Turkish Journal of Dental Hygiene
2022, Volume 2, Page No: 35-45
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Available online at: www.tsdp.net

ISSN: 3062-3472

Original Article

Advances in Preventing Denture Stomatitis: Exploring Antimicrobial Denture Base Materials

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Received: 23 August 2022; **Revised:** 28 October 2022; **Accepted:** 01 November 2022

ABSTRACT

Oral infections can potentially lead to systemic diseases, making their prevention a key priority. One of the most common conditions among complete denture users is denture stomatitis. Developing removable dentures from materials with antimicrobial properties offers a potential solution for preventing this issue. This review examines different modified denture materials, focusing on their antimicrobial effects, advantages, and limitations. It also addresses unresolved aspects regarding their clinical application. A comprehensive search was conducted across 4 databases: Web of Science, PubMed, Google Scholar, and Scopus. The findings show that the incorporation of different modifying agents has led to the development of numerous denture materials with proven antimicrobial properties. These materials, which effectively reduce the growth of pathogens associated with denture stomatitis, can be integrated into modern preventive strategies. However, further clinical studies are needed to evaluate their antimicrobial efficacy in real-world oral conditions, considering the influence of systemic and local factors.

Keywords: Denture materials, Antimicrobial properties, Denture stomatitis, Prevention of denture stomatitis.

How to Cite This Article: Pavlova Z. Advances in Preventing Denture Stomatitis: Exploring Antimicrobial Denture Base Materials. Turk J Dent Hyg. 2022;2:35-45. https://doi.org/10.51847/GCPrBQtz3T

Introduction

Oral health plays a crucial role in the overall nutrition, health status, and quality of life of individuals who wear complete dentures. The oral microbiome is home to a wide array of microorganisms that, in healthy participants, typically do not display pathogenic properties or lead to diseases. This includes over 700 types of bacteria and fungi, with the dominant species belonging to groups such as Firmicutes, Proteobacteria, Fusobacteria, Actinobacteria, Bacteroidetes, Spirochaetes, and Candida [1-3]. However, certain factors can trigger the pathogenic behavior of these normally harmless microorganisms, particularly in denture users. The likelihood of developing oral mucosal diseases in patients with removable dentures ranges from 36.7% to 65% [4, 5]. Studies have shown that the oral microbiome in denture wearers contains fewer microbial species compared to those with natural teeth [6], which facilitates the overgrowth of opportunistic organisms like *C. albicans*, thereby increasing the prevalence of *Candida* species [7]. The biofilm that forms underneath dentures harbors microorganisms on their surface, acting as a reservoir that supports infection development and persistence [8]. One of the most common results of this process is the onset of denture stomatitis [9].

The causes and clinical manifestations of denture stomatitis have been extensively studied. This condition can be triggered by various microorganisms, including bacteria from species such as

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Staphylococcus, *Streptococcus*, *Fusobacterium*, and *Bacteroides*. However, *Candida albicans* is identified as the primary pathogen in over half of the cases [10]. It is widely accepted that denture stomatitis arises from an imbalance in the oral microflora [9, 11].

The body has natural defense mechanisms against denture stomatitis, such as antimicrobial factors in saliva, innate immune responses, adaptive cellular immunity, and a protective barrier offered by the healthy epithelial layer of the oral mucosa. Despite these defenses, the body's immune system is not sufficient to prevent the onset of denture stomatitis [12].

Several local factors directly influence the development of denture stomatitis. These factors include conditions in the oral cavity, such as the quantity of saliva, pH levels, and the integrity of the oral mucosa [9]. Other contributing factors are related to the dentures themselves, such as the surface characteristics of the denture base material [13], the age of the dentures [14, 15], and the level of hygiene maintained for the dentures [16, 17].

The surface properties of denture materials play a critical role in the development of denture stomatitis. Materials with high surface roughness and hydrophobicity can promote the adhesion of microorganisms [18]. To minimize microbial attachment and colonization, denture base materials should ideally be smooth, hydrophilic, and exhibit low porosity [13].

