Surface Characteristics and Microbial Adhesion in Polymethylmethacrylate for Denture Base Submitted to Antimicrobial Agents and Cleaning Agents: A Systematic Review

Keywords

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ABSTRACT

This review aimed to identify the influence of antimicrobial and cleaning agents on surface characteristics such as surface free energy (SFE) and wettability, and microbial adhesion in polymethylmethacrylate (PMMA) for denture base. The review question, based on PICO, was: "Does intervention with antimicrobial and cleaning agents in PMMA influence the surface free energy, wettability, and consequently the microbial adhesion?" and the protocol was registered in Open Science Framework (osf.io/v3xgn). The search was performed in PubMed, Lilacs, Embase, Scopus, and Science Direct databases, using the terms: ("acrylic resin" OR PMMA) AND (antimicrobial OR antibacterial) AND ("electrostatic interaction" OR surface free energy) AND (biofilm OR "bacteria adhesion"), and resulted in 462 articles, of which 7 were included. The antimicrobials polypara-xylylene, carboxybetaine methacrylate, ethylene glycol methacrylate phosphate, and deposition of F and Ag ions in PMMA influenced the SFE and wettability. Denture cleaners reduced microbial adhesion. Five of the included studies evaluated the microbial adhesion, however, only two observed a direct relationship between SFE, wettability, and microbial adhesion. It was concluded that the intervention with antimicrobial and cleaning agents in PMMA can interfere in SFE and surface wettability, but no correlation was observed between microbial adhesion and these surface characteristics in PMMA.

INTRODUCTION

Polymethylmethacrylate (PMMA) is usually used in dentistry as a material for denture base due to physical-mechanical and aesthetic characteristics suitable for this purpose.[1] However, this material undergoes color change, water absorption, and microbial adhesion.[2] Biofilm accumulation is attributed to porous, roughness surface and causes damage such as denture stomatitis, which affects up to 72% of complete denture wearers.[3,4] *Candida* spp., such as *C. albicans* and *C. glabrata*, are predominant in denture biofilm, and other pathogens are also associated, such as *Staphylococcus aureus.*[3,5]

Physicochemical interactions between bacteria and substrate involve surface characteristics and bacteria-specific mechanisms which favored the adhesion process.[6] Bacteria attach to a substrate depending on cell wall components, adhesins (curli or pili) that do a receptor-ligand binding, species virulence, electrostatic forces, nutrients availability, acidic pH, and the biofilm develop through signals as quorum sensing and production of extracellular polysaccharides (EPS).[6] In addition, substrate characteristics that can favor microbial adhesion are related to electrostatic charges, surface free energy (SFE), wettability, roughness, topography, and chemical composition.[3,6] SFE and hydrophilicity can favor the salivary film formation at the surface of dental prosthesis and, consequently, microbial adhesion.[3,5] However, even on hydrophobic surfaces, pili bind to the surface and resist high shear forces acting as nano-springs.[6]

Biofilm accumulation, poor hygiene, continued use of the prosthesis, and inadequate prosthetic devices increase the user's risk of developing stomatitis.[7] Mechanical and chemical methods are the most recommended for their control.[7-9] However, patients with limited motor skills, elderly, and physically handicapped do not have sufficient ability to apply these methods. In addition, the toothpaste and an inadequate brush increase surface abrasion and further favor microorganisms' adhesion.[7]

When local infections caused by fungi and bacteria set in, treatment is usually carried out with antibiotics and antifungals to avoid more serious complications and in some cases replacement of the prosthesis is recommended. Drug therapy not only harms the patient's health but also causes mental stress and economic loss.[9] In addition, drugs such as nystatin, fluconazole, amphotericin B, and chlorhexidine can be ineffective against mature biofilm formed by *Candida* spp. and other pathogens, due to virulence factors and microbial resistance.[1,10]

Antimicrobial agents, such as nano and microparticles, oils, or functional monomers, were incorporated into PMMA to prevent biofilm adhesion and microbial resistance, which also prevents the use of increasingly higher doses of drugs.[3,10,11] In addition to avoiding microbial adhesion, the use of cleaning agents and the incorporation of antimicrobials in PMMA can promote changes in their surface properties.

Surface characteristics of the substrate influence the initial adhesion of the biofilm, however, no evidence was found in the literature that the SFE or wettability is directly correlated with microbial adhesion. Thus, this systematic review aimed to analyze the existing literature that addressed the intervention with antimicrobial agents and cleaning agents in the PMMA and its influence on the surface free energy, wettability, and, consequently, the microorganism adhesion, as well as whether there is a correlation between these two factors.

