PMMA, Polyamide, and PEEK as Denture Bases: A Review of Physical, Mechanical, and Microbiological Properties

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ABSTRACT

This review critically evaluates the physical, mechanical, and biological properties of commonly used denture base materials—polymethyl methacrylate (PMMA), polyamide, and polyether ether ketone (PEEK)—with emphasis on their clinical performance and biocompatibility. A systematic literature search was conducted using PubMed, Scopus, and Google Scholar for studies published between 2008 and 2024, focusing on in vitro, in vivo, and clinical investigations related to denture base materials, fabrication techniques, and microbial interactions. Advances in CAD/CAM and 3D printing technologies were assessed for their impact on prosthesis accuracy and durability. The review also highlights the role of material surface characteristics in microbial colonization, particularly *Candida albicans*, and the subsequent risk of denture stomatitis. Additional factors such as thermocycling, oral hygiene, and patient-related variables were considered for their influence on prosthetic longevity. This comprehensive analysis aims to inform evidence-based material selection and design strategies to improve functional and biological outcomes in removable prosthodontics.

Key words: Denture base material, Polymethyl methacrylate, Polyamide resin, Polyether ether ketone, Microbial adhesion

INTRODUCTION

Polymethyl methacrylate (PMMA) remains the most widely used material for denture bases due to its ease of manipulation, cost-effectiveness, and acceptable physical properties. Despite its advantages, PMMA is associated with several drawbacks that limit its clinical longevity. These include low impact and flexural strength, susceptibility to fracture under functional load, high water absorption, and poor resistance to fatigue over time. The presence of residual monomer can cause mucosal irritation or hypersensitivity in some patients. Furthermore, its surface porosity and roughness encourage microbial accumulation, contributing to oral infections such as denture stomatitis. Its low thermal conductivity may also affect the perception of temperature in food and beverages. These limitations have led to continuous efforts to improve PMMA through various material modifications and fabrication techniques.[1]

Various strategies have been employed to overcome the limitations of PMMA, including

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the incorporation of fibres, nanofillers, and copolymers. These approaches aim to improve its flexural strength, fracture resistance, and surface hardness. Reinforcing PMMA with materials such as glass fibres, zirconia, or silica has resulted in more durable and wear-resistant denture bases. Some modifications also offer improved colour stability and reduced water sorption, enhancing both aesthetics and longevity. The integration of antimicrobial agents has been explored to minimise microbial colonisation on the denture surface. In a study by Abdul-Monem et al., the effects of thermocycling on 3D-printed and CAD/CAM-milled PMMA were assessed. The findings indicated that CAD/CAM-milled samples maintained better surface quality and mechanical properties, highlighting the importance of fabrication technique in denture performance.[2]

Therefore, this review was conducted to bring together and critically evaluate the existing literature on these three materials, with an emphasis on their physical, mechanical, and microbiological properties. The goal is to support evidence-based decisions in clinical practice regarding the most suitable material for denture fabrication.

METHODS

The literature for this review was gathered through a systematic search of electronic databases, including PubMed, Scopus, ScienceDirect, and Google Scholar, covering publications from January 2008 to April 2024. Search terms included combinations of "denture base materials," "PMMA," "polyamide," "PEEK," "flexural strength," "CAD/CAM dentures," and "microbial colonization." Studies were included if they were published in English, peer-reviewed, and focused on the physical, mechanical, or microbiological properties of polymethyl methacrylate, polyamide, or polyether ether ketone as denture base materials. Both in vitro and in vivo studies were considered, along with those evaluating modern fabrication methods such as CAD/CAM and 3D printing. Excluded materials comprised non-denture applications, non-English articles, abstracts, and review papers lacking original data. Preference was given to comparative studies published within the last ten years. References from selected papers were cross-checked to identify additional relevant studies. Ultimately, over 30 eligible articles were critically reviewed to ensure a comprehensive and unbiased summary of current knowledge.

Fabrication Techniques

Digital technologies, especially CAD/CAM systems, have introduced advancements in prosthesis fabrication. Jasiūnaitė and colleagues reported improved hardness, flexural modulus, and dimensional stability in CAD/CAM-produced PMMA compared to conventionally processed samples. These findings were supported by Al-Dwairi et al., who demonstrated superior flexural and impact strengths in CAD/CAM PMMA specimens over traditionally heat-cured variants. These results highlight the mechanical benefits of pre-polymerised PMMA blocks processed through milling techniques.[3,4] Alternative materials such as polyamide and Polyether Ether Ketone (PEEK) are gaining attention. Polyamide, often selected for its flexibility, aesthetic properties, and hypoallergenic nature, offers certain advantages over PMMA. Nonetheless, studies like that by Emera et al. indicated that while alumina nanoparticle-reinforced polyamide resins demonstrated improved flexural strength, they still fell short of the performance seen in high-performance polymers like BioHPP. BioHPP exhibited significantly better mechanical properties and retention, suggesting its potential suitability for long-term denture applications (Table 1).[5]

