Dynamics of Microbial Plaque Formation on Dentures

Subjects: Microbiology

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Whichever polymer is used in the composition of the prosthetic base (poly methyl methacrylate acrylic (PMMA), polyamide (PA), or polyether ether ketone (PEEK)), the simple presence of a removable prosthesis in the oral cavity can disturb the balance of the oral microbiota. This phenomenon is aggravated by poor oral hygiene, resulting in an increased microbial load coupled with the reduced salivation that is associated with older patients. In 15–70% of patients, this imbalance leads to the appearance of inflammation under the prosthesis (denture stomatitis, DS). DS is dependent on the equilibrium—as well as on the reciprocal, fragile, and constantly dynamic conditions—between the host and the microbiome in the oral cavity. Several local and general parameters contribute to this balance. Locally, the formation of microbial plaque on dentures (DMP) depends on the phenomena of adhesion, aggregation, and accumulation of microorganisms. To limit DMP, apart from oral and lifestyle hygiene, the prosthesis must be polished and regularly immersed in a disinfectant bath. It can also be covered with an insulating coating. In the long term, relining and maintenance of the prosthesis must also be established to control microbial proliferation. On the other hand, several general conditions specific to the host (aging; heredity; allergies; diseases such as diabetes mellitus or cardiovascular, respiratory, or digestive diseases; and immunodeficiencies) can make the management of DS difficult.

Candida spp.   dental plaque biofilm   denture management   denture hygiene

denture stomatitis   microbiome   systemic

1. Introduction

A removable prosthesis residing in the oral cavity exposes the existing planktonic microbiota (bacteria, archaea, viruses, and eukaryotic organisms) to stress [1][2][3]. These conditions are favorable for the growth of DMP [4][5][6]. Quantitatively, this biofilm is defined as a community of more than 10^{11} microorganisms per gram of dry weight [7][8], attached to the extrados and intrados of the surface of the prosthesis and sur-rounded by an extracellular matrix (ECM) produced by the bacteria and *Candida* themselves [9][10]. This matrix, composed of macromolecules such as exopolysaccharides, proteins, and DNA [11], provides structural integrity to the biofilm and offers a physical barrier that may be impenetrable to drugs.

In contact between the soft tissues, living tissue and the inert polymer provide another favorable environment in the oral cavity for microbial colonization [12][13][14]. At the level of the intrados, this decreased space leads to a reduction

in oxygenation, salivary flow, and pH, which promotes the activity of secreted aspartyl proteinases (SAPs) in the matrix. This environment plays a central role in the pathogenicity of *Candida* [15][16][17].

The maturation of the *C. albicans* biofilm proceeds according to the same steps but more slowly than the bacterial biofilm. The presence of hyphae and pseudohyphae is the main difference between the two biofilms. Recent targeted studies have explained the initial adhesion to the prosthetic surface, the subsequent development of mature biofilms [18], the formation of the extracellular matrix, and finally, the dispersal mechanism [19][20][21] (**Figure 1**).
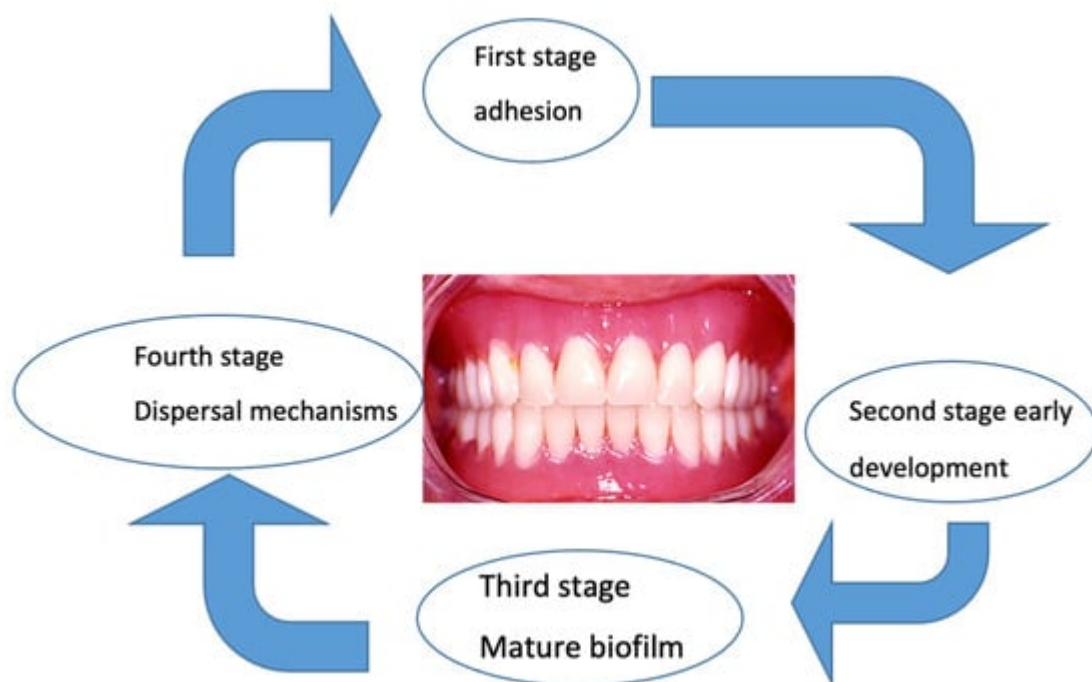

Figure 1. Biofilm envelops the denture in distinct stages. In the transition from the planktonic, free-floating state to the sessile state, attached microorganisms begin radically changing their gene and protein expression profiles.

Up to three quarters of patients who wear removable prostheses can develop an inflammation called "denture stomatitis" (DS). This pathology is characterized by an imbalance of the microbial flora or dysbiosis, resulting simultaneously in an abundance of opportunistic pathogens such as *C. albicans* [22][23], the differential proliferation of certain bacterial species determined using culture and next-generation sequencing (NGS) [24][25][26][27][28][29][30][31][32], and a decrease in microbial diversity [25][26][27].

Dental surgeons aware of the risk posed by this infectious condition to vulnerable patients should regularly check the oral health of users of removable prostheses [33]. For this, although DMP cannot be totally eradicated, it can be controlled through oral hygiene practices that include a daily regimen of brushing the mucous membrane and the denture, followed by rinsing with an antiseptic mouthwash [34][35][36]. Maintaining a healthy state helps to avoid the transition from a harmless commensal to a pathogen.

Several current precautions and methods make it possible to limit the drift of the oral microbiota toward dysbiosis in wearers of removable prostheses.

2. Polymers in the Oral Environment

Once it is introduced in the mouth, a denture is rapidly coated by saliva and constitutes the ideal platform for dynamic microbial growth of DMP [37][38][39]. These biofilms represent a wide range of microorganisms, comprising all three domains of life. Their proximity to the denture polymer offers numerous possibilities for physical and chemical interactions between different species and kingdoms (Delaney, C.; 2019) [40]. On the other hand, the interaction between the prosthetic base and the biofilm on the surface of the oral mucosa can favor the release of potentially toxic substances from the polymer that in turn interact with the host tissues [41].

Biofilm development under an acrylic denture increases the risk of DS fivefold com-pared with a metallic denture [42]. Another drawback associated with poor denture hygiene is bad breath, which can be the cause of patient discomfort [43]. These bad odors are related to the microbial plaque of the denture [44]. Studies using new technologies (next-generation sequencing, NGS) in the field of bacterial identification highlighted the emergence of the phyla Firmicutes and Fusobacteria and the genera Leptotrichia, Atpobium, Megasphaera, Oribacterium, and Campylobacter as being associated with the bad smell of prostheses. Here, good oral hygiene is essential to combat bad odors [45].

In DS, lack of or ineffective brushing in the absence of a cleanser promotes the rapid growth of biofilm on the surface of prostheses [46][47]. Clinically, the selection of polymer used for the prosthetic base must consider the adhesion of microorganisms. This colonization promotes the penetration of the microbiota and reduces the fracture resistance of prostheses [48].