MATERIAL AND METHODS

The register of this systematic review was performed in Open Science Framework (osf.io/v3xgn) and the study followed the PRISMA Extension for Systematic Reviews. The review question, formulated based on PICO was: "Does the intervention with antimicrobial agents and cleansing agents on PMMA influence the surface free energy, wettability, and consequently the microbial adhesion?". The Population consists of the PMMA, the Intervention is the incorporation of antimicrobial agents or the use of cleansing agents, the Comparison is a group with gold-standard material, and the Outcome includes the primary outcome, which is the surface free energy, wettability, and the secondary outcome, which is the microbial adhesion on the surface.

An electronic search was performed on June 21, 2021, in the databases PubMed, Lilacs, Embase, Science Direct, and Scopus, applying the search strategy: ("acrylic resin" OR PMMA) AND (antimicrobial OR antibacterial) AND ("electrostatic interaction" OR surface free energy) AND (biofilm OR "bacteria adhesion"). A complementary search in grey literature or references list did not perform. The manual selection of articles covered a period of 20 years (2001-2021) and was conducted by two authors (G.G.C. and A.B.V.T.) using the Rayyan Systems Inc. site, according to the title and abstract. Articles that met the inclusion criteria were read in full. In case of disagreement in the selection of the articles by the two researchers, the opinion of a third researcher (A.C.R.) was obtained.

Eligibility criteria included *in vitro* research articles, published in English language, in journals with impact factor indexed in Journal Citation Reports (Clarivate), that addressed the influences of antimicrobial agents and cleansing agents on surface free energy and associated properties such as wettability, and on the microbial adhesion in PMMA. Exclusion criteria covered other types of studies, PMMA that was not treated with antimicrobial agents or cleansing agents, and studies that did not evaluate the surface free energy or associated properties such as wettability.

The data extraction of the articles included in this review was performed on Microsoft Word, in a table containing: (1) identification of the article; (2) antimicrobial or cleansing agent applied in the PMMA; (3) surface property evaluated; (4) surface property evaluation method; (5) influences on the adhesion of microorganisms; (6) antimicrobial property evaluation method; (7) main results and conclusion. The risk of bias and methodological quality of the *in vitro* studies was assessed from an adapted protocol of Sarkis-Onofre *et al.* (2014)[12], proposed by Teixeira and Reis (2021)[13]. High risk of bias was considered when studies included one or two of the items evaluated, average risk of bias when included three to four items, and low risk when included five or more items. The items evaluated on the article's methodology were: samples – number (n) and size calculation; experiments - performed by a single investigator, control group defined; preparation of materials according to the manufacturer's instructions; details that enable the reproduction of the study.

Meta-analysis was not performed because the studies included in this review had different objectives. Thus, the results addressed the type of antimicrobial/cleaning agent used; surface property evaluated, and microorganism adhesion.

RESULTS

From the search performed in the databases, 338 references were found in PubMed, 116 in Science Direct, 2 in Embase, 6 in Scopus, and none in Lilacs, totalizing 462 studies *(Table 1)*. Were excluded 11 references duplicated, and the initial selection was performed in 451 articles. Eight studies were selected to reading the full text. One of these studies was excluded because not use antimicrobial or cleansing agents. Seven studies were included in this systematic review. The details of the research are shown in the diagram *(Figure 1)*. In relation to risk of bias and methodological quality of the *in vitro* studies, Shinonaga and Arita (2012)[9] showed a high risk of bias, Bourlidi *et al.* (2016)[3] and Fernandes *et al.* (2010)[5] low risk, and Puri *et al.* (2008),[14] Hayran *et al.* (2018),[7] Jin *et al.* (2020)[8] and Zhou *et al.* (2010),[10] average risk of bias, detailed in Table 2, Figure 2 and Figure 3.

Table 1. Database search strategy.

Database	Search	Found
Embase	('acrylic resin'/exp OR 'acrylic resin' OR pmma) AND ('antimicrobial'/exp OR antimicrobial OR 'antibacterial'/exp OR antibacterial) AND ('electrostatic interaction'/exp OR 'electrostatic interaction' OR 'surface free energy'/exp OR 'surface free energy') AND ('biofilm'/exp OR biofilm OR 'bacteria adhesion')	2
PubMed	((((((("acrylic resin") OR (PMMA)) AND (antimicrobial)) OR (antibacterial)) AND ("electrostatic interaction")) OR ("surface free energy")) AND (biofilm)) OR ("bacteria adhesion"))))))	338
Scopus	(TITLE-ABS-KEY ("acrylic resin") OR TITLE-ABS-KEY (pmma) AND TITLE-ABS-KEY (antimicrobial) OR TITLE-ABS-KEY (antibacterial) AND TITLE-ABS-KEY ("electrostatic AND interaction") OR TITLE-ABS-KEY ("surface AND free AND energy") AND TITLE-ABS-KEY (biofilm) OR TITLE-ABS-KEY ("bacteria AND adhesion"))	6
Science Direct	(("acrylic resin" OR PMMA) AND (antimicrobial OR antibacterial) AND ("electrostatic interaction" OR "surface free energy") AND (biofilm OR "bacteria adhesion"))	116
Lilacs	(("acrylic resin" OR PMMA) AND (antimicrobial OR antibacterial) AND ("electrostatic interaction" OR "surface free energy") AND (biofilm OR "bacteria adhesion"))	0

