientific studies concerning the effect of reinforcement materials of PMMA from year 2004 to 2023 was conducted through an electronic search using PubMed, Scopus, Science Direct, Google Scholar, and Wiley Inter Science engines. It turns out that that significant attempts have been made to enhance the attributes of denture bases, encompassing thermal diffusivity, hardness, surface roughness, and water sorption. The integration of strengthening components within PMMA for creating denture bases has been found to be both biocompatible and advantageous in enhancing its properties. This paper could potentially serve as a valuable resource for the selection materials utilized in denture applications, offering valuable insights into PMMA and its additive reinforcement materials in dentistry.

Keywords: *PMMA, Reinforcement Materials, Denture Base.*

Introduction

Despite the availability of numerous polymeric materials for denture base, PMMA stands out as the superior choice owing to its mouth stability and enhanced aesthetic appeal. Consequently, PMMA continues to be the favored material for removable prostheses and various orthodontic appliances. Since the mid-1940s, PMMA has been extensively utilized in the fabrication of denture bases, making it the go-to option.

In comparison to other polymeric materials, PMMA resin showcases superior impact, mechanical, and physical properties. However, when used independently, these materials possess inadequate mechanical and physical properties, rendering them vulnerable to breakage in the event of accidents or when the patient exerts excessive mastication force on the denture base [1]. Furthermore, PMMA resin is radiolucent and lacks the ability to differentiate from soft tissues. Consequently, pure PMMA is not suitable for utilization as a denture base. Despite the exploration of various other materials for dental prosthetics, none have been able to match the performance of PMMA. Currently, acrylic resin accounts for approximately 90-95% of denture base fabrication. Nevertheless, it is important to acknowledge that acrylic resin denture bases exhibit relatively poor resistance to fatigue fracture when subjected to masticatory loads [2].

The addition of reinforcement materials, such as ceramic, metal, or polymer, enhances the characteristics of composite materials by augmenting their rigidity and strength. This results in the composite material gaining strength and stiffness in a specific direction, while also inhibiting crack propagation. The properties of dental resin composite are influenced by various factors, including the initial properties of matrix and particles, the dispersion and concentration of the particles within the matrix, the interface between the particles and matrix, and the geometric attributes of the particles, particularly their size and shape [3].

Types of denture base materials

Metal: is a versatile material that finds application not only as a denture base but also as a fixed prosthetic such as a crown or bridge in the oral cavity. Metal dentures, specifically those made from a combination of cobalt and chromium, are known for their durability and resistance to breakage. Metal alloys are commonly employed in the construction of partial dentures. In the realm of dental applications, these alloys find extensive use in the production of denture bases for removable dentures that come into contact with both teeth and oral tissues [4].

In the field of dentistry, pure metals are not commonly utilized. However, on occasion, pure gold (Au) is employed as a premium quality inlay, despite its expensive nature. Although gold is biologically well tolerated, it is a material that is too soft. Nevertheless, it demonstrates remarkable chemical stability and is resistant to corrosion. Moreover, alloys composed of cobalt or nickel, along with a substantial amount of chromium, exhibit favorable characteristics for diverse dental purposes. These include the fabrication of removable partial denture frameworks, full denture bases, and temporary tooth surgical and periodontal splints [5].

Acrylic resin: Denture acrylic resin is a versatile material that finds application in denture bases, tooth restorations, and artificial teeth in the field of dentistry. It is available in various forms, such as cold/self-cure, fast cure, heat cure, and light cure acrylic resins, each with different setting times ranging from 12 to 45 minutes.

Denture acrylic resins play a crucial role in the creation of dentures, providing not only aesthetic appeal but also strength, durability, and comfort. The preference for acrylic resins stems from their exceptional attributes, including superior dimensional accuracy, high impact strength, and ease of manipulation. Supplied in the form of a powder and liquid, these resins are employed in the fabrication of denture bases due to their favorable properties such as smooth flow, effortless manipulation, and remarkable impact strength [4].

Flexible materials: such as nylon, polyester, polycarbonates, and polypropylene are used in making dentures. These materials are used in the production of flexible dentures, which are more comfortable, aesthetically pleasing, and less prone to breakage and wear than traditional dentures. Flexible dentures do not require additional metal hooks for keeping the denture in place, and they have inbuilt hooks that make the adjustment process hassle-free. They are also biocompatible, do not cause allergic reactions, and are stain and odor-resistant. Flexible dentures are lightweight, durable, and do not require additional metal hooks. They offer a more natural look and make eating and speaking easier [6].