2.1. Polymer and Microbial Adhesion

A roughness (Ra) promotes adhesion and bacterio-fungal aggregation on acrylic resins [49]. However, some authors point out that the initial colonization does not differ in accordance with the range of dental materials [50][51]. In the same way, research has not highlighted a link between the roughness of the surface, the hydrophobicity/hydrophilicity of the acrylic resin, and the metabolic activity of adherent *C. albicans* cells [52]. Aggregation of *C. albicans* with other microorganisms and the influence of saliva, through its antimicrobial power, flow, and composition, seem to dominate the conditions of adhesion to the surface of a prosthesis (roughness and SFE) [53]. For other authors, *Candida* adhesion was strongly affected by Ra, saliva, and bacteria, but not by SFE [49]. Despite this discrepancy, the results suggest that a reduction in the *C. albicans* biofilm may be related to modifications of the surface of the PMMA thanks to the coating. The coating promotes hydrophilicity and in addition to the influence of roughness [54]. In addition, the DMP is subject to various mechanical constraints such as food tenacity, temperature fluctuations, chewing forces, and the load of the prosthetic device [27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][48][49][50][51][52][53][54][55][56]. Microbial adhesion has been studied in relation to PMMA, in particular, and much less so in relation to PA and PEEK.

2.2. PMMA and Adhesion

PMMA is naturally hydrophobic [57] Gad MM, 2022, but this material, which is used in the composition of dentures, contains many carboxylate and methyl ester groups. This chemical composition, on the one hand, accounts for the hydrophilic nature of the dentures and, on the other hand, produces a large amount of SFE. In vitro, the adhesion of Pseudomonas fluorescens proved to be favorable to hydrophobic surfaces, with the lowest adhesion threshold for a roughness of 0.4 μm. Although the weakest adhesion of mammalian cells occurred at a roughness of 0.1 μm, the latter was favored in the presence of hydrophilic surfaces (PMMA) Choi SY, 2016 [58]. However, the variations in the chemical composition of the material used for the denture base partly explain the disparity in characteristics between the different brands of PMMA on the market Sipahi, 2001 [59]. Compared to the traditional fabrication method, acrylic resin injection offers a reduction in the surface roughness of the prosthesis base as well as decreased bacterial adhesion [60] Moslehifard E, 2022.

2.3. Polyamide and Adhesion

Analysis of the adhesion of microorganisms, in particular, yeasts, to PA remains very limited. Nevertheless, an experiment conducted on the effect of a prosthetic cleanser on the formation of a mycofilm on a PA resin (Flexite MP) and a polymethyl methacrylic resin (Acron MC) showed that C. albicans had a significantly higher growth rate on PA than on PMMA de Freitas Fernandes FS [61].

As a crystalline polymer, PA has better biocompatibility for patients who are allergic to acrylic resins. But over time, PA has significant disadvantages, displaying high water absorption, increased solubility, an overly rough surface, and bacterial contamination. In addition, this material remains difficult to polish and may result in color deterioration in the mouth Vojdani, 2015 [62]. Higher microbial adhesion was recently observed on injection-molded PA than PMMA [63] Sultana, 2023.

In order to remedy this, minimal changes in the injection manufacturing protocol of two PA prosthetic base materials were tested in vitro (Perflex Biosens (BS), Netanya, Israel and VertexTM ThermoSens (TS), Soesterberg, The Netherlands. By slightly modifying the melting temperature (5 °C) and pressure (0.5 bar), no improvement in the surface finish was observed for Biosens, whereas for ThermoSens, the surface roughness was significantly reduced Chuchulska, 2022 [64].

2.4. PEEK and Adhesion

As early as 2007, Kurtz et al. emphasized the non-allergenic properties of PEEK and its low affinity for dental plaque. PEEK is considered hydrophobic and has a low SFE. As a result, C. albicans adhesion is facilitated [65][66]. This was compared to the formation of biofilm on the surface of different materials in vitro (zirconia, titanium, PMMA, and PEEK). In their study, PEEK and PMMA yielded the same results but were linked to less biofilm formation than zirconia and titanium. However, the surface condition of PEEK was smoother than that of zirconia and titanium [67]. It has been reported that PEEK has good biocompatibility in vitro and in vivo, causing neither toxic nor mutagenic effects nor clinically significant inflammation. In addition, PEEK lends itself to sufficiently effective

polishing so as to delay the fixing of microbial plaque [68]. PEEK without any additives is biologically inert and naturally hydrophobic when in contact with saliva. The 80°–90° contact angle of saliva can be reduced by adding plasma coatings, which are effective methods for modifying surface properties [69] to improve the hydrophilicity [67].

When comparing PEEK with other computer-aided design/computer-aided manufacturing (CAD/CAM) materials, PEEK samples are slightly rougher than PMMA samples. The reason is linked to the ceramic particles that are added to PEEK [70].

2.5. Polymer and Accumulation of DMP

After the adhesion of the first colonizers on the denture surface, to preventively limit the accumulation of microorganisms, and particularly of *Candida* and bacteria populations, several parameters can be modified to facilitate the optimization of the manufacture of polymers. The incorporation of antifungal agents into denture base resin may reduce the colonization of *C. albicans* [71]. There are few data on PAs and PEEKs, whereas PMMAs, in contrast, have been the subject of numerous experiments.

For example, nanoparticles (such as fluoridated apatite-coated titanium dioxide, FAp-TiO$_2$) in PMMA facilitate the production of reactive oxygen species by promoting the photocatalytic effect after irradiation, which neutralizes the attachment of *C. albicans.* This effect is sought to facilitate the maintenance of removable prostheses in geriatric patients [72]. The incorporation of bioactive glass (BAG) in thermopolymerized or polymerized acrylic resins at room temperature significantly lowers the adhesion of *C. albicans.* For both types of polymerization, the hardness of acrylic resins is improved by adding BAG [69].

Another parameter can be modified to promote hydrophilicity to limit the adhesion of *C. albicans* on an acrylic resin denture with photopolymerized coating [73]: Plasma treatment of PMMA on the surface increases SFE, facilitates wettability, and lowers the contact angle, all of which reduce the adhesion of *C. albicans* [74][75]. In contrast, trimethylsilane coating increases hydrophobicity, reduces wettability of the denture base surface, and inhibits the adhesion of *C. albicans* [76]. The TiO2 coating creates a super-hydrophilic surface. It thus promotes wettability, which is essential for reducing *Candida* adhesion. The implementation of the PMMA surface coating involves only moderate costs while preserving the properties of the original material [77][78]. Recently, to assess the effectiveness and the antibacterial properties of a silver nanoparticle (NAg), a solution of NAg mixed with acrylic acid and methyl methacrylate (MMA) monomer was tested (in vitro and in vivo on animals) and compared with a PMMA solution without NAg. The results concerning the state of the prosthetic surface, the mechanical properties, the antimicrobial effect of NAg, the longevity, and the biological and toxic harmlessness of the NAg/PMMA prosthesis base were superior to the PMMA base without NAg. However, clinical confirmation must be provided by studies with humans [69][79][80][81][82][83][84][85].

2.6. Polishing to Limit Microbial Adhesion

The adhesion of early microbial colonizers is closely related to the finish of the denture surface. This adhesion during the initial phase of microbial colonization on flexible prostheses is similar to that of acrylic resin prostheses.

This result was confirmed by a laboratory study showing that acrylic resin and PA resin are easily colonized by *Candida* species. However, the growth rate of this fungus is significantly higher on PA resin than on PMMA ($p <$ 0.001) [86].

Different tests of the surface condition of the material (polishing) have shown that the polishing method alone (wood sandpaper: grit 180) is essential in terms of roughness compared with the drying method of self-curing acrylic resin. Moreover, chemical polishing (at 70 °C for 10 s) aggravates the roughness [87][88]. Regarding PMMA resin, the residual monomer acts on the SFE by reducing adhesion and *Candida* growth [61]. For PA resin (Breflex polyamide, Bredent, GmbH Co. KG, Senden, Germany) fabricated using the injection-molding technique, no significant correlation was observed in contact angles for mechanical polishing versus chemical polishing. This difference was related to the specific physical properties of the materials used [89].

The design and manufacture of CAD/CAM prostheses machined from blocks of polymerized PMMA under high temperature and high pressure led to a smoother surface finish than PMMA-HC based on CAD/CAM prostheses [90]. As a result, for patients at risk of *Candida* fungal infection, the surface properties of CAD/CAM PMMA represent a possibility of reduced adhesion of this fungus.

Quezada (2022) [91] and Corsalini (2009) [92], using the same in vitro mechanized and manual polishing methods, attempted to standardize a polishing protocol. However, since contradictory results were reported, with one favoring the manual method and the other the mechanized method, new investigations have to be carried out.

An explanation for the contradictory results is offered by previous research. The structure of PMMA directly after polymerization had a low initial roughness, and subsequent polishing made it easy to reach clinically acceptable values. On the other hand, PAs were more difficult to polish due to their fibrous semi-flexible structure and low surface hardness [93]. Although PEEK and PMMA have similar values of Vickers hardness, the composition and the state of the surface roughness differed between the two materials [94]. Therefore, surface polishing that is specific to the two materials is required.