ANTIMICROBIAL OR CLEANSING AGENT USED IN POLYMETHYLMETHACRYLATE (PMMA)

Bourlidi *et al.* (2016)[3] and Zhou *et al.* (2010)[10] used the antimicrobial Parylene (poly para-xylylene). The PMMA was coated with layers of thickness of 10 μm, 20 μm and 30 μm of Parylene C by Bourlidi *et al* (2016)[3] and Zhou *et al.* (2010)[10] used Parylene N plated on the surface of PMMA and silicone elastomers, which were coated 5 mm thick by chemical vapor deposition. Fernandes *et al.* (2010)[5] used dentures cleaners in the specimens of PMMA and polyamide resin, as the enzymatic cleaning solution, for 3 minutes, sodium bicarbonate-based cleaning solution (CT), for 5 minutes and 0,5% sodium hypochlorite (HC), for 10 minutes. Hayran *et al.* (2018)[7] used tablets of alkaline peroxide denture cleanser (Corega and Fittydent) and neutral peroxide enzymatic denture cleanser (Polident 3 min) in different types of resins (conventional thermosetting acrylic resin, high impact thermosetting acrylic resin and thermoplastic polyamide resin obtained by the rapid injection technique). The tablets were prepared at concentrations 16, 32, 48, 64 and 80 mg/mL, from the dissolution of 1-5 tablets/150 mL in warm distilled water, respectively. Jin *et al.* (2020)[8] used the powder of the antimicrobial Carboxybetaine Methacrylate (CBMA) embedded in PMMA at concentrations of 0% (control), 0.75%, 1.5%, 3%, 5% and 7.5%. Puri *et al.* (2008)[14] evaluated the effect of phosphate group substitution via incorporation of ethylene glycol methacrylate phosphate (EGMP) in PMMA and Shinonaga and Arita (2012)[9] studied the implantation and deposition of fluor (F) and silver (Ag) double ions in PMMA. Octafluoropropane gas (C3F8) was used for implantation and deposition of F ions and for implantation and deposition of Ag ions, a cover of 99.8% Ag mesh was placed 10 mm above the PMMA plates and then sprayed by C3F8 gas.

EVALUATED SURFACE PROPERTY AND MICROORGANISM ADHESION

Jin *et al.* (2020)[8] observed that the addition of carboxybetaine methacrylate (CBMA) powder mixed with the liquid MMA monomer reduces the contact angle of PMMA in proportion to its concentration. Thus, the addition of a concentration of 7.5% conferred lower wettability to the material and, consequently, lower microbial adhesion against *Candida albicans, Actinomyces naeslundii*, e *Veillonella parvula*. PMMA modified with 3% CBMA showed greater effectiveness to inhibit bacterial adhesion than the control, and the aesthetic of the modified PMMA was considered acceptable for practice clinic by the authors. However, mechanical properties deteriorate after the CBMA addition.