The use of flexible dentures and artificial teeth made from acrylic resin material is widespread in the production of dentures due to their ability to absorb liquids in the surrounding oral environment. However, it is important to acknowledge that flexible materials have certain disadvantages, including problems with color change, rapid material degradation, and difficulties in achieving a polished finish [7].

Ideal properties of PMMA denture base material

Acrylic resins emerged in the field of dentistry between 1930 and 1940, serving as the preferred material for denture bases. Nevertheless, PMMA has gradually replaced all other denture materials, including vulcanite, nitrocellulose, phenol formaldehyde, vinyl plastics, and porcelain [8]. Ideally, PMMA is desirable for denture base materials to possess insoluble constituents and demonstrate minimal water sorption. This is crucial since these materials come into contact with saliva, water, and cleansing agents, which can lead to water absorption and the depletion of soluble components [9]. An ideal denture material possesses several properties that are crucial for its effectiveness. These properties include sufficient flexural strength to withstand fractures, high hardness, and durability. It should be strong enough to resist the stresses exerted on it during biting and mastication, and have a high elastic limit to prevent permanent deformation caused by these stresses.

Additionally, it should be easy to manipulate and fabricate for the denture base, and have a reduced density, particularly for the upper denture base. Furthermore, it should be easy to repair, chemically inert or at least compatible with the oral tissues, and exhibit dimensional stability to maintain the shape of the denture base during function. It should also resist the absorption of oral fluids, inhibit bacterial growth, and be easy to clean. Lastly, the ideal denture base materials should be compatible with the oral environment conditions of the patient's mouth.

Heat cured polymerization

The most common polymerization reaction for polymers used in dentistry is addition polymerization and normally used as a denture base for removable prostheses. It is a chemical reaction that transforms small moleculesinto large polymer chains. The process of heat polymerization necessitates a temperature of 60°C to initiate the polymerization of PMMA. A reasonable rate of reaction can be achieved at temperatures ranging from 70-75°C. However, it should be noted that the high temperature involved in the initial process leads to the decomposition of peroxide present in the polymer. To ensure almost complete conversion of monomer in thick areas of the denture base, the final three hours of heating at 100°C are crucial. Acrylic denture base materials primarily consist of PMMA beads and suspension polymerization, which involves the MMA monomer along with an initiator, as presented in Table 1.

Table 1. Composition of acrylic denture base materials.

Materials form		Chemical Composition
Powder	Polymer	Poly methyl methacrylate
	Initiator	Peroxide such as benzoly peroxide
	Pigment	Salts of cadmium, iron or organic dyes
Liquid	Monomer	Methyl methacrylate
	Cross-linking agent	Ethylene glycol dimethacrylate
	Inhibitor	Hydroquinone (trace)
	Activator*	N,N-dimethyl-ρ-toluidine

*Only in self-curing materials

Reinforcement materials

Ceramic particles: Ideally, the denture base plastic should possess a considerable level of impact strength to effectively resist breakage when accidentally dropped. However, this should not be achieved at the cost of compromising other essential properties. The mechanical properties of dental acrylic resins are greatly influenced by the loading of fillers [10]. By employing ceramic filler as reinforcement for acrylic resin and incorporating ceramic as filler at varying concentrations with PMMA, the strength of PMMA acrylic was further reinforced.

The inclusion of ceramic particles in the composite resulted in a reduction in water uptake compared to the base resin. Additionally, a lower uptake was observed in composites formulated with surface-treated ceramic particles. The researchers also noted that the equilibrium uptake decreased as the filler loading increased. However, it is worth mentioning that the specimens in the study exhibited higher water absorption than what would be expected based solely on the resin content. This discrepancy can be attributed to the presence of porosity and aggregates of filler particles within the microstructure of the composite.

Several researcher attempts to improve properties of PMMA denture base materials by using ceramic particles such as; Ihab et al., [11] assessed of ZrO_2 incorporation on impact, tensile strength of PMMA acrylic resin. the result showed significant increase in impact strength occurs in acrylic reinforced with 5 wt.% silanated ZrO_2 nanofillers; Safarabadi et al., [12] investigated influences of additive Al_2O_3 and HA nanoparticles on the mechanical and strength properties of PMMA. The results showed that the mechanical properties of hybrid Nano-composites were significantly improved in comparison with the pure samples in a way that optimal Nano-composite with convenience flexural properties and impact strength is obtained. Alhotan et al., [13] evaluated the flexural strength and surface hardness of PMMA modified by the addition of ZrO_2, TiO_2 at different ratio by weight. This study found that the optimal filler concentrations for reinforcing PMMA from the flexural strength perspective were 3-5 wt.% ZrO_2, and 1.5 wt.% TiO_2. In addition, the surface hardness of the reinforced PMMA generally increased as the content of the fillers increased.