Thus, regarding the polishing of PEEK, Kurahashi et al. (2020) [95] suggest the use of a soft brush coupled with a cleaning agent for more than 3 min to achieve clinically acceptable surface roughness.

Heimer et al. [79] compared the effects of laboratory and chairside polishing methods on the surface roughness of PEEK and reported that chairside polishing of PEEK yielded lower surface/laboratory roughness values.

Fused deposition modeling of PEEK is one of the most practical additive techniques; compared to other polymers, PEEK remains stable over the long term regarding its wear and color [96][97]. The biocompatibility and biostability of PEEK are supported by the U.S. FDA drug and device master files [98]. Another way to limit the initial adhesion of microorganisms and particularly of *C. albicans* on the prosthetic surface is to use a coating.

2.7. Denture Base Surface Coating to Limit Adhesion

Among the types of coatings available, cold plasma under heat-polymerized acrylic resin prevents the early adherence of *C. albicans* [99]. Another goal for coating the polymer (PMMA) with creamers is to enhance the resistance of the denture base surface. Indeed, coating creamers (inorganic–organic hybrid polymeric) enhance the scratch resistance of PMMA denture resin (increasing the flexural strength (FS), flexural modulus (FM), and hardness) [100][101]. To date, in view of the diverse results of experiments, no consensus has been reached on this topic. To fight against the adhesion of *Candida*, the surface of the denture base must be smooth, hydrophilic, and without roughness. Further investigations are needed to better understand the correlation between factors affecting the hydrophobicity of the denture base and the adhesion of *C. albicans.*

2.8. Effects of Cleaning on Denture Materials

Currently, the use of a prosthesis cleanliness index makes it possible to assess the hygiene of prostheses by visualizing the quantity of stains on the intrados of the denture. Rinsing beforehand eliminates invisible microbial plaque. The scores, ranging from 0 (best) to 4 (worst), help to adapt the hygiene instructions for the wearers of dental prostheses [102].

The use of bleach-based cleansers, according to the recommended dosages (containing 1.5% or 2% *w/v* sodium hypochlorite and/or 1.7% *w/v* sodium hydroxide) and duration of use (at least 3 min daily), is associated with sufficient antimicrobial activity against *Streptococcus mutans* and *C. albicans*, without any changes to acrylic color, surface roughness, or mechanical properties [103][104]. However, in the long term, these cleansers corrode and tarnish metal prostheses. Effervescent cleansers have also proven their effectiveness, but they are not recommended in the presence of prosthesis relining materials.

Manual brushing with a toothbrush plus soap and water is the most common method for maintaining removable dentures (Milward P, 2013) [105]. Several adjuvants to increase the effectiveness of manual cleaning in the form of pastes, gels, foams, and powders are on the market [106].

The use of antiseptics to inhibit or eliminate microorganisms and immersion in a chemical solution for 8 h are recommended. Sodium hypochlorite, chlorhexidine diglconate, and alcohol can disinfect or reduce the dental plaque on acrylic resin dentures without being cytotoxic [33][35][36]. The different methods of cleaning dentures can influence the physical and aesthetic characteristics of the prosthesis materials. Also, in order to ensure the clinical durability of removable prostheses, patients and clinicians should be aware of the manufacturer's instructions for use [107].

Although there is no consensus regarding how to best maintain prosthetic hygiene compatible with the patient's state of health [108], the disadvantages of many procedures have been thoroughly evidenced [109].

Hydrogen peroxide-based disinfectants should not be used regularly, as they cause surface roughness of the PMMA. NaOCl is less aggressive and generates slight alterations on the surface of the prosthetic base [110]. In addition, sodium hypochlorite was found to be non-cytotoxic after six months of use [111].

Flexural strength is reduced by immersion cleaning of removable PMMA prostheses modified with nano-ZrO_2. Thus, a significant decrease in this resistance after immersion in different denture cleansers was reported, which was strong for sodium hypochlorite, intermediate for Corega, and low for Renew [110][112][113]. Several habits should be avoided, such as rinsing with boiling water and prolonged maintenance in a dry atmosphere or water, because these alter the qualities of PMMA and promote microbial colonization. Both bleach and isopropyl alcohol (IPA) are highly antimicrobial, but bleach is incompatible with components of metal dental prostheses and IPA mouthwashes damage PMMA [114].

Concerning denture cleaning tablets, the polarity of the resins, the concentrations of the tablets, and the chemical content of the cleanser may directly affect the formation of *C. albicans* biofilm [115]. Thus, the dosage and prescription of disinfecting tablets can vary depending on the resin used to make the prosthetic base. In tablet form, Polident® has been proven to be effective as a denture cleanser. But after 30 days of immersion in a solution based on Polident®, the heat-polymerized acrylic resin may undergo alterations to its physical and mechanical properties. This may be related to the accelerated aging of resins caused by chemicals found in denture cleansers [116].

The mechanical properties of PEEK do not change during the sterilization process. An in vitro study showed that the solubility of PEEK in physiological saliva and distilled water is lower than that of PMMA [94]. In the study by Demirci under the same conditions, the solubility values of PEEK in distilled water were found to be similar to those of PMMA (HP: Ivoclar Vivadent AG., Schaan, Liechtenstein). In the presence of a cleanser (Corega tablet, Protefix tablet (PT), 1% sodium hypochlorite (NaOCl)), the solubility values of PEEK were found to be lower than those of PMMA. In this study, higher water sorption and solubility values were observed than those obtained by Lieberman [94]. The explanation proposed mentions the consequences of the effects of cleansers on PEEK and PMMA surfaces for 120 days. Thus, for these authors, the water sorption and solubility values of PEEK can be attributed to the molecular imbalance occurring on the surface of the PEEK [117].

The use of microwave disinfection in combination with denture cleansers and brushing has also been shown to effectively disinfect dentures, although microwaves may also physically distort denture resin [118]. The personalized implementation of the currently available means for disinfection is informed by the general condition of the patient, the material composition of the prosthetic base, and the presence or absence of DS.

3. Denture Base Relining

After some time (following bone resorption), it is necessary to reline the intrados in order to improve the stability, support, and retention of removable dentures. There are several commonly used relining materials, such as cold or hot polymerization, polymerization in visible light, and acrylic resins polymerized in microwaves [119][120].

At the interface between the reliner and the prosthetic base, the bond strength depends on the chemical composition of the two materials that come into contact with each other [121]. The bonding strength can be improved by treating the two surfaces that are in contact with each other [121][122][123][124]. The parameter

characteristic of relining is the shear bond strength (SBS). This parameter is better for relining using thermosetting resin as well as both CAD/CAM and conventional thermosetting denture resin compared to self-curing relining resin [125][126]. An in vitro study showed that reliners with thermopolymerizable acrylic resins had an increased SBS compared to reliners with self-curing acrylic resins. This also applied to bases of conventional dental prostheses and CAD/CAM but without a significant difference. However, there was a significant difference between autopolymerizing acrylic resin bond strength with CAD/CAM and conventional denture bases.

Autopolymerizing reliner material seems to produce a stronger bond with CAD/CAM denture bases. It has been pointed out that self-curing relining material appears to produce a significantly stronger bond with a CAD/CAM denture base compared to a conventional resin base [126]. Recently, various in vitro tests of the adhesion of composite materials on thermosetting resins, on CAD/CAM, and on printed groups yielded the following results: In order of the best performance regarding the adhesion of high-viscosity/low-viscosity composites (SR Nexco, high viscosity (SR); and Kulzer Creactive, low viscosity (K)), the thermosetting resin group was first, followed by the CAD/CAM group, and finally the 3D-printed groups. However, the differences noted between these groups were not significant [127].

To assess the maintenance of rebased resin bases, five disinfectant solutions were tested: sodium hypochlorite, sodium perborate, chlorhexidine gluconate, apple vinegar, and distilled water. A prosthesis base (Vipi Wave) rebased with an acrylic resin (Tokuya-ma Rebase Fast II) after dipping showed alterations in its roughness regardless of the solution used [113][128]. Kim et al. tested relining using two hard resins, one of the self-hardening type (Tokuyama rebase II) and the other of the light-activated type (Mild Rebaron LC). They carried out these two relinings on a thermoplastic polyamide resin (Biotone; BT), on a classic thermopolymerizable acrylic resin (Paladent 20; PAL20), and, finally, on a thermoplastic acrylic resin (Acrytone; ACT). The results showed that the thermoplastic polyamide resin (Biotone) had the lowest adhesion strength of the three materials tested [129].