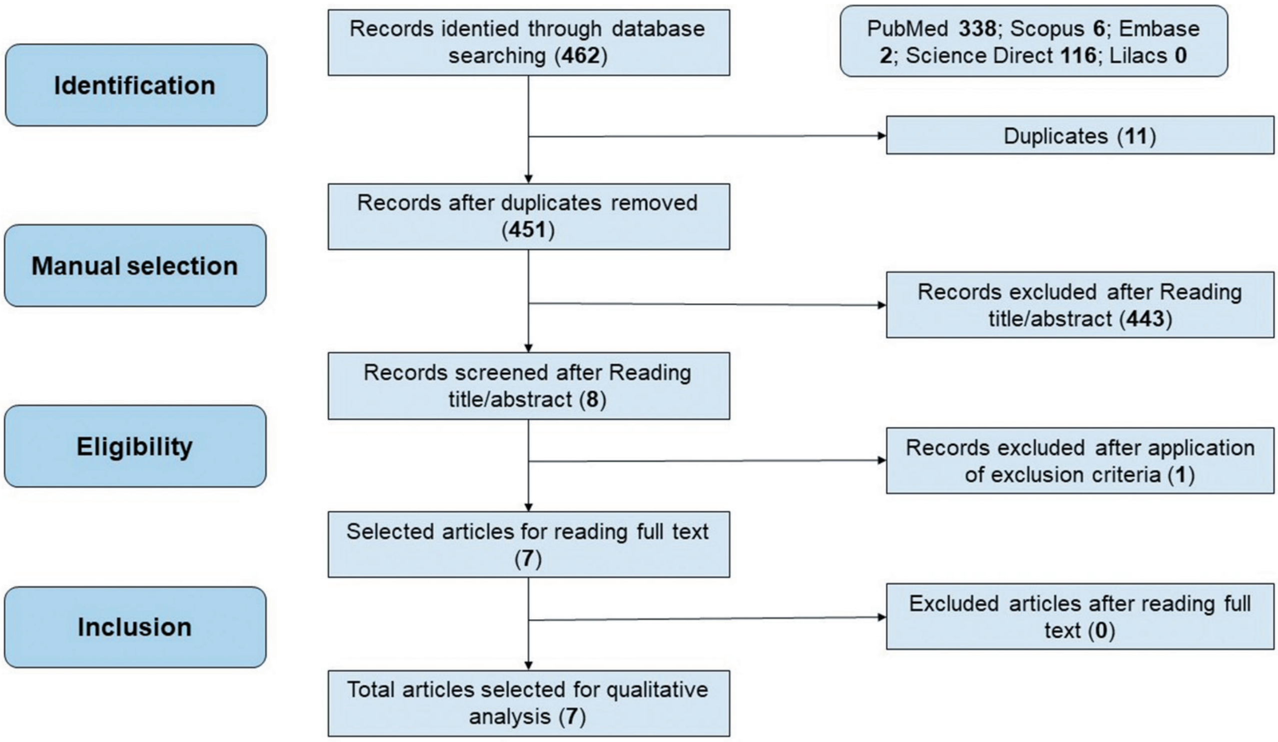

Figure 1: Diagram of steps of the literature research.

Table 2. Methodological quality assessment and risk of bias.

Author, year	Number of samples	Sample size calculation	Tests performed by a single investigator	Adequate control group/ comparison group	Material handling following the manufacturer's instructions	Enough details to allow reproduction	Risk of bias
Bourlidi *et al.*, 2016	yes	yes	no	yes	yes	yes	Low
Fernandes *et al.*, 2010	yes	yes	no	yes	yes	yes	Low
Hayran *et al.*, 2017	yes	no	no	no	yes	yes	Average
Jin *et al.*, 2020	yes	no	no	yes	no	yes	Average
Puri *et al.*, 2008	yes	no	no	yes	yes	yes	Average
Shinonaga *et al.*, 2012	yes	no	no	yes	no	no	High
Zhou *et al.*, 2010	no	no	no	yes	yes	yes	Average

Shinonaga and Arita (2012)[9] verified that the contact angle of the FID-PMMA (PMMA with F ion-implanted and –deposited) and FAgID-PMMA (PMMMA with F and Ag ion-implanted and –deposited) were significantly higher than the PMMA surface. The PMMA surface was relatively flat, while the FID-PMMA and FAgID-PMMA surfaces had a similar structure to a valley hill. In addition, the PMMA surface implanted and deposited with the double ions showed lower *Staphylococcus aureus* adhesion.

Zhou *et al.* (2010)[10] observed that the surface of the PMMA treated with Parylene N did not present significant differences in the contact angle and SFE in relation to the untreated resin.

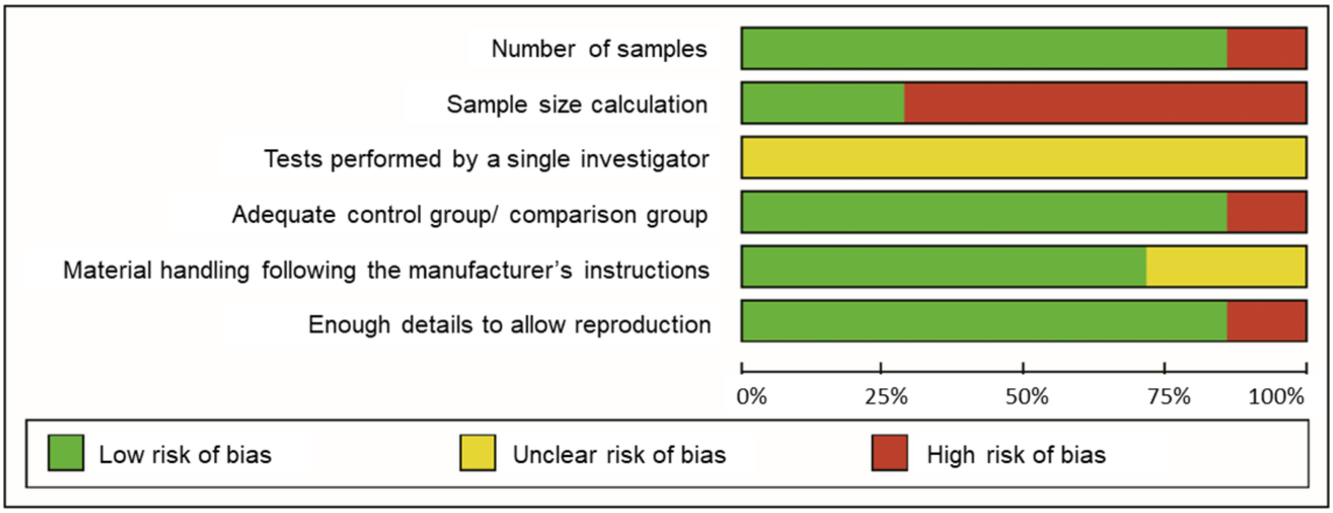

Figure 2: Risk of bias graph.

