Influence of the Incorporation of Antimicrobials on the Impact Strength of Acrylic Resins: A Scoping Review

Keywords

PMMA
Impact Strength
Acrylic Resin
Antimicrobial Agent

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ABSTRACT

Introduction: The incorporation of antimicrobials into acrylic resins promotes the reduction of pathogenic microorganisms and positive impact on the health of users of prosthetic devices. This incorporation may cause changes in the physicochemical and mechanical properties, such as impact strength. Objective: The objective was to answer the question "Does the incorporation of antimicrobials alter the impact strength of acrylic resins?" Methods: The Preferred Reporting Items for Systematic Reviews and Extension of Meta-Analyses for Scoping Reviews (PRISMA-ScR) Checklist guidelines were used. SCOPUS, PubMed, EMBASE, and Science Direct databases were used with the custom search strategy. Studies were selected in two steps. Risk of bias analysis was performed with the quasi-experimental studies tool by the Joanna Briggs Institute (JBI). Results: As a result, 826 articles were found in the databases, and after removing duplicates and applying the proposed eligibility criteria, 11 studies were selected for the qualitative analysis. After applying the JBI tool, a low risk of bias was deferred to all studies. Due to the heterogeneity of the studies, it was not possible to provide a meta-analysis. Conclusion: The incorporation of antimicrobial agents into acrylic resins can, depending on the antimicrobial and the incorporation technique, affect impact strength.

INTRODUCTION

Acrylic resin is a non-resorbable polymer that results from the reaction between the compounds polymethylmethacrylate (polymer) and methyl methacrylate (monomer) through the linking of monomers in a polymeric macromolecule[1,2]. Its versatility enables its application in prosthetic devices because, despite limitations including a low thermal expansion coefficient and low flexural and impact strength, it is simple to manipulate, simple to finish and polish, has good aesthetics, and can be repaired[1-7].

The main causes of fractures are: accidental falls on hard surfaces, usually related to the motor difficulties of elderly users during handling, and fatigue fracture, which consists of deformation by excessive and repetitive masticatory forces, which promote wear[1,5,7,8,9]. In addition, occlusal mismatch, cracks, pores, presence of residual monomer, and lack of adequate mucosal support are characteristics that increase susceptibility to fracture[1,6,7,8,9]. Maxillary prostheses typically fracture by a combination of fatigue and impact forces, while mandibular prostheses are more associated with fractures from impact forces[1,2].

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Impact strength measures the contact force necessary to cause a fracture in a prosthesis[5,10]. To evaluate it, energy is applied by a moving pendulum that hits the static material[11,12]. The energy absorbed in the fracture, considering the dimensions of the evaluated specimen, corresponds to its impact strength[11-13]. Mechanical impact tests that use pendulums are Izod and Charpy and are performed with bar-shaped specimens, which may or may not contain stress-concentrating notches. In the Izod impact tests, the specimens, in the vertical position, are attached by their lower end to the base of the equipment and mechanical stress occurs at the upper end (similar to tests on a cantilever beam). In the Charpy impact test the specimens, in the horizontal position, are supported by their ends, and the mechanical stress is applied at the center (similar to the three-point bending test)[11,13]. Because they feature a simplified geometry of the specimens, the Izod and Charpy tests are suitable for classifying the impact load response of a material[13]. Although there is consistency between their results, the differences between the two techniques prevent their results from being converted into each other.

When an impact stress is applied, failure occurs in the form of microcracks, which then spread rapidly and eventually lead to macroscopic failure[13,14]. However, impact strength can be influenced by the geometry and thickness of the sample, the inhomogeneous distribution and particle size of the acrylic resin, as larger particles settle when mixed with the monomer, which reduces impact strength[8].

The incorporation of nylon fibers, polyamide fibers, and glass fibers acts as a reinforcement structure in the chemical composition of the resin and is an alternative to improve the properties because they fill the empty spaces in the polymer matrix and facilitate the stress distribution pattern[2]. Titanium (TiO2), silver nanoparticles (AgNPs) and zirconia particles have been incorporated as they have high surface area and better distribution, in addition to their morphology, loading, and particle type that may favor improvement[7,15]. The systematic review performed by Gad *et al*, reports that the modifications in the chemical composition of the acrylic resins improve the mechanical properties, but that there is still no material that contains all the ideal characteristics for clinical application[15].

Allied to the condition of a modification of the acrylic resin, one should consider the surface characteristics such as roughness, and porosity that may favor the growth and accumulation of microorganisms such as *Candida albicans*[1,16-18]. Infections, prosthetic stomatitis, and systemic diseases such as aspiration pneumonia, infective endocarditis, and pulmonary candidiasis may be related to prosthetic biofilm[17,18]. Associated with the difficulty of complete disinfection and rapid microbial recolonization, promoting antimicrobial action is an alternative for health promotion[19,20]. In view of this, silver nanoparticles, chitosan, quaternary ammonia, antimicrobial copolymers, and acrylic monomers have been incorporated into the formulation of acrylic resins to promote antimicrobial activity[5,17,18].

The incorporation of antimicrobials into the polymer matrix is performed by different methods, such as manual inclusion, extrusion, vacuum spatulation, and polymer film technique[21]. When added in higher concentrations, the distribution of the antimicrobial particles is impaired and promotes the formation of agglomerates, which, in addition to acting as stress concentrators, reduce the antimicrobial action and mechanical properties as flexural and impact strength[22,23], explained by the insufficient penetration of polymer chains into the spaces between the nanoparticles of the antimicrobial material that causes the poor formation of the interphase zone[23].

In the studies by Takamiya *et al*, Castro *et al*, Santos *et al*, Cierecha *et al*, modification of acrylic resins with antimicrobials showed a reduction of the microorganisms *Candida albicans*, *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus mutans* and *Pseudomonas aeruginosa*[16,17,24,25]. Furthermore, the incorporation of 0.5% silver nanoparticles and nanostructured silver vanadate decorated with silver nanoparticles did not promote changes in the flexural strength[17] and improved the hardness and compressive strength of the modified acrylic resins[25].

The development of acrylic resins with antimicrobial activity and improved mechanical properties is an interesting proposal in relation to health promotion and longevity of dental treatment, besides being a timely research topic, since more and more manufacturers are dedicating themselves to the incorporation of antimicrobial products in dental polymer-based restorations, but such modifications should maintain the mechanical properties already defined as the gold standard for the use in prosthetic devices. Thus, this study aims to analyze the literature and answer the question "Does the incorporation of antimicrobials alter the impact strength of acrylic resins?"