Most complete dentures are fabricated using poly(methyl methacrylate) (PMMA) with heat-activated polymerization. This material's inherent porosity can facilitate the attachment of microorganisms, contributing to the development of denture stomatitis, particularly when compounded with other risk factors, such as inadequate hygiene. However, PMMA tends to have higher hardness compared to elastic denture base materials, leading to lower microbial retention [19]. Some elastic materials, on the other hand, exhibit significant porosity, promoting the formation of larger biofilms populated by diverse microbial communities [20]. A promising approach to combatting denture stomatitis involves the development of modified denture base materials that possess antimicrobial properties, helping to mitigate these challenges.

The purpose of this review is to examine the available dental literature regarding modified denture base materials with antimicrobial effects and to highlight unresolved issues related to their use in preventing denture stomatitis.

Materials and Methods

An electronic search was conducted across four databases: Web of Science, PubMed, Google Scholar, and Scopus. The search terms used included "denture base materials," "modified denture materials," "denture stomatitis," "biofilm formation," "antimicrobial effect," and "antifungal agents."

The retrieved articles were screened based on predefined inclusion and exclusion criteria as outlined below:

Inclusion criteria:

1. Both in vivo and in vitro studies.
2. Research focused on modified denture base materials.
3. Publications in the English language.
4. Articles published between 2018 and 2023.

Exclusion criteria:

1. Studies addressing other types of modified dental materials.
2. Publications in languages other than English.
3. Articles published outside the time range of 2018-2023.

The review aimed to address the following key questions:

- Which modified denture base materials with antimicrobial properties have been studied in the past five years?
- What are the advantages and limitations of these modified denture base materials?
- What uncertainties remain regarding their use in preventing denture stomatitis?

Results and Discussion

Various characteristics, such as hydrophobicity, surface roughness, hardness, and elasticity, play a significant role in the adhesion of microorganisms to denture materials [13]. The primary goal of modifying these materials is to improve their surface properties, shifting from hydrophobic to hydrophilic, and enhancing their mechanical qualities. Common methods for enhancing these materials include adding different modifying agents to the denture acrylic resin or applying an antimicrobial coating to the denture base [21-24].

Incorporation of Nanoparticles into Denture Base Materials

Recent studies have focused on the impact of adding nanoparticles from various materials to denture acrylic resin, showing substantial improvements in surface properties [21-42]. These modified materials exhibit reduced adhesion to *Candida albicans*, the primary pathogen involved in denture stomatitis. This reduction in adhesion is attributed to the enhanced smoothness of the surface, which prevents the firm attachment of microorganisms and promotes easier removal during cleaning. These improved properties suggest that such materials could play a crucial role in preventing denture stomatitis.

One method for enhancing the properties of PMMA is the incorporation of titanium dioxide (TiO2) nanoparticles [21]. These modifications improve the mechanical properties of the material, such as increased micro-hardness, elasticity modulus, and the stability of chemical compounds. These enhancements ensure the material is easier to polish and achieves a high-quality finish. Denture base materials with TiO2 nanoparticles exhibit significant antibacterial effects against both gram-negative and gram-positive bacteria, including *Enterococcus faecalis*, *Pseudomonas aeruginosa*, and fungi like *Candida albicans* [21].

Another approach to altering the properties of denture resins is the use of fillers containing silver nanoparticles, which are known for their broad-spectrum antibacterial properties [43]. Research shows that even in low focus, these nanoparticles inhibit the growth of microorganisms such as *Streptococcus mutans*, *Staphylococcus aureus*, *Candida* species, and others [22]. Takamiya *et al.* [25] demonstrated that adding silver nanoparticles at concentrations of 0.05% and 0.5% to acrylic resin monomer effectively combats *Candida albicans* biofilm and is considered biocompatible. The antibacterial action of silver nanoparticles is attributed to their interaction with the sulfhydryl groups of proteins on bacterial cell membranes, disrupting the integrity of the cell membrane and damaging the intracellular DNA [26, 27].

Different methods for incorporating silver nanoparticles into PMMA have been developed. For example, Bacali *et al.* [28] described the synthesis of a PMMA-graphene silver nanoparticle (G-AgNp) composite using the radio-frequency catalytic chemical vapor deposition (RF-CCVD) method.