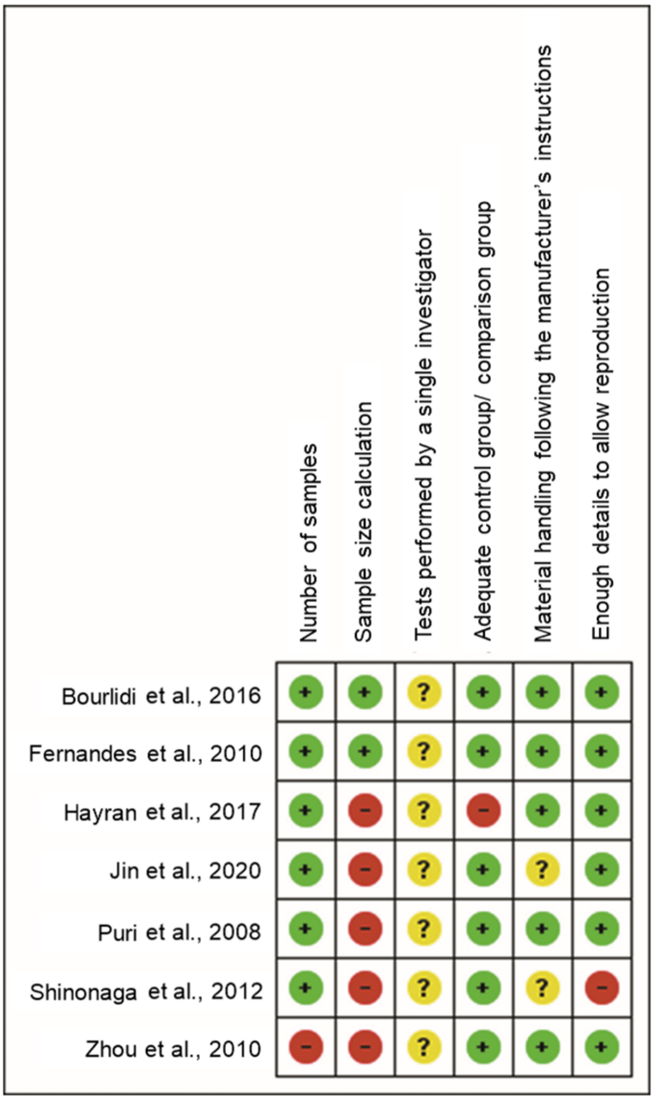

Figure 3: Risk of bias summary.

The treated A-2186 silicone elastomer, on the other hand, showed a significant reduction in the contact angle and higher SFE compared to the untreated elastomer. The adhesion of *C. albicans* to the surfaces of silicone elastomer A-2186 and lucitone 199 resin reduced after the coating with Parylene N, but was no observed relation between SFE and microorganism adhesion.

Fernandes *et al*. (2010)[5] and Hyaran *et al*. (2018)[7] evaluated the antimicrobial action of cleaning agents in PMMA and polyamide resin, however, the authors evaluated the contact angle and SFE of these materials without considering the influence of the cleaning agents on modification of this properties. PMMA showed a higher SFE than the polyamide resin.[5] Thermopolymerizable acrylic resin exhibited the highest SFE and wettability values, while the lowest values were found for the high-impact heat-cured acrylic resin.[7] Furthermore, the polyamide resin showed higher growth *Candida* biofilm compared to the PMMA resin and the denture cleaners were able to reduce biofilm levels for both resins.[5] However, 0.5% sodium hypochlorite was the best cleaning solution for biofilm reduction in relation to the cleaning agents (enzymatic cleaning solution and sodium bicarbonate-based cleaning solution). Still, statistical analysis showed that there are no significant interactions between material, type of biofilm, and treatment used.[5] Hayran *et al*. (2018)[7] were noticed greater anti *Candida* effectiveness of alkaline peroxide denture cleanser (Corega) and neutral peroxide enzymatic denture cleanser (Polident 3 minutes), while alkaline peroxide denture cleanser (Fittydent) was effective only for the polyamide resin. However, for polyamide and high-impact PMMA resins, alkaline peroxide denture cleanser (Corega) was the most effective in removing the biofilm and, for conventional PMMA, neutral peroxide enzymatic denture cleanser (Polident 3 minutes), was the most effective. Still, conventional and high-impact PMMA presented greater spreadability of the biofilm through the irregular surface and the polyamide presented a smooth textured surface. The antifungal activity was influenced by the characteristics of the resins, their roughness, type and concentrations of the cleaner. The evaluation of the surface characteristics of the materials studied after treatment with cleaning agents would be interesting for a possible correlation between the observed surface changes, the antimicrobial properties, and the presence of biofilm adhesion data in the control group would allow comparison between resins.