METHODS

This scoping review was registered in the OpenScience Framework (osf.io/pu34c) and prepared according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist in order to answer the question, "Does the incorporation of antimicrobials alter the impact strength of acrylic resins?"

The Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework is illustrated in Table 1.

Table 1. PICOS model used in the study.

P	Acrylic resins
I	Antimicrobial agent
C	control group
O	Impact Strength
S	*In vitro* studies

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Appropriate keywords were selected with the terms of the Medical Subject Heading combined with the use of boolean operators (AND, OR). The SCOPUS, PubMed/Medline, EMBASE, and Science Direct databases were searched with the following keywords: ("acrylic resin") AND (Antimicrobial OR antibifilm OR bactericide) AND ("impact strength" OR "impact resistance").

For each database, a customized search strategy was performed, as can be seen in Table 2. All searches were conducted in November 2022. In addition to the electronic search, a manual search was performed, and the reference lists of the selected articles were displayed.

A two-stage selection of articles was conducted. The initial search was performed by one author (I.F). The articles found in the databases were evaluated by reading the titles and abstracts and discarding the studies that did not fit the inclusion and exclusion criteria. In phase two, the selected studies were fully evaluated. Disagreements regarding inclusion and data extraction were resolved by a discussion with a second and third reviewers (J.A.M.A and A.C.R). The data extracted from the included papers were tabulated in Microsoft Excel (Microsoft® Excel® para Microsoft 365 MSO- Versão 2410 - 64 bits).

Inclusion criteria were: 1) *in vitro* studies; 2) evaluation of denture base resins incorporated with antimicrobial agents; 3) acrylic resins with prosthetic purposes; 4) evaluation of impact strength by the methods Charpy, Izod, or the Dynstat Test specified by the German Standard DIN 53435; 5) no time or language restrictions for study selection.

Exclusion criteria were: 1) articles that did not incorporate antimicrobial agents in the formulation of denture base resins; 2) acrylic resins for orthodontic purposes; 3) PMMA surgical types of cement; 4) no evaluation of impact strength; 5) review articles, book chapters, conference abstracts, short communications, letters to the editor, and patent literature.

Table 2. Search strategies applied in each database (Embase, Pubmed, Scopus, Science Direct).

Database	Search
EMBASE November 11th, 2022	('acrylic resin'/exp OR 'acrylic resin' OR pmma) AND ('antimicrobial'/exp OR antimicrobial OR 'anti biofilm') AND ('impact strength'/exp OR 'impact strength' OR 'impact resistance')
PubMed November 11th, 2022	("acrylic resin" OR PMMA) AND (Antimicrobial OR "anti biofilm") AND ("impact strength" OR "impact resistance")
Scopus November 11th, 2022	(("acrylic resin" OR pmma) AND (antimicrobial OR "anti biofilm") AND ("impact strength" OR "impact resistance"))
Science Direct November 11th, 2022	('acrylic resin' OR PMMA) AND (Antimicrobial OR 'anti biofilm') AND ('impact strength' OR 'impact resistance') filter applied: research articles.

The quasi-experimental studies tool (non-randomized experimental studies) of the Joanna Briggs Institute (JBI) was adapted to assess the risk of bias. For the classification of the methodological quality of the studies, each question was scored with "yes", "no" and " unclear". So when all questions were answered with "yes" the study was considered with high quality (low risk of bias), studies that had from six to seven "yes" were moderate quality (medium risk of bias), and when five or less "yes" low quality (high risk of bias). The analysis was performed by using a software program (RevMan 5.3; The Nordic Cochrane Center).

RESULTS

Eight hundred and twenty-six articles were found in the databases, of these 49 were duplicates and were excluded. For reading in full, 10 articles were selected and of these nine compose this systematic scoping review. One study was not available for full-text access and for this reason, was not included. An additional manual search was performed and two studies were selected to compose this review, totaling 11 studies included. Figure 1 shows the selection process in detail.

The studies incorporated in this scoping review showed a low risk of bias for the questions adapted from the JBI quasi-experimental studies tool. Only the studies by Menezes *et al* and Jani *et al* presented "unclear risk" for the question "Was appropriate statistical analysis used?", because the studies do not address in detail how the statistical analysis of the data expressed in the results of their respective studies was performed. Figures 2 and 3 show in detail the qualitative analysis of the risk of bias.

The characteristics of the studies are detailed in Table 3.

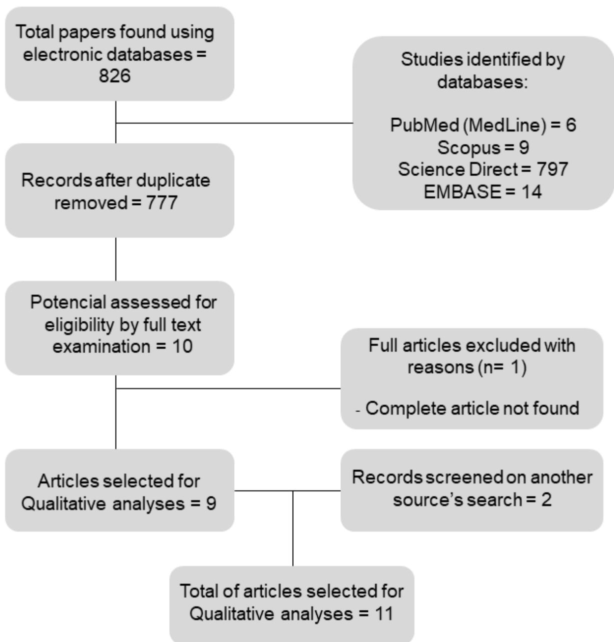

Figure 1: Flow diagram of literature search and selection criteria.