More recently, Vuksic Josip et al. (2023) [130] tested relining (with a soft denture liner and a silicone-based, direct relining method) on several resins: (1) Meliodent heat cure (Kulzer, Hanau, Germany), denture base material, PMMA, heat-cured; (2) Vertex Thermosens (Vetex Dental, Soesterberg, The Netherlands), denture base material, PA, technical injection; (3) three CAD/CAM subtractive materials; and (4) two CAD/CAM additive materials. With the same reliner (GC Reline II Soft), the bond strength of the PA (Vertex) and both additive manufactured denture bases was significantly lower than that of the three materials used for subtractive denture fabrication and heat-cured PMMA. However, the authors expressed their reservations because, to date, there are only a few studies available, mainly on flexible rebasing. The tests differ between these studies, and different materials were used as controls (PMMA from different manufacturers).

The bioinert nature of PEEK can make adhesive bonding difficult. The SBS of PEEK can be increased by roughening the material or by embedding molecules on the surface through sandblasting, acid treatment, laser, or adhesive systems.

SBS values greater than 10 MPa between PEEK and resin-based composites have been reported to be clinically acceptable. However, the hydrophobic surface and low SFE of PEEK make it difficult to establish a strong and long-lasting bond. Therefore, PEEK material surface treatments and adhesive systems with resin are hot research topics focused on the application of PEEK in the restorative field. Modalities concerning the effectiveness of bonding to the surface of PEEK are not yet sufficiently developed for routine use.

4. General Conditions and Dentures

Whichever material is chosen, after adhesion, inadequate oral hygiene facilitates the accumulation of biofilm, colonizing the surface of the prosthesis. This biofilm can constitute a risk factor for infection, especially for patients who are older or who are immuno-compromised and/or have endocrine deficiency [131]. For these patients, special vigilance is necessary regarding prosthetic oral hygiene in order to avoid infectious complications.

Indeed, this additional microbial load can lead to an imbalance between bacterial species, bacteriophages, and fungi, thus promoting the resistance and virulence of mycofilms to the detriment of the host. The secretions of bacteria and fungi, by participating in the aggression of biotic surfaces (mucous membranes and teeth), promote the production of various inflammatory mediators such as cytokines [132]. The use of removable prostheses in these conditions after a certain period of time promotes bone resorption.

Some older denture wearers have medical conditions such as arthritis and dementia that can impair their ability to carry out oral hygiene procedures effectively, thus requiring assistance from caretakers and some education [133]. Specific treatments are available if a *Candida* infection is suspected [134], with accompanying denture disinfection/cleaning or replacement [135]. Other conditions such as Parkinson's disease can lead to dentures falling out of patients' hands because of trembling. In these cases, thanks to its flexibility, the PA prosthesis makes it possible to overcome small bone and mucous undercuts. Crossing this undercut promotes retention. The prosthetic base made of PA, due to its high resilience and impact resistance, is less prone to fractures than PMMA [136].

For patients who are hypoallergenic to prosthetic materials, different alternatives exist. Whether PMMA, PEEK, or PA, the polymerization reaction releases more or fewer toxic molecules. By dissolving in the saliva, these molecules can diffuse away from the mouth [137][138]. These are essentially, after the polymerization, the residual monomers (MMA, methyl methacrylate; BuMA, butyl methacrylate; EMA, ethyl methacrylate; EGDMA, ethylene glycol dimethacrylate) that are responsible for the toxic and allergenic effects of acrylates [139].

This residual monomer depends both on the method of polymerization (duration, cold or heat) and on the volume of the prosthetic base; it only becomes stable after 2 weeks of wearing the dentures. It is low for thermopolymerized resins and at the palatal level of the thin prosthetic base [135].

Moreover, the acidic environment and the temperature of the oral cavity promote the release of substances contained in resins such as formaldehydes, benzoyl peroxides, benzoic acid, hydroquinone, and phthalates, as

well as cobalt, nickel, and beryllium. With respect to the mucous membrane, these products can cause type IV allergic reactions, or an intolerance can appear in the long term [140].

As a remedy, so-called hypoallergenic resins for dental prostheses have appeared on the market. To be suitable for hypoallergenic patients, the denture base resins should contain only a very small amount of MMA [141].

MMA can be replaced by diurethane dimethacrylate, polyurethane, polyethylene terephthalate, polyethylene terephthalate, or polybutylene terephthalate. However, only two of these have similar mechanical characteristics to PMMA resin standards: Polyan Plus® and TMS Acetal Dental [140].

The in vitro comparison between PMMA and PA regarding cytotoxicity has not revealed any obvious differences. Findings remain disparate about the materials studied and the protocols used. The results vary depending on the duration of the experiments and on the different parameters analyzed, such as temperature and surface condition supplement II. For patients with low stress tolerance and sensitivity to metallic materials, PEEK is indicated for partial removable prostheses. PA bases are also an alternative for patients who are allergic to other denture base materials and for patients with microstomia [142].

References

1. Hao, Y.; Huang, X.; Zhou, X.; Li, M.; Ren, B.; Peng, X.; Cheng, L. Influence of dental prosthesis and restorative materials interface on oral biofilms. Int. J. Mol. Sci. 2018, 19, 3157.

2. Sachdeo, A.; Haffajee, A.D.; Socransky, S.S. Biofilms in the edentulous oral cavity. J. Prosthodont. 2008, 17, 348–356.

3. Sang, T.; Ye, Z.; Fischer, N.G.; Skoe, P.E.; Echeverría, C.; Wu, J.; Aparicio, C. Physical-chemical interactions between dental materials surface, salivary pellicle and Streptococcus gordonii. Colloids Surf. B 2020, 190, 110938.

4. Mitchell, K.F.; Zarnowski, R.; Sanchez, H.; Edward, J.A.; Reinicke, E.L.; Nett, J.E.; Mitchell, A.P.; Andes, D.R. Community participation in biofilm matrix assembly and function. Proc. Natl. Acad. Sci. USA 2015, 112, 4092–4097.

5. Ercalik-Yalcinkaya, S.; Ozcan, M. Association between oral mucosal lesions and hygiene habits in a population of removable prosthesis wearers. J. Prosthodont. 2015, 24, 271–278.

6. Latib, Y.O.; Owen, C.P.; Patel, M. Viability of Candida albicans in denture base resin after disinfection: A preliminary study. Int. J. Prosthodont. 2018, 31, 436–439.

7. Cruz, P.C.; Andrare, I.M.; Peracini, A.; Souza-Gugelmin, M.C.M.; Silva-Lovato, C.H.; de Souza, R.F.; Paranhos, H.d.F.O. The effectiveness of chemical denture cleansers and ultrasonic device in biofilm removal from complete dentures. J. Appl. Oral Sci. 2011, 19, 668–673.

8. Axe, A.S.; Varghese, R.; Bosma, M.; Kitson, N.; Bradshaw, D.J. Dental health professional recommendation and consumer habits in denture cleansing. J. Prosthet. Dent. 2016, 115, 183–188.

9. Abaci, Ö. Investigation of extracellular phospholipase and proteinase activities of Candida species isolated from individual's denture wearers and genotypic distribution of Candida albicans strains. Curr. Microbiol. 2011, 62, 1308–1314.

10. Zarnowski, R.; Westler, W.M.; Lacmbouh, G.A.; Marita, J.M.; Bothe, J.R.; Bernhardt, J.; Lounes-Hadj Sahraoui, A.; Fontaine, J.; Sanchez, H.; Hatfield, R.D.; et al. Novel entries in a fungal biofilm matrix encyclopedia. mBio 2014, 5, e01333-14.

11. Kavanaugh, J.S.; Flack, C.E.; Lister, J.; Ricker, E.B.; Ibberson, C.B.; Jenul, C.; Moormeier, D.E.; Delmain, E.A.; Bayles, K.W.; Horswill, A.R. Identification of extracellular DNA-binding proteins in the biofilm matrix. mBio 2019, 10, e01137-19.

12. Cahn, L.R. The Denture sore mouth. Ann. Dent. 1936, 3, 33–36.

13. Koopmans, A.S.; Kippuw, N.; de Graaff, J. Bacterial involvement in denture-induced stomatitis. J. Dent. Res. 1988, 67, 1246–1250.

14. Campos, M.S.; Marchini, L.; Bernardes, L.A.; Paulino, L.C.; Nobrega, F.G. Biofilm microbial communities of denture stomatitis. Oral Microbiol. Immunol. 2008, 23, 419–424.