Boulidi *et al*. (2016)[3] and Puri *et al*. (2008)[14] evaluated the SFE and wettability of PMMA treated with different layers of Parylene C and phosphate-containing monomer (EGMP), replacing the liquid MMA monomer at different concentrations, respectively. observed that the Parylene C increased the SFE in relation to the uncoated samples, and the coating with a 10 µm layer of Parylene C soothed the surface. Puri *et al*. (2008)[14] noticed that the increase in the phosphate concentration decreased the contact angle, which indicates an increase in hydrophilicity. Both authors did not evaluate the antimicrobial properties of the treated specimens.

The literature documentation of the surface characteristics and microbial adhesion in different samples of dental polymers are shown with greater details in Table 3.

DISCUSSION

This systematic review evaluated the influence of intervention with antimicrobial agents and cleaning agents in polymethylmethacrylate (PMMA) on the surface free energy, wettability, and, consequently, microbial adhesion. The antimicrobials poly para-xylylene, carboxybetaine methacrylate, ethylene glycol methacrylate phosphate, and deposition of F and Ag double ions in PMMA changed the surface characteristics and the adhesion of microorganisms, as well as the cleaning agents evaluated, with or without a direct relationship between both properties.

The electrostatic condition of the PMMA can be evaluated by physicochemical properties of the surface as SFE, wettability, roughness, and surface electrochemistry, since forces how Coulomb, Van der Waals, electrostatic charge, and Lewis acid-base interactions are strongly influenced by the size and shape of the charges of the PMMA. These characteristics can be attracting or repel other molecules and microorganisms.[15]

The low SFE of the material can influence initial microbial adhesion, promote less retention, and reduce biofilm formation.[3] Bourlidi *et al*. (2016)[3] did not evaluate the antimicrobial effectiveness of the PMMA with parylene C, focusing only on the SFE. Samples coated with parylene N showed a reduction of *Candida albicans* adhesion, despite the increase of SFE.[10] However, it was no observed difference in *C. albicans* adhesion between PMMA coated with parylene C and uncoated samples.[16] It was observed that the type of parylene used in the treatment of PMMA influences the adhesion of microorganisms since the parylene N shows a unique molecular movement on deposition in polymer surface, which gives superior penetration abilities to parylene C.[16]

Although cleaning agents act on the prosthesis after the biofilm formation, their interaction with the surface of the material can promote changes. Fernandes *et al*. (2010)[5] evaluated the SFE of the PMMA and polyamide resin before treatment with cleaning agents. There is a lack of studies in the literature that assess the influence of the denture cleaners on the SFE the PMMA before the biofilm formation, thus, a correlation between the surface changes generated by these agents and the microbial adhesion can be established. As for the better antimicrobial efficacy observed in the 0.5% NaOCl (sodium hypochlorite) in relation to denture cleaners,[5] another study also demonstrated lower colonization by *C. albicans* and *C. glabrata* in PMMA after treatment with 0.5% NaOCl compared to other denture cleaners and sodium bicarbonate solution,[17] corroborating with the result found by the article included in this review.

Hyaran *et al*. (2017)[7] did not observe a relationship between the SFE of the different resins and the spreadability of the biofilm, since the polyamide resin showed the second-highest SFE, the lowest adhesion of microorganisms, and surface smoothness. The surface roughness appears to be related to microbial adhesion, as the authors reported that the high-impact and conventional PMMA had greater biofilm spreadability and irregular surface, despite the lower SFE of high-impact PMMA. Therefore, bacterial adhesion to resins has not been fully elucidated based on hydrophilicity and SFE, and there is no consensus in the literature. Hahnel *et al*. (2012)[18] did not find a correlation between the SFE of denture base resins and the adhesion of microorganisms, while Cazzaniga *et al*. (2015)[19] cited that a high SFE increases bacterial adhesion in relation to a substrate with low SFE. In addition, some failures prevent the proper analysis of Hayran *et al*. (2017)[7] study, since the authors did not include an adequate control group for comparison, and also did not evaluate the influence of cleaning agents on the SFE of the resins, thus, it is not possible to compare SFE and microbial adhesion in this study.

Jin *et al*. (2020)[8] and Shinonaga and Arita (2017)[9] it was observed that the intervention with CBMA and FAgID in PMMA, respectively, reduce the wettability and microbial adhesion. However, a statistical test to verify the correlation between these properties should be performed. The coefficient of Pearson, which measures the degree of linear correlation between two variables, could be applied. Also called "product-moment correlation coefficient" or "Pearson's ρ", uses a metric scale ranging from 1 (positive correlation between the variables) to -1 (negative correlation between the variables).[20] From this analysis, it would be possible to conclude if the wettability in fact influenced the biofilm formation in these studies.