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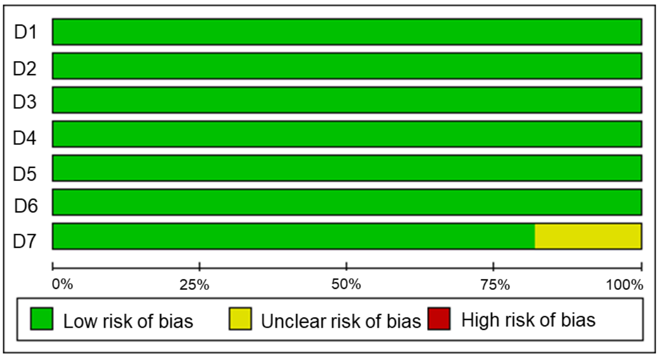

Figure 2: Qualitative analysis with adapted the quasi-experimental studies appraisal tool by the Joanna Briggs Institute. D1-Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?; D2- Were the specimens included in any comparisons similar?; D3- Were the specimens included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?; D4- Was there a control group?; D5- Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?; D6- Were the outcomes of participants included in any comparisons measured in the same way?; D7- Was appropriate statistical analysis used?

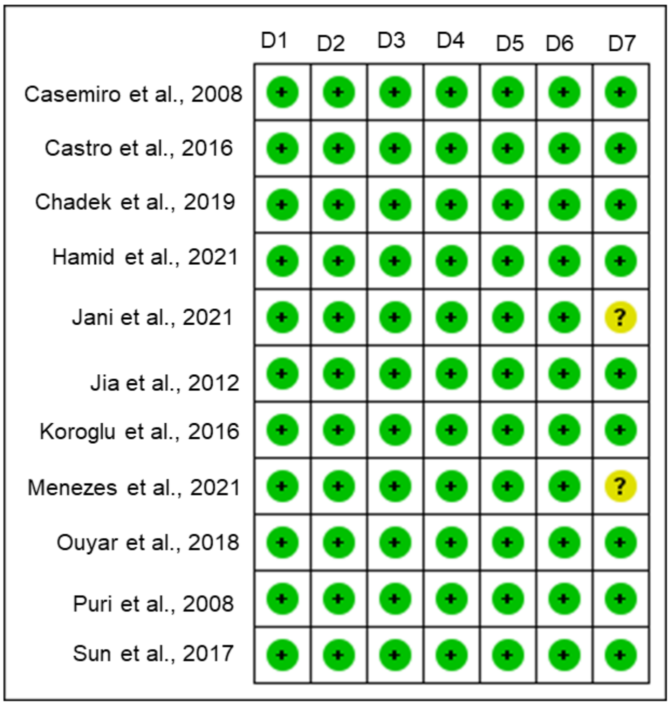

Figure 3: Qualitative analysis of each study according to adaptation of the Joanna Briggs Institute's quasi-experimental studies evaluation tool. D1-Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?; D2- Were the specimens included in any comparisons similar?; D3- Were the specimens included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?; D4- Was there a control group?; D5- Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?; D6- Were the outcomes of participants included in any comparisons measured in the same way?; D7- Was appropriate statistical analysis used?.

The studies that comprise this review performed the incorporation of antimicrobial agents to the composition of acrylic resins (polymethylmethacrylate - PMMA) heat-polymerized[6,26-31,33,34], self-cured[28,35], microwave-polymerized[30,31]. Most studies performed the incorporation of materials containing the silver ion, such as silver ion nanoparticle (AgNPs)[28,35]; $AgVO_3$[26]; silver-zinc zeolite[31]; NAg[32]; and silver sodium hydrogen zirconium phosphate (S – P)[34]. The nanomaterial nano Selenium (Se) was incorporated[27]. The study by Hamid *et al* incorporated a natural antimicrobial agent *Azadirachta indica* (AI)[29], and Puri *et al*, incorporated ethylene glycol methacrylate phosphate (EGMP)[6] *(Table 4*).

The acrylic resins modified with the antimicrobials were compared to a control group, that is a group without the modification. For the evaluation of the impact strength three methods were used, the Charpy[27,29,30,33,34], the Izod[6,26,28,31,35], and the Dynstat Test specified by the German Standard DIN 53435[32], demonstrated in Figure 4. Specimens were prepared according to ISO179-1:2010[27,34], ISO 180:2001[27,31], ISO 1567: 1999[29,30,33], DIN 53435[32], and ASTM D256[26,28].

The studies of Castro *et al.*[28], Jani *et al.*[27], Sun *et al.*[32], and Chladek *et al.*[34] performed the impact strength test with specimens without notching, while Menezes *et al.*[26], Hamid *et al.* [[29]], and Puri *et al.* [[6]], performed notching on their specimens, the one by Hamid *et al* in V-shape[29]. Casemiro *et al.*[31], Oyar *et al.*[33], Koroglu *et al.*[30], and Jia *et al.*[35] did not mention notching in their studies. *(Table 5*)

The results were varied regarding the mechanical performance of the acrylic resins modified with antimicrobials. Most studies showed no statistically significant differences between the control groups and the groups with the incorporation of antimicrobials[6,26,29,30,32-34]. In contrast, the results of Castro *et al.*[28], Jani *et al.*[27], and Casemiro *et al.*[31] showed a reduction in the impact strength of modified acrylic resins compared to the control group. *(Table 6*)

DISCUSSION

The correlation between changes in the mechanical properties of denture base resins to provide durability and functional effectiveness of prosthetic devices, in contrast to the need for materials with antimicrobial properties that can promote health and prevent diseases in the elderly, motivates studies such as this one, which aims to analyze the current state of the art regarding the correlation of research that presents antimicrobial activity with mechanical behavior, by evaluating impact resistance.

Antimicrobial agents have emerged as an alternative to reduce the public health problem of bacterial resistance to conventional antibiotics, because they are capable of acting through different mechanisms of action, such as inducing the production of reactive oxygen species (ROS), damaging the cell membrane, blocking bacterial DNA replication[20,36,37].

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Table 3. Data extraction of the articles selected to compose this review.