The utilization of nanotechnologies has the potential to improve the characteristics of PMMA denture bases, including mechanical strength, biocompatibility, and antimicrobial properties, thereby increasing their appropriateness for use in dental procedures. The advancement in the field of nano-science and nanotechnology has paved the way for the development of novel materials within the nano-scale range, exhibiting distinct characteristics compared to their bulk counterparts. Despite their smaller dimensions, these materials offer a larger active surface area, enhancing their overall utility. Extensive research has demonstrated the superior effectiveness of incorporating nano-fillers over micro fillers in enhancing the properties of composite materials [14].

Nanoparticles addition to PMMA determines better mechanical properties than micro-particles addition. Addition of ZrO_2 nanoparticles and nano-tubes improved the flexural, tensile and impact strength, reduced porosity and water absorption [15, 16]. Carbon-based materials have been used in many applications, as a result of their favorable properties. In carbon-based composites, different types of additives are utilized, such as carbon black, carbon nano-tubes, and carbon nano-fibers.

Several researcher attempts to improve properties of PMMA denture base materials by using nanoparticles such as; Naji [17] investigated the impacts of incorporation of TiO_2 nanotubes to PMMA on the remaining monomer content of the of PMMA denture base. The results showed reduce in the residual monomer content significantly, which improves the physical, chemical and biological properties of the acrylic denture base material. Elshereksi et al., [18] investigated the effects of nanobarium titanate (NBT) loadings on tensile and flexural properties, and evaluated surface roughness and hardness of the PMMA nano-composites. The flexural modulus increased with increasing filler loadings. The tensile and flexural strength improved with increasing concentration of NBT up to 5 wt.% and then decreased by an additional amount of NBT introduced into the nanocomposite resin.

Rubber: the incorporation of rubber into PMMA as a means of reinforcement has proven to be the most successful and widely accepted method thus far. This approach serves as an alternative to the traditional PMMA denture base resin. However, the significant drawback lies in its high cost, which can be up to twenty times that of conventional resin, thereby limiting its regular usage. The rubber particles are effectively bonded to methyl methacrylate, ensuring a strong connection with the acrylic matrix. It is well-established that the addition of rubber in denture base resins yields superior results compared to unreinforced conventional acrylic resins. This is primarily due to the formulation's comparable properties, as highlighted by [19].

The incorporation of rubbers into PMMA resin, which consists of a dispersed interpenetrating network of rubber and PMMA, leads to the propagation of a developing crack through the PMMA. However, this crack propagation decelerates upon reaching the rubber interface. The primary objective of utilizing rubber reinforced resins is to enhance their capacity to absorb larger amounts of energy at higher strain rates before experiencing fracture, surpassing the capabilities of standard resins.

Several researcher attempts to improve properties of PMMA denture base materials by using rubber such as; Alhareb et al., [20] investigated the effect of nitrile butadiene rubber (NBR together with Al_2O_3/YSZ as filler loading in PMMA denture base on the thermal and mechanical properties. The PMMA composites have better thermal stability, and the fracture toughness, Vickers hardness and flexural modulus values were statistically increased compared to the unreinforced PMMA matrix. Salih et al., [21] studied the mechanical strengthens of PMMA containing 2% of silicone rubber and natural rubber reinforced by natural nano-particles of pomegranate peel. The results showed an appreciably improvement in the values of flexural strength, max. Shear stress, impact strength and fracture toughness for both groups of hybrids nano-composites specimens

Fibers: To assess the impact strength of acrylic resin denture base material, several studies were conducted to explore the influence of incorporating various fiber types. The fibers examined included carbon, glass, and polyethylene. The results demonstrated that the addition of glass and carbon fibers yielded an increase in impact strength when compared to the control group specimens, which did not contain any filler. Conversely, the inclusion of glass woven and silk fibers resulted in a decrease in impact strength. Therefore, it is not advisable to utilize these fibers as reinforcement materials. In the PMMA denture base, a variety of fibers were employed, such as polyethylene, glass, and carbon fibers, as demonstrated in the study conducted by [22]. The findings revealed that these fibers enhanced the impact strength of the denture base.