Puri *et al*. (2008)[14] did not evaluate the antimicrobial activity of phosphate group substitution via incorporation of ethylene glycol methacrylate phosphate (EGMP) into PMMA, but this intervention increased the wettability, causing a decrease in the hydrophobicity of the PMMA. Also, no studies were found evaluating the antimicrobial potential of EGMP. Park *et al*. (2003)[21] and Park *et al*. (2008)[22] suggested that *Candida* adhesion in resins can be reduced by the increase of the hydrophilicity. Meirowitz *et al*. (2021)[23] reported that *Candida*'s proteins, as mucins, have high adhesion ability, even on hydrophobic surfaces, facilitating biofilm formation.

Table 3. Literature documentation of the surface characteristics and microbial adhesion in different samples of dental polymers.

Author, year	Type of sample	Evaluated surface property	Evaluation of microbial adhesion	Results/Conclusions
Bourlidi *et al.* (2016)	Polymethylmethacrylate (PMMA) coated with 10 µm, 20 µm and 30 µm thick layers of Parylene C.	Surface free energy (SFE) and Roughness (Ra) of treated PMMA.	Not evaluated.	Coating with 10 µm layer of Parylene C had a smoothing effect on surfaces that resemble the denture adaptation surface, but did not reach Ra values below the limit of 0.2 µm of colonization microbial. The use of a 10 µm coating produced favorable results compared to a 20 µm and a 30 µm coating in relation to the surface roughness of the acrylic resin. Regarding SFE, coating with Parylene C of all thicknesses resulted in specimens with values statistically significantly higher than their uncoated counterparts.
Fernandes *et al.* (2010)	PMMA and Poliamida treated with enzymatic cleaning solution, for 3 minutes, sodium bicarbonate-based cleaning solution, for 5 minutes, and 0,5% sodium hypochlorite, for 10 minutes.	Contact angle and Surface free energy (SFE) of PMMA and Polyamide without the cleaning agents.	Individual and united development of the *Candida albicans* and *Candida glabrata* biofilm, under the action of cleaning agents.	PMMA exhibited significantly higher SFE than the polyamide resin and all tested biofilms (single and double species) showed significantly higher growth on the polyamide resin. Denture cleaners significantly decreased *Candida* spp. levels compared to the negative control, however, 0.5% NaOCl solution was the only effective agent as no viable cells were observed after the treatment. There was no significant difference between denture cleaning solutions in reducing *Candida* spp. levels. The denture cleaners resulted in a greater reduction of *C. albicans* than *C. glabrata* in the biofilm of both species. However, the statistical analysis revealed no significant interactions between the material, type of biofilm, and treatment.
Hayran *et al.* (2017)	Different types of resins (conventional heat-polymerized PMMA, high impact heat-polymerized PMMA and thermoplastic polyamide resin obtained by the rapid injection technique) treated with Corega and Fittydent alkaline peroxide denture cleanser tablets and Polident 3 min neutral peroxide enzymatic denture cleanser.	Contact angle, Surface free energy (SFE) and Wettability of dfferent types of resin without the cleaning agents.	Adhesion of *Candida albicans* biofilm, under the action of cleaning agents.	The heat-polymerized PMMA exhibited the highest SFE value, while the lowest values were found for the high-impact heat-polymerized PMMA. The wettability value of these resins was in the following order: heat-polymerized PMMA> thermoplastic polyamide resin by rapid injection technique> high impact heat-polymerized PMMA. According to the results of the antimicrobial tests, Polident 3 minutes and Corega tablets exhibited strong anticandida effects on *C. albicans* biofilm in all denture resins with 2 tablets/150 mL of water concentration, whereas Fittydent showed only anticandida effects against biofilm in the thermoplastic polyamide resin with 2½ tablets/150 mL of water concentration. Corega's anticandida activity was higher in polyamide thermoplastic resins obtained by the rapid injection technique and high impact heat-polymerized PMMAcompared to Polident and Fittydent. However, the anticandida activity of Polident 3 minutes was stronger in conventional heat-polymerized PMMA. *C. albicans* biofilm effectively spread on the conventional and high impact heat-polymerized PMMA resins surface, due to fissures and notched on the surface. The thermoplastic polyamide resin displayed a smooth and regular texture. The results describe a high anticandida effect which is directly dependent on the concentrations of the tablets used and it was shown that the anticandida activity appears to be a function of the nature of the resins, their harshness, type of cleaner and specific cleaner concentrations.

Table 3 continued overleaf

Table 3 continued: Literature documentation of the surface characteristics and microbial adhesion in different samples of dental polymers.