Author year	Objective	Antimicrobial Agent and incorporation	Assays	Results and Main conclusions
Casemiro et al., 2008[31]	To evaluate the impact strength and antimicrobial activity of acrylic resins incorporated with different percentages of silver-zinc zeolites.	Silver-zinc zeolites incorporated with 2.5%; 5.0%, 7.5% and 10.0% polymer of two heat-polymerized resins (QC20 and Lucitone 550) and a microwave-polymerized resin (Onda-Cryl).	Impact strength Izod n=10 5.5J load and did not report notching.	Incorporation of 5%, 7.5% and 10% zeolite into the QC20 resin decreased impact strength ($p < 0.05$). There was no statistical difference ($p > 0.05$) between the control and the 2.5% group. A significant decrease in impact strength was observed for Lucitone 550 resin in all groups with silver-zinc zeolite incorporation. No significant differences were found between the 5% and 7.5% groups and between the 5% and 10% groups ($p > 0.05$). The Onda-Cryl resin showed reduced impact strength with zeolite incorporation at 5% ($p < 0.05$). The control and 2.5% groups showed no statistical differences ($p > 0.05$).
Castro et al., 2016[28]	To evaluate the antibacterial activity and impact strength of two acrylic resins incorporated with different percentages of b-$AgVO_3$.	Nanostructured silver vanadate decorated with silver nanoparticles (b-$AgVO_3$) incorporated at 5% and 10% to the polymer of self-cured and heat-polymerized acrylic resins.	Impact strength Izod n=10 2J load without notch.	The groups with 5% (70.60 J/m) and 10% (51.10 J/m) showed significant reduction in impact strength compared to control (157.70 J/m) for self-cured resin and 5% (67.90 J/m), 10% (53.50 J/m) and control (174.70 J/m) of the heat-polymerized resin. When comparing the resins, there was a significant difference ($p= 0.020$) with higher values for the control group and 10% of the heat-polymerized resin and 5% for the self-cured resin. Thus, it is concluded that the addition of b-$AgVO_3$ to acrylic resins reduced the impact strength.
Chladek et al., 2019[34]	To evaluate the impact strength of acrylic resins modified with Silver and Sodium Phosphate, Hydrogen and Zirconium (S - P) to promote antimicrobial activity.	Silver sodium hydrogen zirconium phosphate (S - P) incorporated into polymer and monomer, respectively, 0.25 and 0.7; 0.5 and 1.3; 1 and 2.6; 2 and 5.1; 4 and 9.9; 8 and 18.6; in heat-cured resin.	Impact strength Charpy n=25 Did not inform the load or the presence of notch.	The incorporation of S-P decreased the resin impact strength values. The mean values after 2 days in distilled water were 18.4 kJ/mm^2 for control and 5.6 kJ/mm^2 for composite for group 8 polymer and 18.6 monomer, which corresponds to 70% reduction. Storage in distilled water caused a reduction in the mean impact strength values ($p<0.05$). Thus, it is concluded that the modified acrylic resin showed a reduction in impact strength was observed after two days stored in distilled water.
Hamid et al., 2021[29]	To investigate the influence of AI polymer on the impact strength of heat-polymerized acrylic resins.	Azadirachta indica (AI) incorporated at 0.5, 1, 1.5, 2 and 2.5 wt% into the polymer of the heat-polymerized acrylic resin.	Impact strength Charpy n=10 5.5J load and a V-shaped notch of 1.2 mm depth.	It was observed that as the concentration of IA incorporated into the acrylic resin increased, the decline in impact strength increased, however, this reduction was not statistically significant. Among the IA groups, the highest impact strength value was in the 0.5%AI group (12.39 ± 1.71), while the lowest value was in the 2.5%AI group (11.74 ± 1.56). Thus, it is concluded that IA polymer incorporated into heat-polymerized acrylic resin polymer as an antifungal agent did not significantly alter the impact strength.
Jani et al., 2021[27]	To investigate the incorporation of different concentrations of Se particles into the mechanical properties of acrylic resins.	Nano-selenium (Se) incorporated at 5%, 10% and 15% to the monomer of the heat-polymerized resin.	Impact strength Charpy n=10 2J load without notch.	A statistical difference was observed between the groups with higher impact strength for the control group with 83.0667 kJ/m^2, 5% Se group with 68.2000 kJ/m^2, 10% Se group with 66.6000 kJ/m^2 and 15% Se group with 62.3333 kJ/m^2. Thus, it can be concluded that the addition of Se nanoparticles contributed to a decrease in the mechanical quality of the heat-cured acrylic resin.
Jia C-L et al., 2012[35]	To investigate the effect of incorporating silver nanoparticles into acrylic resin on impact resistance.	Silver nanoparticles (AgNPs) incorporated at 0.5%, 1%, 1.5%, 2%, 2.5% and 3% into self-curing resin polymer.	Impact Strength Izod n=10 Did not inform the load or the presence of notch.	The incorporation of 1% AgNPs presented the highest impact strength with values of 6.41 ± 0.40 kJ/m^2. It was observed that as the concentration increased, its impact strength decreased, and presented statistical difference compared to the control (6.32 ± 0.96 kJ/m^2) for the 2.5% (5.43 ± 0.57 kJ/m^2) and the 3% (5.21 ± 0.72 kJ/m^2) groups. Thus, it can be concluded that adding larger amounts of AgNPs (2.5% and 3%) to self-cured acrylic resin reduced impact strength.

Table 3 Continued overleaf......

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Table 3. Data extraction of the articles selected to compose this review continued....