Microbiological Considerations

Microbial colonization, particularly by *Candida albicans*, remains a significant concern with denture use. The formation of biofilm on denture surfaces can lead to denture stomatitis and other oral infections. Gad's systematic review identified surface roughness, contact angle, and hydrophobicity as key determinants of *Candida* adhesion. These surface characteristics create microenvironments that favour microbial retention, especially when the material lacks sufficient polishability or is exposed to oral fluids over time.[6]

PEEK has emerged as a high-performance denture base polymer due to its excellent biocompatibility and mechanical resilience. An investigation by Ismiyati focused on its interaction with oral microbiota, particularly *Candida albicans*, comparing it with thermoplastic nylon. The findings indicated that PEEK exhibited minimal biofilm formation, whereas nylon demonstrated weak biofilm-forming capabilities, underscoring PEEK's advantage in reducing microbial colonization.[7]

Chladek et al. observed that prolonged exposure of PMMA to Candida albicans led to deterioration of surface hardness without evidence of microbial penetration into the bulk material. This suggests that surface modifications or protective coatings might effectively enhance the resistance of PMMA to microbial colonization.[8] Koch et al. found that materials with a higher polar component of surface free energy showed significantly higher *Candida* proliferation, indicating that intrinsic material properties directly affect microbial behaviour.[9] Efforts to reduce microbial adherence have included the incorporation of antifungal agents and surface-active monomers into the denture base matrix. Sivakumar's review of antimicrobial modifications to PMMA identified methacrylic acid and phosphate-based groups as effective in reducing microbial adhesion.[10] However, such additions may compromise mechanical properties and raise concerns about potential cytotoxicity, highlighting the importance of balancing antimicrobial activity with material safety (Table 2).

Patient-Specific Factors

The interaction between denture base materials and patient-specific factors has also been explored. Abdel Ghany conducted a clinical comparison between conventional acrylic and polyamide dentures in diabetic patients and found a lower rate of microbial colonisation on polyamide surfaces. This result is clinically relevant, given that patients with systemic conditions like diabetes are more prone to oral infections.[11] In vitro studies by Abed et al. evaluating the biofilm-forming potential of three acrylic types—conventional, flexible, and compact—demonstrated the highest bacterial adhesion in conventional acrylics. Flexible materials showed intermediate levels, while compact acrylics were the least susceptible. These results suggest that structural density and surface uniformity play crucial roles in microbial adhesion.[12]

The use of flexible dentures, often made from polyamide or other thermoplastic resins, has been a subject of interest, particularly for patients with aesthetic concerns or anatomical challenges. While their flexibility and esthetics are beneficial, their lower hardness and polishability may limit their long-term performance. Nevertheless, studies like those by Olms et al. showed that polyamide and PMMA did not differ significantly in bacterial colonization or cytological impact after intraoral use, supporting their continued use in clinical practice.[13]

Hygiene and Long-Term Clinical Considerations

Hygiene-related studies further reinforce the importance of material selection. Majchrzak and colleagues reported that poor hygiene over time, especially among patients with systemic conditions, led to colonization with multidrug-resistant *Staphylococcus* strains.[14] O'Donnell's work showed that a significant proportion of dentures harboured respiratory pathogens, with implications for systemic health, especially in elderly populations prone to aspiration pneumonia [15]

Surface Modification and Polishability

Surface polishing and finishing techniques also contribute to reducing microbial colonization. Radford's findings emphasized that smoother denture surfaces inhibit *Candida* adherence, while rough surfaces promote colonization.[16] Polishing techniques can significantly lower surface roughness, as demonstrated by Abuzar et al., who showed that both polyamide and PMMA can achieve clinically acceptable smoothness with conventional polishing methods, although PMMA is generally more responsive.[17]

Table 1. Summary of key studies on physical and mechanical properties of denture base materials