15. Salerno, C.; Pascale, M.; Contaldo, M.; Esposito, V.; Busciolano, M.; Milillo, L.; Guida, A.; Petruzzi, M.; Serpico, R. Candida-associated denture stomatitis. Med. Oral Patol. Oral Cir. Bucal 2011, 16, e139–e143.

16. Schaller, M.; Borelli, C.; Korting, H.C.; Hube, B. Hydrolytic enzymes as virulence factors of Candida albicans. Mycoses 2005, 48, 365–377.

17. Cavalcanti, Y.W.; Wilson, M.; Lewis, M.; Williams, D.; Senna, P.M.; Del-Bel-Cury, A.A.; Silva, W.J. Salivary pellicles equalize surfaces' charges and modulate the virulence of Candida albicans biofilm. Arch. Oral Biol. 2016, 6, 129–140.

18. Rickard, A.H.; Gilbert, P.; High, N.J.; Kolenbrander, P.E.; Handley, P.S. Bacterial coaggregation: An integral process in the development of multi-species biofilms. Trends Microbiol. 2003, 11, 94–100.

19. Ruhl, S.; Eidt, A.; Melzl, H.; Reischl, U.; Cisar, J.O. Probing of microbial biofilm communities for coadhesion partners. Appl. Environ. Microbiol. 2014, 80, 6583–6590.

20. Fox, E.P.; Bui, C.K.; Nett, J.E.; Hartooni, N.; Mui, M.C.; Andes, D.R.; Nobile, C.J.; Johnson, A.D. An expanded regulatory network temporally controls Candida albicans biofilm formation. Mol. Microbiol. 2015, 96, 1226–1239.

21. Li, P.; Seneviratne, C.J.; Alpi, E.; Vizcaino, J.A.; Jin, L. Delicate metabolic control and coordinated stress response critically determine antifungal tolerance of Candida albicans biofilm persisters. Antimicrob. Agents Chemother. 2015, 59, 6101–6112.

22. Santana, I.L.; Gonçalves, L.M.; de Vasconcellos, A.A.; da Silva, W.J.; Cury, J.A.; Cury, A.A.D.B. Dietary carbohydrates modulate Candida albicans biofilm development on the denture surface. PLoS ONE 2013, 8, e64645.

23. Arendorf, T.M.; Walker, D.M. The prevalence and intra-oral distribution of Candida albicans in man. Arch. Oral Biol. 1980, 25, 1–10.

24. Morse, D.J.; Smith, A.; Wilson, M.J.; Marsh, L.; White, L.; Posso, R.; Bradshaw, D.J.; Wei, X.; Lewis, M.A.O.; Williams, D.W. Molecular community profiling of the bacterial microbiota associated with denture-related stomatitis. Sci. Rep. 2019, 9, 10228.

25. O'Donnell, L.E.; Robertson, D.; Nile, C.J.; Cross, L.J.; Riggio, M.; Sherriff, A.; Bradshaw, D.; Lambert, M.; Malcolm, J.; Buijs, M.J.; et al. The oral microbiome of denture wearers is influenced by levels of natural dentition. PLoS ONE 2015, 10, e0137717.

26. Teles, F.R.; Teles, R.P.; Sachdeo, A.; Uzel, N.G.; Song, X.Q.; Torresyap, G.; Singh, M.; Papas, A.; Haffajee, A.; Socransky, S. Comparison of microbial changes in early redeveloping biofilms on natural teeth and dentures. J. Periodontol. 2012, 83, 1139–1148.

27. Murugesan, S.; Al Ahmad, S.F.; Singh, P.; Saadaoui, M.; Kumar, M.; Al Khodor, S. Profiling the salivary microbiome of the Qatari population. J. Transl. Med. 2020, 18, 127.

28. Perić, M.; Živković, R.; Milić Lemić, A.; Radunović, M.; Miličić, B.; Arsenijević, V.A. The severity of denture stomatitis as related to risk factors and different Candida spp. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. 2018, 126, 41–47.

29. Vila, T.; Sultan, A.S.; Montelongo-Jauregui, D.; Jabra-Rizk, M.A. Oral Candidiasis: A disease of opportunity. J. Fungi 2020, 6, 15.

30. Steele, J.G.; Treasure, E.T.; Fuller, E.; Morgan, M.Z. Complexity and maintenance—A report from the Adult Dental Health Survey. In Adult Dental Health Survey 2009—Northern Ireland Key Findings; O'Sullivan, I., Ed.; The Health and Social Care Information Centre: London, UK, 2011; pp. 7–9.

31. Theilade, E.; Budtz-Jørgensen, E.; Theilade, J. Predominant cultivable microflora of plaque on removable dentures in patients with healthy oral mucosa. Arch. Oral Biol. 1983, 28, 675–680.

32. Shi, B.; Wu, T.; McLean, J.; Edlund, A.; Young, Y.; He, X.; Lv, H.; Zhou, X.; Shi, W.; Li, H.; et al. The denture-associated oral microbiome in health and stomatitis. mSphere 2016, 1, e00215–e00216.

33. Lof, M.; Janus, M.; Krom, B. Metabolic interactions between bacteria and fungi in commensal oral biofilms. J. Fungi 2017, 3, 40.

34. Senpuku, H.; Sogame, A.; Inoshita, E.; Tsuha, Y.; Miyazaki, H.; Hanada, N. Systemic diseases in association with microbial species in oral biofilm from elderly requiring care. Gerontology 2003, 49, 301–309.

35. Yildirim-Bicer, A.Z.; Peker, I.; Akca, G.; Celik, I. In vitro antifungal evaluation of seven different disinfectants on acrylic resins. Biomed Res. Int. 2014, 2014, 519098.

36. Ardizzoni, A.; Pericolini, E.; Paulone, S.; Orsi, C.F.; Castagnoli, A.; Oliva, I.; Strozzi, E.; Blasi, E. In vitro effects of commercial mouthwashes on several virulence traits of Candida albicans, viridans streptococci and Enterococcus faecalis colonizing the oral cavity. PLoS ONE 2018, 13, e0207262.

37. Radford, D.R.; Challacombe, S.; Walter, J.D. Denture plaque and adherence of candida albicans to denture-base materials in vivo and in vitro. Crit. Rev. Oral Biol. Med. 1999, 10, 99–116.

38. Zheng, W.; Tsompana, M.; Ruscitto, A.; Sharma, A.; Genco, R.; Sun, Y.; Buck, M.J. An accurate and efficient experimental approach for characterization of the complex oral microbiota. Microbiome 2015, 3, 48.

39. Fujinami, W.; Nishikawa, K.; Ozawa, S.; Hasegawa, Y.; Takebe, J. Correlation between the relative abundance of oral bacteria and Candida albicans in denture and dental plaques. J. Oral Biosci. 2021, 63, 175–183.

40. Delaney, C.; O'Donnell, L.E.; Kean, R.; Sherry, L.; Brown, J.L.; Calvert, G.; Nile, C.J.; Cross, L.; Bradshaw, D.J.; Brandt, B.W.; et al. Interkingdom interactions on the denture surface: Implications for oral hygiene. Biofilm 2019, 1, 100002.

41. Kostic, M.; Pejcic, A.; Igic, M.; Gligorijević, N. Adverse reactions to denture resin materials. Eur. Rev. Med. Pharmacol. Sci. 2017, 21, 5298–5305.

42. Figueiral, M.H.; Azul, A.; Pinto, E.; Fonseca, P.A.; Branco, F.M.; Scully, C. Denture-related stomatitis: Identification of aetiological and predisposing factors? A large cohort. J. Oral Rehabil. 2007, 34, 448–455.

43. Coulthwaite, L.; Verran, J. Development of an in vitro denture plaque biofilm to model denture malodour. J. Breath Res. 2008, 2, 017004.

44. Yitzhaki, S.; Reshef, L.; Gophna, U.; Rosenberg, M.; Sterer, N. Microbiome associated with denture malodour. J. Breath Res. 2018, 12, 027103.

45. Garg, R.; Garg, R.K. Denture hygiene, different strategies. Webmed Cent. Dent. 2010, 10, WMC00932.

46. Rüttermann, S.; Trellenkamp, T.; Bergmann, N.; Raab, W.H.R.; Ritter, H.; Janda, R. A new approach to influence contact angle and surface free energy of resin-based dental restorative

materials. Acta Biomater. 2011, 7, 1160–1165.

47. Liber-Knéc, A.; Łagan, S. Surface Testing of Dental Biomaterial Determination of Contact Angle and Surface Free Energy. Materials 2021, 14, 2716.