Koroglu et al., 2016 [30]	To evaluate the impact strength of two acrylic resins containing AgNPs .	Silver nanoparticles (AgNPs) corporated with 0.3, 0.8, and 1.6 wt% into the monomer of microwave-polymerized and heat-polymerized acrylic resins.	Impact strength Charpy n-=7 Did not inform the load or the presence of notch.	The addition of AgNPs had no effect on the impact strength of both resins (p>0.05), obtaining for the heat-polymerized resin the values control group 12.32 kJ/m², 0.3% group 10.78 kJ/m², 0.8% group 11.64 kJ/m² and 1.6% 11.14 kJ/m². For the microwave-polymerized resin, the values were obtained for the control group 10.93 kJ/m², 0.3% 10.80 kJ/m², 0.8% 10.35 kJ/m2 and 1.6% with 10.37 kJ/m2. Thus, it is concluded that the addition of AgNPs had no effects in terms of impact strength in the acrylic resins evaluated.
Menezes et al., 2021 [26]	To evaluate a new incorporation process of $AgVO_3$ into acrylic resin and its influence on impact strength	Silver vanadate ($AgVO_3$) incorporated at 0.5% into the polymer of the heat-polymerized acrylic resin.	Impact strength Izod n= 6 1.0J load and with notch.	The control group showed impact strength of 134.1 J/m and the $AgVO_3$ group was statistically similar to the control group with 137.3 J/m, but the $AgVO_3$ group silanized with γ-methacryloxypropyltrimethoxysila ne (MPS) showed higher impact strength with 146.4 J/m. Thus, the results suggest that the application of the silane MPS in $AgVO_3$, can produce an acrylic resin with superior mechanical properties.
Oyar et al 2018 [33]	To evaluate the impact strength of acrylic resins incorporated with AgNPs.	Silver nanoparticles (AgNPs 40nm, 50nm e 60nm) incorporated at 0.05% and 02% in each nm into the monomer of heat-polymerized acrylic.	Impact strength Charpy n=7 Did not inform the load or the presence of notch.	There were no statistical differences between the groups with incorporation of different sizes of AgNPs particles to the acrylic resin, however, a small improvement in impact strength was observed for the group with 0.05% AgNPs 60 nm. Thus, it is concluded that the addition of silver nanoparticles showed no effects on the impact strength of the acrylic resin evaluated.
Puri et al., 2008 [6]	To determine the effect of replacing the phosphate group by the incorporation of EGMP on the impact strength of acrylic resins.	Ethylene glycol phosphate methacrylate (EGMP) incorporated at 10%, 15% and 20% to the monomer of the heat-polymerized acrylic resin.	Impact strength Izod n= 16 2J load and a notch depth of 1.2 ±0.1 mm.	No statistical differences were found among the groups evaluated, with the impact strength of the control group being 4.56 kJ/m², the 10% group 4.59 kJ/m², the 15% group 4.52 kJ/m², and the 20% group 4.28 kJ/m². Thus, it can be concluded that incorporation of phosphate into acrylic resin by monomer substitution does not negatively affect its impact strength.
Sun et al., 2017 [32]	To evaluate the method of preparation of PMMA incorporated with NAg and the impact strength.	Nano Prata (NAg) incorporated 1:3 (v:v) resin polymer and 3:6:2 (v:v:w) resin monomer. It was not informed which type of resin.	Impact strength DIN n=12 Did not inform the load or the presence of notch.	There was no statistical difference between the groups incorporated with NAg for control group impact strength values was 6.33±0.28 kJ/m², polymer-incorporated NAg group 6.35±0.68 kJ/m² and monomer-incorporated NAg group 6.47±0.36 kJ/m². Thus, we can conclude that NAg incorporation exhibited impact strength in accordance with clinical requirements.

EGMP= Methacrylate ethylene glycol phosphate; EGDMA= ethylene glycol dimethacrylate; $AgVO_3$= Silver vanadate; $AgVO_3$-M= VSilver vanadate modified with γ-methacryloxypropyltrimethoxysilane; MPS= γ-methacryloxypropyltrimethoxysilane; b-$AgVO_3$= Nanostructured silver vanadate decorated with silver nanoparticles; AI= *Azadirachta indica*; Se= Nano-selenium; AgNPs = Silver nanoparticles; NAg = nano silver; MMA = methylmethacrylate; S – P = Silver sodium hydrogen zirconium phosphate.

Nanoparticles are the most commonly used antimicrobials, including silver, zinc oxide, titanium dioxide and copper nanocomposites[36-38]. Antimicrobial proteins, such as peptides and enzymes derived from the host's defense mechanism, can be used[36,38], as well as chlorhexidine, chitosan, copolymers and acrylic monomers are used in dentistry, as they have the ability to reduce microbial adhesion and biofilm formation[37,39]. It is worth noting that antimicrobials can also be classified as non-leachable, those that become part of the polymeric chain, and leachable or nanoparticulate, however, the studies that make up this systematic scoping review did not perform further analyses that allowed us to perform such a classification.

The correlation between the promotion of antimicrobial activity and changes in the mechanical behavior of acrylic resins must be evaluated in order to identify the clinical predictability of the modified material. Knowledge of the mechanism of

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Table 4. Types of resin, antimicrobial agents and concentrations used.

Acrylic resin	Antimicrobial agent	Concentration
Heat-polymerized	AgNps, Silver ion compounds	0.3, 0.8, 1.6 wt%; 0.05%, 0.2%; 0.5% - 3%
Self-cured	β-$AgVO_3$, $AgVO_3$	5%, 10%; 0.5%
Microwave-polymerized	Silver-Zinc Zeolite	2.5% - 10%
Polymer & Monomer	Silver sodium hydrogen zirconium phosphate (S-P), Nano Selenium, *Azadirachta indica* (AI), EGMP.	0.25 - 18.6; 5%, 10%, 15%; 0.5% - 2.5%; 10%, 15%, 20%

EGMP= Methacrylate ethylene glycol phosphate; $AgVO_3$= Silver vanadate; b-$AgVO_3$= Nanostructured silver vanadate decorated with silver nanoparticles; AI= *Azadirachta indica*; Se= Nano-selenium; AgNPs = Silver nanoparticles; NAg = nano silver; MMA = methylmethacrylate; S – P = Silver sodium hydrogen zirconium phosphate.

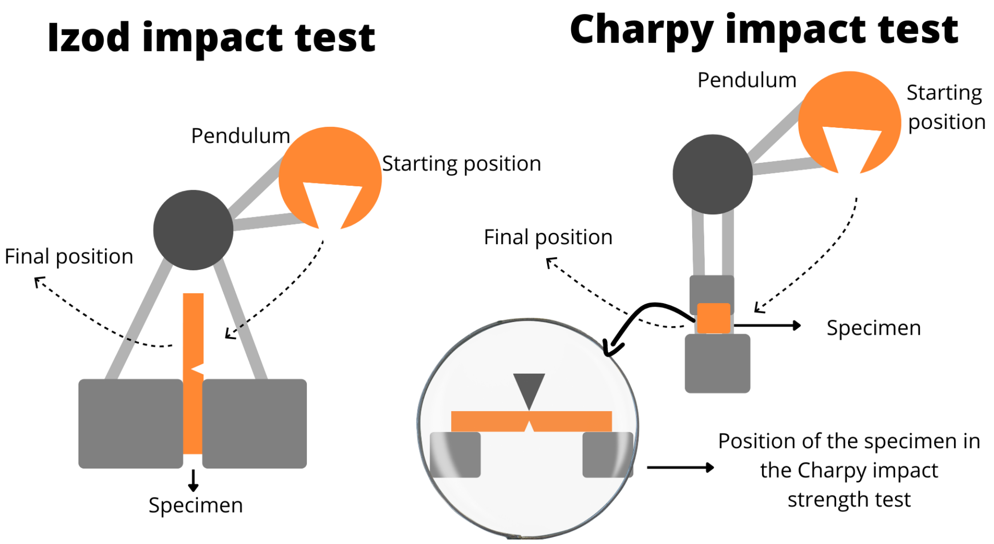

Figure 4: Illustration of Izod and Charpy impact strength tests, showing specimen positioning and equipment design.