Sun *et al.* [29] developed a novel type of denture material (NS/PMMA) by integrating a silver nanoparticle solution with methyl methacrylate monomer and acrylic acid.

De Matteis *et al.* [22] demonstrated that editing PMMA with citrate-capped silver nanoparticles at a concentration of 3.5 wt% led to a significant reduction in Candida biofilm coverage, decreasing it from 90% to just 6%.

Pai *et al.* [30] investigated how the flexural strength of PMMA resins is affected by incorporating titanium dioxide nanoparticles and silver nanoparticles, both individually and in combination. The study categorized reinforced groups by concentration levels of 0.5, 1, 2, and 3%, revealing that as the nanoparticle concentration increased, flexural strength gradually decreased, accompanied by noticeable color changes in the material.

Regardless of the method used to introduce silver nanoparticles into PMMA, studies consistently confirm their non-toxic nature and strong antibacterial properties [22, 29, 31]. However, some drawbacks include a decline in the alterations in material color and flexural strength of denture base resins [30, 31].

Recent studies have explored the impact of incorporating a two-component nanocomposite made of boron nitride and silver nanocomposite into the denture base material. This modification resulted in considerable improvements in mechanical properties, with compressive strength rising by 53.5% and flexural strength increasing by 56.7% compared to unmodified materials. Additionally, denture materials containing 1.4 wt.% boron nitride/silver nanocomposite exhibited a 92.1% higher antibacterial activity than their non-modified counterparts [32].

Another widely used nanoparticle for PMMA modification is zinc oxide (ZnONP), typically ranging in size from 10 to 100 nm [33]. The incorporation of ZnO nanoparticles enhances the material's hydrophilicity, thereby reducing microbial adhesion potential [34].

Additionally, researchers have investigated the effect of modifying PMMA by incorporating nano-graphene oxide (nGO) into the polymer powder. This modification has been found to enhance flexural strength and surface hardness while providing a long-term effect in preventing microbial attachment to the denture surface [35].

Our analysis of incorporating zirconium oxide nanoparticles into denture material revealed a pronounced and lasting antifungal effect. This edit enhances the material's tensile strength; however, it negatively affects surface roughness and reduces transparency [36].

Gad *et al.* [37] investigated the characteristics of PMMA denture material reinforced with a combination of Zirconium Oxide nanoparticles and glass fibers. Their findings indicate that this modified material offers excellent biocompatibility and superior aesthetics, as the alteration does not impact the color of PMMA.

Another study explored how artificial aging influences the antifungal properties of zirconium dioxide nanoparticles (ZrO2NPs) incorporated into denture material [38]. The researchers reported that adding ZrO2NPs provides a sustained antifungal effect, with 1% being identified as the most effective concentration [38]. However, other studies have not demonstrated a sufficiently strong reduction in *C. albicans* while using PMMA modified with zirconium oxide nanoparticles [23].

In recent years, considerable research has focused on modifying denture resins by integrating nanodiamonds. Unlike metal or metal oxide nanoparticles, nanocarbon-based materials exhibit greater chemical stability, excellent biocompatibility, and no cytotoxic effects [39]. Nanodiamonds possess antibacterial properties, which are believed to result from the oxygen-containing functional groups on their surface interacting with bacterial cell components. Additionally, nanodiamond inclusion improves the mechanical properties of PMMA, notably reducing surface roughness and enhancing its polishing capability [39].

Fouda *et al.* [40] discovered that introducing nanodiamonds in concentrations ranging from 0.5% to 1% into PMMA significantly reduces *C. albicans* adhesion, further reinforcing their potential for improving denture base materials.

Another explored modification involves incorporating SiO2-nanoparticles into PMMA denture base resin. The introduction of nano-SiO2 in low concentrations has been shown to decrease *C. albicans* adhesion to the denture surface while also enhancing hardness. However, at higher concentrations, the material exhibits drawbacks such as increased surface roughness and reduced translucency [41].

Additionally, specialized formulations containing micro-nanoparticles have been developed for creating a silicon-based coating on denture surfaces. These coatings form an ultra-hydrophilic layer that provides a self-cleaning effect, contributing to improved oral hygiene and reduced microbial retention [24].