The effect of five types of aesthetic fibers with different lengths and concentrations, at a weight of 3%, as reinforcement for denture base resin on flexural strength was investigated by [23]. The study revealed an increase in flexural strength. The impact of water absorption on the impact strength of impregnated glass fiber-reinforced composites was investigated by [24]. The study results revealed that water absorption did not have a significant impact on the impact strength of the glass FRC.

Whiskers glass and glass flake: PMMA denture bases can be reinforced with various materials to enhance their mechanical properties. Some of the commonly used reinforcing agents include silanated glass fiber, and glass flakes. The incorporation of glass fiber reinforcement has been identified as a significant factor in enhancing the mechanical properties of PMMA denture bases. In-depth analysis has been carried out to examine the impact of adding glass flakes to PMMA denture base resin, specifically focusing on flexural properties and impact strength. The findings demonstrate that the flexural strength of unmodified PMMA denture base resin decreases with an increase in the concentration of glass flakes. The use of glass flakes for reinforcing PMMA denture bases may not lead to the expected improvements in mechanical properties [25]. Additionally, Franklin et al., [26] conducted a study to examine the reinforcement of glass flake and the addition of trevalon in denture base acrylic material. The results revealed a significant increase in fracture toughness compared to the use of trevalon alone. Furthermore, the study suggested the incorporation of whiskers glass or other reinforcement materials into the PMMA denture base resin as a means to enhance its mechanical properties, such as flexural strength, toughness, and flexural modulus.

Metals: The enhancement of radiopacity in PMMA polymer can be achieved through the addition of heavy metal salts, although this presents a challenge given the general incompatibility between most heavy metal salts and PMMA. While various heavy metals have been studied in an attempt to boost the radiopacity of PMMA, issues such as insufficient physical or chemical bonding of additives to the matrix and the tendency of salts to segregate have been raised. Nonetheless, some research has demonstrated that the incorporation of heavy metal salts can enhance the radiopacity of PMMA [27]. The incorporation of heavy metal salts into PMMA can improve its radiopacity, making it more visible in diagnostic radiographs. This is particularly important in dental applications, where radiopaque materials are essential for detecting dental restorations and prostheses.

The use of metal wire to reinforce PMMA resin is a common practice in dental laboratories for fabricating denture bases. Studies have confirmed that the addition of metal wire reinforcement can increase the transverse strength of the denture base resin [28]. A systematic review conducted by Somani et al., [29] highlighted the utilization of metal wires as strengtheners for PMMA. The study revealed that these wires have demonstrated the ability to enhance the strength of PMMA. The currently used metal alloys for reinforcement in denture bases include aluminum alloy, gold, cobalt chromium alloy, nickel chromium alloy, and titanium. In order to enhance the fracture resistance, dimensional stability, accuracy, and retention of dentures, the utilization of metal reinforcements is imperative.

Several researcher attempts to improve properties of PMMA denture base materials by using metal such as; Vojdani & Khaledi, [28] measured the transverse strength of PMMA reinforced with metal wire. The transverse strength increased significantly. Mithran et al., [30] evaluated and compare the impact strength of unmodified and modified PMMA with addition of different concentrations of silver particles. The impact strength of modified PMMA was significantly enhanced with addition of varying concentrations of silver particles, although, it was observed that with an increase in the concentration of silver particles, a subsequent decrease in the tensile strength of the final polymer material was observed. Ardakani et al., [31] evaluated the effect of metal mesh reinforcement on the flexural strength of PMMA. Reinforcing the PMMA with metal mesh significantly enhances its flexural strength. Aoyagi et al., [32] they found that, the bending deflection increased with the addition of silver and platinum. The bending strength was lowest with the addition of gold, highest with the addition of palladium. Vickers hardness increased with the addition of palladium.

Conclusion

Within the limitations of this review study, it was concluded that the reinforced PMMA material is the top choice for denture base, and the addition of reinforcement materials to PMMA denture base materials can improves most their properties. The advancements made in PMMA denture base have shown promising results in their properties. The current era has witnessed significant advancements have been made in addressing the disadvantages of PMMA denture base resins, suggesting that future research will introduce newer materials that are more biocompatible and possess superior mechanical endurance. Subsequently, this progression is expected to enhance the quality of treatment and care provided to patients.

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