Table 5. Methods Used for Impact Resistance Testing.

Study	Method	Standard ISO/DIN/ASTM	Notch
Jani et al	Charpy	ISO179-1:2010	Without notch
Menezes et al	Izod	ASTM D256	With notch
Sun et al	Dynstat	DIN 53435	Without notch
Puri et al	Izod	ISO 180:2001	With notch
Casemiro et al	Izod	ISO 1567:1999	Not mentioned

Table 6. Impact Resistance Results with Different Agents.

Study	Antimicrobial agent	Concentration	Impact resistance (kJ/m² ou J/m)	Results
Puri et al	EGMP	10%, 15%, 20%	4.56 - 4.28 kJ/m²	No significant difference
Menezes et al	$AgVO_3$	0.5%	134.1 - 146.4 J/m	Observed increase (not significant)
Jia et al	AgNPs	2.5%, 3%	6.32 - 5.21 kJ/m²	Significant reduction
Hamid et al	*Azadirachta indica* (AI)	0.5% - 2.5%;	Reduction ($p = 0.175$)	Not a significant reduction

EGMP= Methacrylate ethylene glycol phosphate; $AgVO_3$= Silver vanadate; b-$AgVO_3$= Nanostructured silver vanadate decorated with silver nanoparticles; AI= *Azadirachta indica*; Se= Nano-selenium; AgNPs = Silver nanoparticles; NAg = nano silver; MMA = methylmethacrylate; S – P = Silver sodium hydrogen zirconium phosphate.

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action of each antimicrobial agent, as well as their concentrations, can enable strategies to reduce the quantities incorporated, since fewer alterations to the polymeric matrix are observed with small concentrations, with consequent maintenance of the material's resistance.

In dentistry, silver nanoparticles and titanium dioxide are the materials most commonly used as antimicrobial agents[37]. The studies included in this scoping review, in agreement with Steve An's review, mainly presented the use of silver nanoparticles, such as AgNPs[30], b-$AgVO_3$[28], $AgVO_3$[26], silver-zinc zeolite[31], nanosilver (NAg)[32]. The mechanism of action of AgNPs is based on their adhesion to the microbial cell wall and cytoplasmic membrane, which allows the absorption of silver ions and the inactivation of respiratory enzymes, which leads to the production of ROS, which act to rupture the cell membrane and modify deoxyribonucleic acid (DNA); with consequent microbial death. It is recommended that, when in small quantities, they are not cytotoxic and do not cause immune responses[39].

The trace element Selenium (Se) is responsible for maintaining normal biological functions and preventing oxidative damage to cells[40,41]. As an antimicrobial agent, it acts to inhibit bacterial proliferation and biofilm formation by altering osmotic balance, which promotes the breakdown of bacterial cell membrane integrity. In addition, it can act in the promotion of cell contraction and the formation of ROS in bacteria[40-42]. In its nanoparticulate form, Se has low toxicity, greater bioavailability, wide distribution potential, greater surface area and controlled release activity, which enhances its action and antimicrobial efficacy[40]. Jani *et al.* found that the lowest percentage of 5% Se showed no antimicrobial efficacy and that higher concentrations of 10% and 15% were effective[27].

The natural antimicrobial *Azadirachta indica* (AI) is derived from a medicinal tree from the Indian subcontinent and is popularly known for its applications in products used in traditional medicine[29,43]. Its alkaloid and flavonoid components are responsible for the ability to prevent microbial infections. Moreover, it is suggested that its mechanism of action is linked to azadirachtin, the bioactive metabolite that presents the inhibitory activity of enzymes involved in DNA replication, which infer in its indication as an antimicrobial agent[43].

The antimicrobial action of ethylene glycol methacrylate phosphate (EGMP) is due to the alteration of electrostatic charges promoted by the incorporation of phosphate into its composition[6]. This change transforms the acrylic resin surface into hydrophilic, that is, less susceptible to microorganism adhesion because hydrophilic surfaces affect cell interactions, bacterial adhesion, and biofilm formation[6,44].

The studies that compose this scoping review[6,26-35] evaluated the influence of incorporating antimicrobials on the impact resistance of acrylic resins. Specimen thickness and geometry, stress concentrations, manufacturing variables, resin type, and chemical composition are some characteristics that can alter impact strength because they are characteristics directly responsible for the arrangement and bond strength between the polymer chains, which can lead to changes in the mechanical behavior[5,13,45-47]. Thus, in this review, it was not possible to perform the correlation of the results of the different studies, because they presented incomparable parameters to enable the formation of consolidated conclusions[13,45,46].

Another factor that is directly linked to impact strength is notching, characterized as a preparation that concentrates stress, overcomes surface defects in the specimen, and directs the fracture in a specific direction[13]. Notches can be prepared during or after specimen preparation[10,13] and depending on the time, some problems can occur, such as causing a change in the radius of the notch and causing residual stresses and hidden cracks, respectively, and for this reason, making specimens for this assay is a challenge[10].

Watannabe *et al.*[10] developed a technique to perform impact strength testing with small specimens prepared by CAD/CAM blocks and report the difficulty in obtaining standardized samples that allowed faithful representation of the strength by this new method. They concluded that specimens 12 mm in diameter by 1.5 mm thick can be used for impact strength evaluation[10].

ISO 179-1:2010 and ASTM D256 report that Charpy and Izod impact strength tests can be performed with or without the presence of the notch, but the results obtained are different and thus difficult to be compared[48,49]. Some studies that make up this scoping review used samples without notch[27,28,32,34] and others with notch[6,26,29], which corroborates the difficulty of comparing the results of the selected studies. The notch test offers a conservative assessment that is close to the real failure conditions, since materials suffer initial failures due to imperfections. The non-notched test is used when the general capacity of the material to absorb impact energy without failing is to be assessed. For the selected studies, we can consider that prosthesis bases have openings made for the correct positioning of brakes and muscle inserts, which can act as notches. Therefore, the results of specimens with notches are more representative of real conditions.