Correa *et al.* [42] introduced heat-cured Polymethyl methacrylate acrylic enhanced with copper nanoparticles (nCu) to fabricate dentures with antimicrobial properties. Their findings indicate that this modified material maintains its mechanical and aesthetic qualities while effectively inhibiting *Candida* species growth on both the patient's palate and denture surface.

The surface characteristics of denture base materials are also influenced by the fabrication method. Recent advancements emphasize the development of denture base materials using digital technologies. PMMA-based polymers designed for CAD/CAM fabrication undergo pre-polymerization, which enhances final hardness and minimizes porosity, thereby reducing microbial retention and lowering the risk of denture stomatitis [43, 44].

Denture base composites created through additive 3D printing technology have been further enhanced with nanoparticles, including Nano-silver-loaded zirconium phosphate (6SNP3). Studies on these materials have demonstrated improvements in mechanical properties and significant antibacterial effects, particularly against *Escherichia coli* [45].

Khattar *et al.* [46] investigated the antibiofilm activity and surface roughness of a 3D-printed denture base resin edited with varying concentrations of zirconium dioxide nanoparticles (0.5, 1, 3, and 5 wt%). Their results revealed that incorporating ZrO2 nanoparticles at a low concentration (0.5%) effectively inhibited *C. albicans* adhesion and proliferation while maintaining the surface smoothness of the 3D-printed resin.

Aati *et al.* [47] introduced an innovative 3D-printed denture base resin material incorporating a mesoporous silica nanocarrier loaded with silver (Ag/MSN) to enhance both its mechanical properties and antimicrobial effectiveness. Different concentrations of Ag/MSN (ranging from 0.0 to 2.0 wt%) were integrated into the acrylate resin-based formulation. It was observed that adding Ag/MSN at concentrations below 1% significantly increased surface hardness. However, when the concentration reached or exceeded 1.0 wt%, surface roughness was notably affected. The modified 3D-printed resin exhibited improved antimicrobial activity against *C. albicans*, with its inhibitory effectiveness directly linked to the amount of Ag/MSN incorporated.

In summary, incorporating nanoparticles generally leads to enhanced mechanical strength and antibacterial properties in PMMA. Despite these benefits, one drawback is that higher nanoparticle concentrations can sometimes result in undesired color alterations in the material. To address this limitation, a proposed solution is the development of two-layered dentures, where only the inner layer is modified. This approach maintains the antimicrobial benefits by reducing microbial adhesion while preserving the denture's aesthetic appearance [40].

Denture Base Materials edited with Various Inorganic and Natural Components

The ongoing search for effective methods to enhance denture base materials and prevent denture stomatitis remains a key focus in research. In the past years, beyond the use of nanoparticles, a broad range of other materials and ingredients—either individually or in combination—have been explored for this purpose. One approach involves modifying denture base materials by incorporating inorganic compounds. A notable example is the integration of N-dimethylaminoethyl methacrylate (DMAEMA) [48]. This modified denture resin exhibits antimicrobial activity against *S. aureus* (gram-positive), *E. coli* (gram-negative), and *C. albicans*. However, according to researchers [48], the inclusion of DMAEMA, especially at higher concentrations, may lead to compromised color stability, alterations in mechanical properties, increased surface roughness, and reduced flexural strength.

Further studies have evaluated the impact of zinc-dimethacrylate (ZDMA) modification on PMMA's mechanical and antibacterial properties. Findings suggest that incorporating up to 5 wt% ZDMA enhances mechanical strength while also exhibiting antibacterial efficacy against *Streptococcus mutans* [49].

Gad *et al.* [50] investigated the influence of Thymoquinone (TQ) on the mechanical characteristics of PMMA denture base materials. Their results showed that when TQ was added at concentrations exceeding 1%, it significantly decreased flexural strength and elastic modulus. However, at lower concentrations (0.5%–1% TQ), no adverse effects on surface properties were noted, making it a viable antifungal additive for PMMA.