48. Helal, M.A.; Fadl-Alah, A.; Baraka, Y.M.; Gad, M.M.; Emam, A.-N.M. In-vitro comparative evaluation for the surface properties and impact strength of CAD/CAM milled, 3D printed, and polyamide denture base resins. J. Int. Soc. Prev. Community Dent. 2022, 12, 126–131.

49. Pereira-Cenci, T.; Cury, A.A.D.B.; Cenci, M.S.; Rodrigues-Garcia, R.C.M. In vitro candida colonization on acrylic resins and denture liners: Influence of surface free energy, roughness, saliva, and adhering bacteria. Int. J. Prosthodont. 2007, 20, 308–310.

50. Olms, C.; Yahiaoui-Doktor, M.; Remmerbach, T.; Stingu, C. Bacterial colonization and tissue compatibility of denture base resins. Dent. J. 2018, 6, 20.

51. Mukai, Y.; Torii, M.; Urushibara, Y.; Kawai, T.; Takahashi, Y.; Maeda, N.; Ohkubo, C.; Ohshima, T. Analysis of plaque microbiota and salivary proteins adhering to dental materials. J. Oral Biosci. 2020, 62, 182–188.

52. de Foggi, C.C.; Machado, A.L.; Zamperini, C.A.; Fernandes, D.; Wady, A.F.; Vergani, C.E. Effect of surface roughness on the hydrophobicity of a denture-base acrylic resin and Candida albicans colonization. J. Investig. Clin. Dent. 2016, 7, 141–148.

53. Vila, T.; Rizk, A.M.; Sultan, A.S.; Jabra-Rizk, M.A. The power of saliva: Antimicrobial and beyond. PLoS Pathog. 2019, 15, 1008058.

54. Queiroz, J.R.C.; Fissmer, S.F.; Koga-Ito, C.Y.; Salvia, A.C.R.D.; Massi, M.; Sobrinho, A.S.d.S.; Júnior, L.N. Effect of diamond-like carbon thin film coated acrylic resin on candida albicans biofilm formation: Effect of dlc film on biofilm formation. J. Prosthodont. 2013, 22, 451–455.

55. Bajunaid, S.O.; Baras, B.H.; Weir, M.D.; Xu, H.H.K. Denture acrylic resin material with antibacterial and protein-repelling properties for the prevention of denture stomatitis. Polymers 2022, 14, 230.

56. Sarkar, A.; Kuehl, M.N.; Alman, A.C.; Burkhardt, B.R. Linking the oral microbiome and salivary cytokine abundance to circadian oscillations. Sci. Rep. 2021, 11, 2658.

57. Gad, M.M.; Abualsaud, R.; Khan, S.Q. Hydrophobicity of denture base resins: A systematic review and meta-analysis. J. Int. Soc. Prev. Community Dent. 2022, 12, 139–159.

58. Choi, S.Y.; Habimana, O.; Flood, P.; Reynaud, E.G.; Rodriguez, B.J.; Zhang, N.; Casey, E.; Gilchrist, M.D. Material-and feature-dependent effects on cell adhesion to micro injection moulded medical polymers. Colloids Surf. B Biointerfaces 2016, 145, 46–54.

59. Sipahi, C.; Anil, N.; Bayramli, E. The effect of acquired salivary pellicle on the surface free energy and wettability of different denture base materials. J. Dent. 2001, 29, 197–204.

60. Moslehifard, E.; Ghaffari, T.; Abolghasemi, H.; Maleki Dizaj, S. Comparison of conventional pressure-packed and injection molding processing methods for an acrylic resin denture based on microhardness, surface roughness, and water sorption. Int. J. Dent. 2022, 2022, 7069507.

61. de Freitas Fernandes, F.S.; Pereira-Cenci, T.; da Silva, W.J.; Filho, A.P.R.; Straioto, F.G.; Del Bel Cury, A.A. Efficacy of denture cleansers on candida spp. biofilm formed on polyamide and polymethyl methacrylate resins. J. Prosthet. Dent. 2011, 105, 51–58.

62. Vojdani, M.; Giti, R. Polyamide as a denture base material: A literature review. J. Dent. 2015, 16, 1–9.

63. Sultana, N.; Ahmed, S.; Nandini, V.V.; Lathief, J.; Boruah, S. An in vitro comparison of microbial adhesion on three different denture base materials and its relation to surface roughness. Cureus 2023, 15, e37085.

64. Chuchulska, B.; Hristov, I.; Dochev, B.; Raychev, R. Changes in the surface texture of thermoplastic (monomer-free) dental materials due to some minor alterations in the laboratory protocol—Preliminary study. Materials 2022, 15, 6633.

65. da Rocha, L.G.D.O.; Ribeiro, V.S.T.; de Andrade, A.P.; Gonçalves, G.A.; Kraft, L.; Cieslinski, J.; Suss, P.H.; Tuon, F.F. Evaluation of staphylococcus aureus and candida albicans biofilms adherence to peek and titanium-alloy prosthetic spine devices. Eur. J. Orthop. Surg. Traumatol. 2022, 32, 981–989.

66. Hahnel, S.; Wieser, A.; Lang, R.; Rosentritt, M. Biofilm formation on the surface of modern implant abutment materials. Clin. Oral Impl Res. 2015, 26, 1297–1301.

67. Skirbutis, G.; Dzingutė, A.; Masiliūnaitė, V.; Šulcaitė, G.; Žilinskas, J. A review of peek polymer's properties and its use in prosthodontics. Stomatologija 2017, 19, 19–23.

68. Neugebauer, J.; Adler, S.; Kisttler, F.; Kistler, S.; Bayer, G. The use of plastics in fixed prosthetic implant restoration. Zwr-Ger. Dent. J. 2013, 122, 242–245.

69. Gad, M.M.; Abu-Rashid, K.; Alkhaldi, A.; Alshehri, O.; Khan, S.Q. Evaluation of the effectiveness of bioactive glass fillers against candida albicans adhesion to PMMA denture base materials: An in vitro study. Saudi Dent. J. 2022, 34, 730–737.

70. Vulović, S.; Todorović, A.; Stančić, I.; Popovac, A.; Stašić, J.N.; Vencl, A.; Milić-Lemić, A. Study on the surface properties of different commercially available cad/cam materials for implant-supported restorations. J. Esthet. Restor. Dent. 2022, 34, 1132–1141.

71. Khattar, A.; Alghafli, J.A.; Muheef, M.A.; Alsalem, A.M.; Al-Dubays, M.A.; AlHussain, H.M.; AlShoalah, H.M.; Khan, S.Q.; AlEraky, D.M.; Gad, M.M. Antibiofilm activity of 3D-printed nanocomposite resin: Impact of ZrO2 nanoparticles. Nanomaterials 2023, 13, 591.

72. Sawada, T.; Sawada, T.; Kumasaka, T.; Hamada, N.; Shibata, T.; Nonami, T.; Kimoto, K. Self-cleaning effects of acrylic resin containing fluoridated apatite-coated titanium dioxide. Gerodontology 2014, 31, 68–75.

73. Lazarin, A.A.; Machado, A.L.; Zamperini, C.A.; Wady, A.F.; Spolidorio, D.M.P.; Vergani, C.E. Effect of experimental photopolymerized coatings on the hydrophobicity of a denture base acrylic resin and on Candida albicans adhesion. Arch. Oral Biol. 2013, 58, 1–9.

74. Qian, K.; Pan, H.; Li, Y.; Wang, G.; Zhang, J.; Pan, J. Time-related surface modification of denture base acrylic resin treated by atmospheric pressure cold plasma. Dent. Mater. J. 2016, 35, 97–103.

75. Yildirim, M.S.; Hasanreisoglu, U.; Hasirci, N.; Sultan, N. Adherence of candida albicans to glow-discharge modified acrylic denture base polymers. J. Oral Rehabil. 2005, 32, 518–525.

76. Liu, T.; Xu, C.; Hong, L.; Garcia-Godoy, F.; Hottel, T.; Babu, J.; Yu, Q. Effects of trimethylsilane plasma coating on the hydrophobicity of denture base resin and adhesion of Candida albicans on resin sur-faces. J. Prosthet. Dent. 2017, 118, 765–770.

77. Darwish, G.; Huang, S.; Knoernschild, K.; Sukotjo, C.; Campbell, S.; Bishal, A.K.; Barão, V.A.; Wu, C.D.; Taukodis, C.G.; Yang, B. Improving polymethyl methacrylate resin using a novel titanium dioxide coating. J. Prosthodont. 2019, 28, 1011–1017.