The influence of antimicrobial incorporation on the impact strength property was evaluated according to three methodologies: Charpy[27,29,30,33,34], Izod[6,26,28,31,35], and the methodology described in DIN 53435[32]. Improved impact strength results after antimicrobial incorporation were found in the study by Menezes *et al.*[26] This enhancement can be attributed to the silane MPS layer that was applied to the polymer matrix to enhance $AgVO_3$ contact and dispersion[26,50]. The silanization process, which involves hydrolyzing MPS, promotes the formation of silanol groups, in turn, form covalent bonds with the hydroxyl present on the surface of $AgVO_3$. According to FTIR results, this process allows for the modification of the material's surface charge, hydrophobicity, and stability, which enabled better homogenization of the antimicrobial to the polymer matrix[26,50].

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The systematic review published by Somani *et al.*[8] reports that the incorporation of reinforcing fibers, such as glass, metals, and carbon, act as loading components to assist in dissipating forces, however, for the incorporation to result in improved mechanical behavior, such as impact strength, the fibers must be stiff and exhibit adequate adhesion to the polymer, which can be achieved by silanizing the particle[8].

It was expected that an acrylic resin close to the ideal would be found, one that presented better mechanical performance to impact resistance and the presence of antimicrobial activity. However, some challenges were encountered by researchers that made it impossible to develop this, such as the studies by Castro *et al*., Jani *et al*., Casemiro *et al*., and Jia *et al*. which reported reduced impact strength[27,28,31,35]. Van Der Waals interactions and the weak interfacial adherence of antimicrobials with the organic matrix may be responsible for the formation of agglomerates, which, besides causing surface defects such as micro-cracks and pores, may also act as stress concentrators, weakening the system and providing the greater possibility of fracture[27,28,31]. It was observed in the study conducted by Jia *et al* that the higher the concentration of the incorporated antimicrobial agent, the more difficult it is to homogenize and form agglomerates[27,28,31], and therefore they present a significant reduction in the impact strength of the modified acrylic resin[35]. Strategies to improve the dispersion of the material in the polymer matrix are desirable in order to reduce the formation of agglomerates that directly interfere with the concentration of tensions and alter the impact resistance of the resins.

Although it was challenging to compare the studies in this systematic review due to heterogeneity, it was possible to observe that the incorporation of antimicrobial agents promotes changes in the impact strength of 7-10 denture base resins.

CONCLUSIONS

In view of the findings of this scoping review, it was concluded that the incorporation of antimicrobial agents to acrylic resins for denture bases can, depending on the antimicrobial and the incorporation technique, influence their impact strength negatively by forming agglomerates and positively with slight improvements or no changes in the mechanical impact strength performance of acrylic resins. This review encourages studies to be carried out evaluating different methods of incorporating antimicrobial nanomaterials into acrylic resins, since the method of incorporation can influence the final structure of the polymeric matrix and alter mechanical resistance results such as impact resistance.

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The authors declare that there is no conflict of interest.

REFERENCES

1. Silva, A.S., Carvalho, A., Barreiros, P., de Sá, J., Aroso, C. and Mendes, J.M. Comparison of fracture resistance in thermal and self-curing acrylic resins-an *in vitro* study. *Polymers (Basel).* 2021; **13**:1234.
2. Gül, E.B., Atala, M.H., Eşer, B., Polat, N.T., Asiltürk, M. and 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.
3. Zafar, M.S. Prosthodontic Applications of Polymethyl Methacrylate (PMMA): An update. *Polymers (Basel).* 2020; **12**:2299.
4. Paul, L., Ravichandran, R., Kumar, K.H., Nair, V.V,. Janardanan, K. and Deepthi, V.S. Effect of titanium dioxide nanoparticles incorporation on tensile and impact strength in two different acrylic denture base resins. *Int Dent J Students Res*. 2020; **8**:65-74.
5. Bangera, M.K., Kotian, R. and Madhyastha, P. Effects of silver nanoparticle-based antimicrobial formulations on the properties of denture polymer: A systematic review and meta-analysis of *in vitro* studies. *J Prosthet Dent*. 2023; **129**:310-321.
6. Puri, G., Berzins, D.W., Dhuru, V.B., Raj, P.A., Rambhia, S.K., Dhir, G. *et al*. Effect of phosphate group addition on the properties of denture base resins. *J Prosthet Dent*. 2008; **100**:302–308.
7. Zafar, M.S. Prosthodontic applications of Polymethyl Methacrylate (PMMA): An update. *Polymers (Basel).* 2020; **12**:2299.
8. Somani, M.V., Khandelwal, M., Punia, V. and Sharma, V. The effect of incorporating various reinforcement materials on flexural strength and impact strength of polymethylmethacrylate: A meta-analysis. *J Indian Prosthodont Soc*. 2019; **19**:101-112.
9. Al-Harbi, F.A., Abdel-Halim, M.S., Gad, M.M., Fouda, S.M., Baba, N.Z., AlRumaih, H.S., *et al* Effect of nanodiamond addition on flexural strength, impact strength, and surface roughness of PMMA denture base. *J Prosthodont*. 2019; **28**:e417–425.
10. Watanabe, S., Ishida, Y., Miura, D., Miyasaka, T. and Shinya, A. Development of a weight-drop impact testing method for dental applications. *Polymers (Basel)*. 2020; **12**:2803.
11. de Jager, N., Münker, T.J.A.G., Guilardi, L.F., Jansen, V.J., Sportel, Y.G.E. and Kleverlaan, C.J. The relation between impact strength and flexural strength of dental materials. *J Mech Behav Biomed Mater*. 2021; **122**:104658.
12. da Cruz Perez, L.E., Machado, A.L., Canevarolo, S.V., Vergani, C.E., Giampaolo, E.T. and Pavarina, A.C. Effect of reline material and denture base surface treatment on the impact strength of a denture base acrylic resin. *Gerodontology*. 2010; **27**:62-69.
13. Graupner, N. and Kühn, N. Influence of sample thickness, curvature and notches on the Charpy impact strength - An approach to standardise the impact strength of curved test specimens and biological structures. *Polymer Testing*. 2021; **93**:106864.
14. Chris DeArmitt. Chap. 23 *Functional Fillers for Plastics,Editor(s): Myer Kutz, In Plastics Design Library, Applied Plastics Engineering Handbook* (Second Edition), William Andrew Publishing. 2017;517-532.
15. Gad, M.M., Fouda, S.M., Al-Harbi, F.A., Näpänkangas, R. and Raustia, A. PMMA denture base material enhancement: a review of fiber, filler, and nanofiller addition. *Int J Nanomedicine*. 2017; **12**:3801-3812.
16. Dos Santos, R.L.O., Sarra, G., Lincopan, N., Petri, D.F.S., Aliaga, J., Marques, M.M., *et al*. Preparation, antimicrobial properties, and cytotoxicity of acrylic resins containing poly(diallyldimethylammonium chloride). *Int J Prosthodont*. 2021; **34**:635–641.