Additionally, Da Silva Barboza *et al.* [51] explored the modification of conventional polymethylmethacrylate by incorporating di-n-butyldimethacrylate-tin, zirconium methacrylate, and tin methacrylate into the PMMA resin's liquid component. Their study revealed that the inclusion of di-n-butyldimethacrylate-tin notably increased the material's hardness while reducing surface roughness. Moreover, this modified formulation exhibited superior antifungal activity against *C. albicans* compared to conventional PMMA. Similarly, Khader *et al.* [52] confirmed that integrating a modified monomer into PMMA led to enhanced antimicrobial properties and cytocompatibility while maintaining mechanical strength and color stability.

Enhancing the Antimicrobial Properties of Denture Resins through Natural Additives

One investigated strategy to enhance the antimicrobial efficacy of denture resins involves incorporating different concentrations of Phytoncide (1.25, 2.5, 3.75, and 5%) into the monomer liquid. This modification resulted in a significant reduction in Candida albicans levels, as well as a decrease in biofilm thickness beneath the dentures [53].

Another approach explored the integration of food preservatives into PMMA, specifically sodium metabisulfite (0.5% w/w) and potassium sorbate (1.0% w/w). Studies revealed that these additives improved the antimicrobial performance of the material while maintaining biocompatibility without exhibiting cytotoxic effects [54].

Additionally, the potential of processing denture resins with probiotics has been examined to evaluate their antibacterial properties. *Lactobacillus rhamnosus* and *Lactobacillus casei* demonstrated antifungal activity against *Blastoconidia* and *C. albicans*, effectively inhibiting colony formation on the denture surface [55].

Another method involves incorporating natural antifungal agents such as chitosan, neem powder, and henna into denture resins [56, 57]. Clinical trials have confirmed the antimicrobial efficacy of cytosine against *Candida albicans* [58, 59].

Hamid *et al.* [60] edited heat-polymerized polymethyl methacrylate denture base material by introducing different concentrations of *Azadirachta indica* (AI) powder (0.5, 1, 1.5, 2, and 2.5 wt%). The results indicated that while surface roughness remained largely unaffected, material hardness decreased at a concentration of 2.5% AI. Furthermore, flexural strength and translucency exhibited a noticeable decline across all tested concentrations.

Venante *et al.* [61] explore an approach to preventing *Candida albicans* biofilm formation by applying a coating of Fibrin Biopolymer infused with antimicrobial agents, such as digluconate chlorhexidine or *Punica granatum* alcoholic extract, onto conventional heat-polymerized and pre-polymerized polymethyl methacrylate. Their findings suggest that this technique is an effective method for managing denture biofilm development.

Another proposed surface modification involves the application of cinnamon-laden nanofibers to the denture base material. Research indicates that incorporating 20 wt.% of these nanofibers onto PMMA surfaces significantly inhibits *C. albicans* adhesion and growth. However, increasing the concentration beyond 20 wt.% may introduce cytotoxic effects on epithelial cells, with a 40 wt.% concentration leading to elevated cell death rates [62].

Overall, the impact of incorporating natural ingredients into denture resins is largely dependent on concentration levels. While they can enhance antimicrobial properties, excessive amounts may negatively affect material characteristics, including increased surface roughness, potential cytotoxicity, and alterations in color [57, 63, 64].

Rather than serving as a preventive measure, modifying PMMA with antimicrobial medications is primarily explored as a treatment approach for denture stomatitis. The inclusion of agents such as chlorhexidine diacetate or nystatin at their minimum inhibitory concentrations in denture reline materials has been identified as a potential therapeutic strategy [65, 66]. Among these, chlorhexidine has demonstrated the most effective results in managing the condition [67, 68]. This method is particularly beneficial in cases where patients have underlying health issues that compromise immune function.

Recent investigations have also focused on enhancing denture base materials by incorporating the protein-repellent agent 2-methacryloyloxyethyl phosphorylcholine (MPC), either alone or in combination with dimethylaminohexadecyl methacrylate [69, 70]. These biomaterials exhibit notable antifungal properties while maintaining the material's surface texture. However, one limitation observed is a reduction in flexural strength following their incorporation.

Denture stomatitis remains the most common oral condition affecting elderly individuals who wear removable dentures. With the global rise in the number of patients using complete dentures and the highest incidence of denture stomatitis, the development of effective preventative measures for this condition has become an issue of significant social importance [4].