Author, year	Type of sample	Evaluated surface property	Evaluation of microbial adhesion	Results/Conclusions
Jin *et al.* (2020)	Powder of the antimicrobial Carboxybetaine Methacrylate (CBMA) embedded in PMMA at concentrations of 0% (control), 0.75%, 1.5%, 3%, 5% and 7.5%.	Wetability of treated PMMA.	Adhesion of multispecies biofilm of *Candida albicans, Actinomyces naeslundii, e Veillonella parvula*	The results showed a decreasing trend for wettability with increasing amounts of CBMA. Control samples had the highest mean contact angle, while 7.5% CBMA samples had the lowest. The amount of adsorbed microorganisms was greater for the control group than for the other experimental groups. However, all groups were covered with live microorganisms, the surface of the control group exhibited greater amounts than those of the test groups, and the 3% CBMA groups exhibited the least bacterial adhesion. Overall, the results indicate that the ability of PMMA with 3% CBMA to inhibit bacterial adhesion was significantly greater than the control. The addition of an adequate amount to PMMA inhibited the adhesion of fungi and bacteria and suppressed multispecies biofilm growth.
Puri *et al.* (2008)	PMMA incorporated with ethynoglycol methacrylate phosphate (EGMP) with 10, 15 and 20% by volume of the liquid MMA monomer.	Wettability of the samples.	Not evaluated.	There was a general trend of decreasing contact angle with increasing phosphate concentration. This indicates greater hydrophilicity with the addition of phosphate. The polished surfaces also had significantly smaller contact angles than the unpolished samples.
Shinonaga *et al.* (2012)	PMMA with F ion-implanted and –deposited (FID-PMMA) and F and Ag ion-implanted and -deposited (FAgID-PMMA).	Contact angle and Surface analyze by AFM of modified PMMA.	Adhesion of *Staphylococcus aureus* biofilm.	The water contact angles of the FID-PMMA and FAgID-PMMA surfaces were significantly larger than the PMMA surface and the PMMA surface was relatively flat, while the FID-PMMA and FAgID-PMMA surfaces had a similar structure to a valley-hill. The surface roughness values of FID-PMMA and FAgID-PMMA were not significantly different from those of the PMMA surface and the surface of PMMA implanted and deposited with F and Ag double ions exhibited hydrophobic properties. Antibacterial activity was notably increased in PMMA implanted and deposited with double ion F and Ag, which highlights the potential of this method to confer antibacterial properties.
Zhou *et al.* (2010)	PMMA and silicone elastomer coated with 5 mm thick parylene N.	Contact angle and Surface free energy (SFE) of the treated acrylic resin.	Adhesion of *C. albicans* to surfaces with and without parylene coating.	The contact angle values of the silicone elastomer (A-2186) significantly decreased after the parylene coating treatment, while in the case of the PMMA (lucitone 199), there was no statistically significant difference between before and after the parylene coating. The surface energy value of the A-2186 silicone elastomer was lower than that of the A-2186-parylene, while there was no significant difference between the free surface energy of lucitone 199 and L199-parylene. Adhesion of *C. albicans* to surfaces of silicone elastomer A-2186 and lucitone 199 PMMA before and after parylene coating was shown to be significantly different. This result indicated that parylene coated with silicone elastomer and resin for denture base can reduce the adhesion of *C. albicans* to its surface.

Functionalization of the PMMA, either with a coating or incorporation of antimicrobials, provides changes in the surface characteristics which prevents microbial adhesion and, consequently, infections, due to the release of chemical compounds that interacts with bacterial and fungal cells.[6,11] These studies can be further explored in order to investigate surface changes that alter electrostatic charges, SFE, hydrophobic characteristics, and their relationship with biofilm formation.

By the adopted methodology, it was verified that the incorporation or treatment of the PMMA with antimicrobials and cleaning agents alters the SFE and wettability, as well as the biofilm formation due to the antimicrobial action of the agents. However, the correlation between these properties is still not clear. Also, there is a lack of statistical correlation tests to confirm the influence of one property on another.

CONCLUSION

Based on the results of this systematic review, it was concluded that intervention with antimicrobial agents and cleaning agents in PMMA can influence surface free energy and wettability. Furthermore, the agents were also able to reduce microbial adhesion, but the correlation between the two is not clear.

MANUFACTURERS DETAILS

- Peroxide enzymatic Cleaning Solution: Polident 3 minute; Polident- GSK Oral Health Partner, Middlesex, United Kingdom.
- Alkaline peroxide: Corega Tabs; Block Drug Co, Jersey City, NJ, USA.
- Alkaline peroxide: Fittydent Cleansing Tabs; Fittydent International GmbH, Wien, Austria.
- 0,5% Sodium Hypochlorite: Proderma Pharmacy, Piracicaba, Brazil.
- Lucitone 199 resin: Dentsply International, York, PA, USA.
- A-2186 Silicone Elastomer: Factor II, Inc, Lakeside, Ariz, USA.

DISCLOSURE STATEMENT

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