Author & Year	Material(s) Studied	Type of Study	Focus of Study	Methods/Tests Used	Key Findings
Abdul-Monem et al. (2024)	3D-printed vs. CAD/CAM resins	In vitro	Effect of thermocycling	Surface hardness, roughness, fracture toughness, and SEM	Thermocycling reduced hardness and toughness; CAD/CAM is better than 3D printing
Le Bars et al. (2023)	PMMA, Polyamide, PEEK	Review	Oral microbiota & denture materials	Narrative review	All materials disturb oral flora; *C. albicans* leads to denture stomatitis; hygiene is key.
Alqutaibi et al. (2023)	PMMA	Review	Overview of DBMs	Literature review	PMMA is widely used but not ideal; it needs enhancements using fibres/nanofillers
Ismiyati (2022)	PEEK, Thermoplastic Nylon	In vitro	*Candida* hydrophobicity and biofilm formation	Contact angle, biofilm assays	PEEK non-biofilm former; nylon weak biofilm former
Gad (2022)	PMMA	Review	*Candida* adhesion and surface properties	Systematic review	Surface roughness and hydrophobicity increase *C. albicans* adhesion
Jasiūnaitė et al. (2022)	CAD/CAM vs. conventional PMMA	In vitro	Mechanical properties	CAD/CAM comparison	CAD/CAM PMMA had better strength and dimensional stability
Chladek et al. (2022)	PMMA	In vitro	Mechanical change after *C. albicans* exposure	Strength, SEM	Surface hardness decreased after fungal exposure

Emera (2021)	Al2O3-modified polyamide, BioHPP	Clinical	Mechanical & clinical adaptation	Flexural strength, retention, and adaptation	BioHPP showed superior mechanical performance and good clinical results
Zafar (2020)	PMMA	Review	Applications & modifications	Literature review	PMMA is versatile; it needs reinforcements for improved properties
Abed et al. (2020)	Heat-cure, flexible & compact acrylic	In vitro	Bacterial biofilm	Biofilm assay, SEM	Conventional acrylic showed the highest bacterial adhesion

Table 2: Summary of studies on microbial colonization, hygiene, and clinical performance of denture materials

Author & Year	Material(s) Studied	Type of study	Focus of Study	Methods/Tests Used	Key Findings
Al-Dwairi et al. (2020)	CAD/CAM PMMA vs. conventional	In vitro	Mechanical properties	Flexural & impact strength	CAD/CAM has better strength; brand differences exist
Olms et al. (2018)	PMMA, Polyamide	Clinical	Intraoral bacterial colonization	Split-mouth design	No cytological differences; similar bacterial colonization
Abdel Ghany (2016)	Acrylic vs. Polyamide	Clinical	Microbial colonization in diabetics	Oral swabs, culture	Polyamide had less microbial colonization
Majchrzak et al. (2016)	Various dentures	Clinical	Denture hygiene & infection	Swab testing	Poor hygiene over time; MDR *Staphylococci* present
O'Donnell et al. (2016)	Denture plaque	Clinical	Respiratory pathogens	qPCR	Dentures harbour respiratory pathogens; 37% had stomatitis
Vojdani (2015)	Polyamide	Review	Mechanical, aesthetic & biocompatibility review	Literature review	Polyamide is good in certain cases, but requires careful follow-up
Koch et al. (2013)	Various DBRs	In vitro	*Candida* adhesion with ageing	Thermal cycling, incubation	Surface energy affects *Candida* proliferation
Ucar et al. (2012)	Polyamide, PMMA	In vitro	Mechanical properties comparison	Flexural, hardness tests	Polyamide is strong, but lower modulus than PMMA
Abuzar et al. (2010)	Polyamide, PMMA	In vitro	Surface roughness & polishability	Profilometer	Polyamide polishability within an acceptable range
Ali et al. (2008)	UDMA, PMMA	In vitro	Mechanical property comparison	Vickers Hardness, flexural tests	UDMA is superior to both heat- and auto-cured PMMA

DISCUSSION

Compared to PMMA and polyamide, PEEK and BioHPP display superior mechanical strength and excellent biocompatibility. Their low microbial adherence and chemical stability make them promising, especially for long-term use. Nevertheless, their high cost, processing complexity, and limited long-term clinical data hinder widespread use. However, a common issue across materials is the balance between strength and biological safety. Modifications often enhance one property at the expense of another. Therefore, material selection must consider patient-specific needs such as hygiene, anatomy, and systemic health [18-20].

CONCLUSION

This review highlights the comparative strengths and weaknesses of PMMA, polyamide, and PEEK as denture base materials. PEEK and BioHPP show excellent mechanical and biological properties, but are restricted by cost and limited clinical data. Much of the existing research is based on laboratory studies, with limited long-term clinical evidence. Differences in testing methods also make direct comparisons difficult. Future studies should focus on standardized clinical trials that consider functional performance, microbial behaviour, and patient-related factors. Ultimately, the choice of denture base material should reflect a balance between clinical needs, patient comfort, and long-term success.

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