A review of the dental literature reveals a wide range of innovative modifications to denture base materials that possess antimicrobial properties. For successful prevention of denture stomatitis, dental practitioners must make informed decisions regarding the selection of denture base materials. These decisions should be based on a thorough understanding of the material's mechanical properties and clinical behavior.

Extensive research is focused on enhancing the antimicrobial and mechanical characteristics of denture base materials through different modifying agents [24-42, 44, 45]. Despite these efforts, there remains no consensus on which materials are most effective at preventing denture stomatitis.

Among the most studied modifications are those incorporating nanoparticles [25-34, 36, 38-42]. The majority of research on these materials focuses on their antimicrobial effects, particularly against *Candida albicans*, the primary pathogen responsible for denture stomatitis. However, fewer studies examine the efficacy of modified denture materials against bacterial pathogens or a broader spectrum of microorganisms [21, 48, 49].

Discussion

At present, it is not possible to definitively determine that edited materials could be most effective in preventing oral infections. However, the materials modified with silver nanoparticles appear to show the most promise, given their direct effects on the cells of the primary pathogen involved in denture stomatitis, *C. albicans* [22, 26, 27]. Moreover, most studies have demonstrated that these modifications also enhance the material's mechanical properties. Nonetheless, further comparative studies are needed to evaluate the antimicrobial efficacy of materials edited with other agents.

The key benefits of these modifications include improvements in the surface characteristics of the material, such as increased final hardness and reduced porosity, which in turn help to minimize microbial adhesion on the denture surface [58]. Additionally, easier polishing and maintenance of higher hygiene standards have been observed. Despite these advantages, the results concerning the mechanical properties of modified materials are not consistent [24, 39, 40]. Several studies have indicated that some editing agents may negatively impact certain mechanical properties. For instance, a reduction in flexural strength could undermine the material's ability to withstand the masticatory forces, potentially leading to more frequent fractures of the dentures [30, 31].

Another drawback of editing agents, such as silver nanoparticles and SiO2 nanoparticles, is their impact on the color of denture materials [30, 41]. Changes in the color properties of denture base materials could affect the aesthetic outcome of denture treatments. Many studies have highlighted the trade-off between the concentration of editing agents, where higher concentrations enhance the antimicrobial effectiveness but also result in negative changes to some mechanical and optical properties [30, 41, 60]. While increasing the concentration of these agents provides better protection against denture stomatitis, it simultaneously compromises certain material characteristics, particularly color. Some research also indicates potential harm to epithelial cells when high concentrations of natural modifying agents are used [62]. Therefore, it is recommended that modifying agents be applied at the lowest effective concentrations. However, this raises the question that the antimicrobial effect of these modified materials, at lower concentrations, will be sufficient to ensure long-term prevention of denture stomatitis. More research is needed to determine the optimal balance between modifying agent concentration, antimicrobial effectiveness, and material biocompatibility. Additionally, it remains unclear whether these modified materials maintain their antibacterial properties over time. One study has evaluated the impact of artificial aging on the antifungal activity of edited denture base material [38], but there is insufficient research on the effects of cleaning agents and disinfection procedures on the antimicrobial properties of modified materials.

Most studies have been conducted under laboratory conditions, which do not provide insight into how the materials perform in real-life conditions inside the patient's mouth. Clinical trials are limited, and factors such as differences in saliva pH, exposure to medications, and contact with food and drink have not been adequately explored concerning their impact on the antimicrobial properties of these materials. Furthermore, it remains unclear whether the antimicrobial properties of modified materials would be effective enough to prevent denture stomatitis in patients with compromised health, such as those with diabetes or immunodeficiency, who are more susceptible to oral infections.

Conclusion

In this study, we have developed a range of modified denture base materials that exhibit antimicrobial properties, which are essential for being part of modern approaches to preventing denture stomatitis. However, before these materials can be seamlessly adopted into routine dental practice, several key issues regarding their behavior in clinical settings still need to be addressed. The long-term durability of their antimicrobial effects, particularly when exposed to various oral cavity conditions, hygiene practices, patient health status, and medication use, remains unclear. Therefore, further clinical research, including comparative studies, is necessary to evaluate the effectiveness of these materials in real-world conditions, taking into account the influence of both systemic and local factors.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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