78. Zamperini, C.A.; Machado, A.L.; Vergani, C.E.; Pavarina, A.C.; Giampaolo, E.T.; da Cruz, N.C. Adherence in vitro of candida albicans to plasma treated acrylic resin. Effect of plasma parameters, surface roughness and salivary pellicle. Arch. Oral Biol. 2010, 55, 763–770.

79. Heimer, S.; Schmidlin, P.R.; Roos, M.; Stawarczyk, B. Surface properties of polyetheretherketone after different laboratory and chairside polishing protocols. J. Prosthet. Dent. 2017, 117, 419–425.

80. Heimer, S.; Schmidlin, P.R.; Stawarczyk, B. Discoloration of pmma, composite, and peek. Clin. Oral Investig. 2017, 21, 1191–1200.

81. Nishi, Y.; Seto, K.; Murakami, M.; Harada, K.; Ishii, M.; Kamashita, Y.; Kawamoto, S.; Hamano, T.; Yoshimura, T.; Kurono, A.; et al. Effects of denture cleaning regimens on the quantity of Candida on dentures: A cross-sectional survey on nursing home residents. Int. J. Environ. Res. Public. Health. 2022, 19, 15805.

82. Duyck, J.; Vandamme, K.; Krausch-Hofmann, S.; Boon, L.; De Keersmaecker, K.; Jalon, E.; Teughels, W. Impact of denture cleaning method and overnight storage condition on denture biofilm mass and composition: A cross-over randomized clinical trial. PLoS ONE 2016, 11, e0145837.

83. Sun, J.; Wang, L.; Wang, J.; Li, Y.; Zhou, X.; Guo, X.; Zhang, T.; Guo, H. Characterization and evaluation of a novel silver nanoparticles-loaded polymethyl methacrylate denture base: In vitro and in vivo animal study. Dent. Mater. J. 2021, 40, 1100–1108.

84. Garcia, A.A.M.N.; Sugio, C.Y.C.; de Azevedo-Silva, L.J.; Gomes, A.C.G.; Batista, A.U.D.; Porto, V.C.; Soares, S.; Neppelenbroek, K.H. Nanoparticle-modified PMMA to prevent denture stomatitis: A systematic review. Arch. Microbiol. 2022, 204, 75.

85. Apip, C.; Martínez, A.; Meléndrez, M.; Domínguez, M.; Marzialetti, T.; Báez, R.; Sánchez-Sanhueza, G.; Jaramillo, A.; Catalán, A. An in vitro study on the inhibition and ultrastructural alterations of candida albicans biofilm by zinc oxide nanowires in a PMMA matrix. Saudi Dent. J. 2021, 33, 944–953.

86. Young, B.; Jose, A.; Cameron, D.; McCord, F.; Murray, C.; Bagg, J.; Ramage, G. Attachment of candida albicans to denture base acrylic resin processed by three different methods. Int. J. Prosthodont. 2009, 22, 488–489.

87. Meirowitz, A.; Rahmanov, A.; Shlomo, E.; Zelikman, H.; Dolev, E.; Sterer, N. Effect of denture base fabrication technique on Candida albicans adhesion in vitro. Materials 2021, 14, 221.

88. Mondelli, R.; Garrido, L.M.; Soares, A.; Rodriguez-Medina, A.; Mondelli, J.; de Lucena, F.; Furuse, A. Effect of simulated brushing on surface roughness and wear of bis-acryl-based materials submitted to different polishing protocols. J. Clin. Exp. Dent. 2022, 14, e168–e176.

89. Alammari, M.R. The influence of polishing techniques on pre-polymerized cad/cam acrylic resin denture bases. Electron. Physician 2017, 9, 5452–5458.

90. Al-Fouzan, A.F.; Al-mejrad, L.A.; Albarrag, A.M. Adherence of candida to complete denture surfaces in vitro: A comparison of conventional and CAD/CAM complete dentures. J. Adv. Prosthodont. 2017, 9, 402.

91. Quezada, M.M.; Salgado, H.; Correia, A.; Fernandes, C.; Fonseca, P. Investigation of the effect of the same polishing protocol on the surface roughness of denture base acrylic resins. Biomedicines 2022, 10, 1971.

92. Corsalini, M.; Boccaccio, A.; Lamberti, L.; Pappalettere, C.; Catapano, S.; Carossa, S. Analysis of the performance of a standardized method for the polishing of methacrylic resins. Open Dent. J. 2009, 3, 233–240.

93. Sahin, O.; Koroglu, A.; Dede, D.Ö.; Yilmaz, B. Effect of surface sealant agents on the surface roughness and color stability of denture base materials. J. Prosthet. Dent. 2016, 116, 610–616.

94. Liebermann, A.; Wimmer, T.; Schmidlin, P.R.; Scherer, H.; Löffler, P.; Roos, M.; Stawarczyk, B. Physicomechanical characterization of polyetheretherketone and current esthetic dental cad/cam polymers after aging in different storage media. J. Prosthet. Dent. 2016, 115, 321–328.

95. Kurahashi, K.; Matsuda, T.; Ishida, Y.; Ichikawa, T. Effect of polishing protocols on the surface roughness of polyetheretherketone. J. Oral Sci. 2020, 62, 40–42.

96. Liu, Y.; Fang, M.; Zhao, R.; Liu, H.; Li, K.; Tian, M.; Niu, L.; Xie, R.; Bai, S. Clinical applications of polyetheretherketone in removable dental prostheses: Accuracy characteristics, and performance. Polymers 2022, 14, 4615.

97. Choi, J.J.E.; Uy, C.E.; Plaksina, P.; Ramani, R.S.; Ganjigatti, R.; Waddell, J.N. Bond strength of denture teeth to heat cured, cad/cam and 3d printed denture acrylics. J. Prosthodont. 2020, 29, 415–421.

98. Behr, M.; Rosentritt, M.; Lang, R.; Handel, G. Glass fiber-reinforced abutments for dental implants. a pilot study: Glass fiber-reinforced abutments for dental implants. A pilot study. Clin. Oral Implant. Res. 2001, 12, 174–178.

99. Pan, H.; Wang, G.; Pan, J.; Ye, G.; Sun, K.; Zhang, J.; Wang, J. Cold plasma-induced surface modification of heat-polymerized acrylic resin and prevention of early adherence of candida albicans. Dent. Mater. J. 2015, 34, 529–536.

100. Gül, E.B.; Atala, M.H.; Eşer, B.; Polat, N.T.; Asiltürk, M.; Gültek, A. Effects of coating with different ceromers on the impact strength, transverse strength and elastic modulus of polymethyl methacrylate. Dent. Mater. J. 2015, 34, 379–387.

101. Güngör, A.; Kayaman-Apohan, N.; Mert, A.; Kahraman, M.V. Preparation and characterization of light curable hybrid coating: Its potential application for dental restorative material. J. Polym. Res. 2008, 15, 389–395.

102. Mylonas, P.; Milward, P.; McAndrew, R. Denture cleanliness and hygiene: An overview. Br. Dent. J. 2022, 233, 20–26.

103. Estrela, A.; Estrela, C.R.A.; Barbin, E.L.; Spano, J.C.E.; Marchesan, M.A.; Pecora, J.D. Mechanism of action of sodium hypochlorite. Braz. Dent. J. 2002, 13, 113–117.

104. De Sousa Porta, S.R.; de Lucena-Ferreira, S.C.; da Silva, W.J.; Del Bel Cury, A.A. Evaluation of sodium hypochlorite as a denture cleanser: A clinical study. Gerodontology 2015, 32, 260–266.

105. Milward, P.; Katechia, D.; Morgan, M.Z. Knowledge of removable partial denture wearers on denture hygiene. Br. Dent. J. 2013, 215, E20.

106. Kumar, B.; Sandhu, P.K.; Kumar, A.N.; Patil, C.P. A comparative study for plaque removing efficacy between commonly used denture cleansers in India. J. Indian. Prosthodont. Soc. 2017, 17, 295–300.

107. De Souza, R.F.; de Freitas Oliveira Paranhos, H.; Lovato da Silva, C.H.; Abu-Naba'a, L.; Fedorowicz, Z.; Gurgan, C.A. Interventions for cleaning dentures in adults. Cochrane Data-Base Syst. Rev. 2009, 4, CD007395.

108. Tulbah, H.I. Anticandidal efficacy on polymide based denture resin using Photodynamic therapy, chemical and herbal disinfectants and their effect on surface roughness and hardness.

Photodiagn. Photodyn. Ther. 2022, 39, 102874.

109. Ramage, G.; O'Donnell, L.; Sherry, L.; Culshaw, S.; Bagg, J.; Czesnikiewicz-Guzik, M.; Brown, C.; McKenzie, D.; Cross, L.; MacInnes, A.; et al. Impact of frequency of denture cleaning on microbial and clinical parameters—A bench to chairside approach. J. Oral Microbiol. 2019, 11, 1538437.

110. Costa, R.T.F.; Pellizzer, E.P.; Vasconcelos, B.C.d.E.; Gomes, J.M.L.; Lemos, C.A.A.; Moraes, S.L.D. Surface roughness of acrylic resins used for denture base after chemical disinfection: A systematic review and meta-analysis. Gerodontology 2021, 38, 242–251.

111. Masetti, P.; Arbeláez, M.I.A.; Pavarina, A.C.; Sanitá, P.V.; Jorge, J.H. Cytotoxic potential of denture base and reline acrylic resins after immersion in disinfectant solutions. J. Prosthet. Dent. 2018, 120, 155.

112. Gad, M.M.; Abualsaud, R.; Fouda, S.M.; Rahoma, A.; Al-Thobity, A.M.; Khan, S.Q.; Akhtar, S.; Al-Harbi, F.A. Effects of denture cleansers on the flexural strength of PMMA denture base resin modified with ZrO2 nanoparticles. J. Prosthodont. 2021, 30, 2356244.

113. Amaya, A.M.I.; Vergani, C.E.; Barbugli, P.A.; Pavarina, A.C.; Sanitá, P.V.; Jorge, J.H. Long-term effect of daily chemical disinfection on surface topography and Candida albicans biofilm formation on denture base and reline acrylic resins. Oral Health Prev. Dent. 2020, 18, 999–1010.

114. Kiesow, A.; Sarembe, S.; Pizzey, R.L.; Axe, A.S.; Bradshaw, D.J. Material compatibility and antimicrobial activity of consumer products commonly used to clean dentures. J. Prosthet. Dent. 2016, 115, 189–198.

115. Mert, D.; Kamnoedboon, P.; Al-Haj Husain, N.; Özcan, M.; Srinivasan, M. CAD-CAM complete denture resins: Effect of relining on the shear bond strength. J. Dent. 2023, 131, 104438.

116. Yuan, S.P.; Lin, H.; Pan, S.; Lou, L.L.; Xu, Y.X. Effect of Polident denture cleansers on the properties of heat-polymerized denture base acrylic resin. Beijing Da Xue Xue Bao Yi Xue Ban 2012, 44, 946–949.

117. Demirci, F.; Tanik, A. Comparison of the effect of denture cleansers on long-term water sorption and solubility of polyetheretherketone with other denture base materials. Clin. Exp. Health Sci. 2022, 12, 672–677.

118. Sesma, N.; Rocha, A.L.; Lagana, D.C.; Costa, B.; Morimoto, S. Effectiveness of denture cleanser associated with microwave disinfection and brushing of complete dentures: In vivo study. Braz. Dent. J. 2013, 24, 357–361.

119. Arun Kumar, P.; Iniyan, K.; Balasubramaniam, R.; Viswanathan, M.; Hines, P.J.; Monnica, V. The effect of surface treatments on the shear bond strength of acrylic resin denture base with different repair acrylic resin: An in vitro study. J. Pharm. Bioall Sci. 2019, 11, 380.

120. Kreve, S.; Dos Reis, A.C. Denture liners: A systematic review relative to adhesion and mechanical properties. Sci. World J. 2019, 2019, 6913080.

121. Ates, S.M.; Caglar, I.; Ozdogan, A.; Duymus, Z.Y. The effect of denture cleansers on surface roughness and bond strength of a denture base resin. J. Adhes. Sci. Technol. 2017, 31, 171–181.

122. Kümbüloğlu, Ö.; Yildirim, B.; Al-Haj Husain, N.; Özcan, M. Adhesion potential of relining materials to polyamide and PMMA-based denture base materials: Effect of surface conditioning methods. J. Adhes. Sci. Technol. 2019, 33, 1939–1947.

123. AlZaher, Z.A.; Almaskin, D.F.; Qaw, M.S.; Abu Showmi, T.H.; Abualsaud, R.; Akhtar, S.; Gad, M.M. Chemo-mechanical approach to improve repair bond strength of denture teeth. Int. J. Dent. 2020, 2020, 8870361.

124. Choi, J.E.; Ng, T.E.; Leong, C.K.Y.; Kim, H.; Li, P.; Waddell, J.N. Adhesive evaluation of three types of resilient denture liners bonded to heat-polymerized, autopolymerized, or CAD-CAM acrylic resin denture bases. J. Prosthet. Dent. 2018, 120, 699–705.

125. Takahashi, Y.; Chai, J. Shear bond strength of denture reline polymers to denture base polymers. Int. J. Prosthodont. 2001, 14, 271–275.

126. Taghva, M.; Enteghad, S.; Jamali, A.; Mohaghegh, M. Comparison of shear bond strength of CAD/CAM and conventional heat-polymerized acrylic resin denture bases to auto-polymerized and heat-polymerized acrylic resins after aging. J. Clin. Exp. Dent. 2022, 14, 72–78.

127. Choi, J.J.E.; Ramani, R.S.; Ganjigatti, R.; Uy, C.E.; Plaksina, P.; Waddell, J.N. Adhesion of denture characterizing composites to heat cured, CAD/CAM and 3D printed denture base resins. J. Prosthodont. 2021, 30, 83–90.

128. Luo, C.; Liu, Y.; Peng, B.; Chen, M.; Liu, Z.; Li, Z.; Kuang, H.; Gong, B.; Li, Z.; Sun, H. PEEK for oral applications: Recent advances in mechanical and adhesive properties. Polymers 2023, 15, 386.

129. Kim, J.H.; Choe, H.C.; Son, M.K. Evaluation of adhesion of reline resins to the thermoplastic denture base resin for non-metal clasp denture. Dent. Mater. J. 2014, 33, 32–38.

130. Vuksic, J.; Pilipovic, A.; Poklepovic Pericic, T.; Kranjcic, J. Tensile bond strength between different denture base materials and soft denture liners. Materials 2023, 16, 4615.

131. Müller, F. Oral hygiene reduces the mortality from aspiration pneumonia in frail elders. J. Dent. Res. 2015, 94, 14–16.

132. Le Bars, P.; Kouadio, A.A.; Bandiaky, O.N.; Le Guéhennec, L.; de La Cochetière, M.F. Host's immunity and Candida species associated with denture stomatitis: A narrative review. Microorganisms 2022, 10, 1437.

133. Ruiz Núñez, M.d.R.; Raulino, M.; Goulart Castro, R.; Schaefer Ferreira de Mello, A.L. Dental plaque control strategies for the elderly population: A scoping review. Int. J. Dent. Hyg. 2022, 20, 167–181.

134. Patil, S.; Rao, R.S.; Majumdar, B.; Anil, S. Clinical appearance of oral candida infection and therapeutic strategies. Front. Microbiol. 2015, 6, 1391.

135. Chladek, G.; Nowak, M.; Pakieła, W.; Mertas, A. Effect of Candida Albicans Suspension on the Mechanical Properties of Denture Base Acrylic Resin. Materials 2022, 15, 3841.

136. Dhiman, R.; Chowdhury, S.R. Midline fractures in single maxillary complete acrylic vs flexible dentures. Med. J. Armed Forces India 2009, 65, 141–145.

137. Takahashi, Y.; Imazato, S.; Russell, R.R.B.; Noiri, Y.; Ebisu, S. Influence of Resin Monomers on Growth of Oral Streptococci. J. Dent. Res. 2004, 83, 302–306.

138. Kostić, M.; Igić, M.; Gligorijević, N.; Nikolić, V.; Stošić, N.; Nikolić, L. The use of acrylate polymers in dentistry. Polymers 2022, 14, 4511.

139. Yoshii, E. Cytotoxic effects of acrylates and methacrylates: Relationships of monomer structures and cytotoxicity. J. Biomed. Mater. Res. A 1997, 37, 517–524.

140. Hinz, S.; Bensel, T.; Bömicke, W.; Boeckler, A.F. In Vitro analysis of the mechanical properties of hypoallergenic denture base resins. Materials 2022, 15, 3611.

141. Pfeiffer, P.; An, N.; Schmage, P. Repair strength of hypoallergenic denture base materials. J. Prosthet. Dent. 2008, 100, 292–301.

142. Hirasawa, M.; Tsutsumi-Arai, C.; Takakusaki, K.; Oya, T.; Fueki, K.; Wakabayashi, N. Superhydrophilic co-polymer coatings on denture surfaces reduce candida albicans adhesion— An in vitro study. Arch. Oral Biol. 2018, 87, 143–150.