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17. Takamiya, A.S., Monteiro, D.R., Gorup, L.F., Silva, E.A., de Camargo, E.R., Gomes-Filho, J.E., *et al*. Biocompatible silver nanoparticles incorporated in acrylic resin for dental application inhibit *Candida albicans* biofilm. *Mater Sci Eng C Mater Biol Appl*. 2021; **118**:111341.
18. An, S., Evans, J.L., Hamlet, S. and Love, R.M. Incorporation of antimicrobial agents in denture base resin: A systematic review. *J Prosthet Dent*. 2021; **126**:188-195.
19. Raj, P.A. and Dentino, A.R. Denture polymers with antimicrobial properties: a review of the development and current status of anionic poly(methyl methacrylate) polymers. *Future Med Chem*. 2013; **5**:1635-1645.
20. Qiu, H., Si, Z., Luo, Y., Feng, P., Wu, X., Hou, W., *et al*. The mechanisms and the applications of antibacterial polymers in surface modification on medical devices. *Front Bioeng Biotechnol*. 2020; **8**:910.
21. de Castro, D.T., Teixeira, A.B.V., do Nascimento, C., Alves, O.L., de Souza, Santos, E., *et al*. Comparison of oral microbiome profile of polymers modified with silver and vanadium base nanomaterial by next-generation sequencing. *Odontology*. 2021; **109**:605-614.
22. Chladek, G., Basa, K., Mertas, A., Pakieła, W., Żmudzki, J., Bobela, E., *et al*. Effect of storage in distilled water for three months on the antimicrobial properties of Poly(methyl methacrylate) denture base material doped with inorganic filler. *Materials (Basel)*. 2016; **9**:328.
23. Baeka, K., Shinb, H. and Choa, M. Multiscale modeling of mechanical behaviors of Nano-SiC/epoxy nanocomposites with modified interphase model: Effect of nanoparticle clustering. *Compos Sci Technol*. 2021; **203**:1-9.
24. Cierech, M., Kolenda, A., Grudniak, A.M., Wojnarowicz, J., Woźniak, B., Gołaś, M., *et al*. Significance of polymethylmethacrylate (PMMA) modification by zinc oxide nanoparticles for fungal biofilm formation. *Int J Pharm*. 2016; **510**:323-335.
25. Castro, D.T., Holtz, R.D., Alves, O.L., Watanabe, E., Valente, M.L., Silva, C.H., *et al*. Development of a novel resin with antimicrobial properties for dental application. *J Appl Oral Sci*. 2014; **22**:442-449.
26. Menezes, B.R.C., Sampaio, A.G., Silva, D.M., Montanheiro, T.A.M., Koga-Ito, C.Y. and Thim, G.P. $AgVO_3$ nanorods silanized with γ-MPS: An alternative for effective dispersion of $AgVO_3$ in dental acrylic resins improving the mechanical properties. *Appl Surf Sci*. 2021; **543**:148830.
27. Jani, G.H., Mohialdeen, H.K. and Alheeti, O.A.R. Antibacterial and mechanical performance of nano selenium reinforced acrylic denture base. *Pakistan J Med Heal Sci*. 2021; **15**:320–324.
28. De Castro, D.T., Valente, M.L.C., Agnelli, J.A.M., Lovato Da Silva, C.H., Watanabe, E., *et al*. *In vitro* study of the antibacterial properties and impact strength of dental acrylic resins modified with a nanomaterial. *J Prosthet Dent*. 2016; **115**:238–246.
29. Hamid, S.K., AlDubayan, A.A.H., Alghamdi, L.A., Akhtar, S., Khan, S.Q., Ateeq jlal, S., *et al*. Mechanical, surface, and optical properties of PMMA denture base material modified with *azadirachta indica* as an antifungal agent. *J Contemp Dent Pract*. 2021; **22**:655–664.
30. Köroğlu, A., Şahın, O., Kürkçüoğlu, I., Dede, D.Ö., Özdemır, T. and Hazer, B. Silver nanoparticle incorporation effect on mechanical and thermal properties of denture base acrylic resins. *J Appl Oral Sci*. 2016; **24**:590–596.
31. Casemiro, L.A., Martins, C.H.G., Pires-De-Souza, F.D.C.P. and Panzeri, H. Antimicrobial and mechanical properties of acrylic resins with incorporated silver-zinc zeolite - Part I. *Gerodontology*. 2008; **25**:187–194.
32. Sun, J., Wang, L., Wang, J., Li, Y., Zhou, X., Guo, X., *et al*. 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.
33. Oyar, P., Sana, F. A. and Durkan, R. Comparison of mechanical properties of heat-polymerized acrylic resin with silver nanoparticles added at different concentrations and sizes. *J Appl Polym Sci*. 2018; **135**:45807.
34. Chladek, G., Pakieła, K., Pakieła, W., Żmudzki, J., Adamiak, M. and Krawczyk, C. Effect of antibacterial silver-releasing filler on the physicochemical properties of Poly(methyl methacrylate) denture base material. *Materials (Basel)*. 2019; **12**:4146.
35. Jia, C.L., Wang, X.R., Zhang, C.T., Sun, S.Q. and Yang, Y. Evaluation on *in vitro* antibacterial effect of room curing polymethylmethacrylate material adding nano-silver base inorganic antibacterial agents. *J of Jilin Univ. Med. Ed*. 2012; **38**:899-903.
36. Cao, Y., Naseri, M., He, Y., Xu, C., Walsh, L.J. and Ziora, Z.M. Non-antibiotic antimicrobial agents to combat biofilm-forming bacteria. *J Glob Antimicrob Resist*. 2020; **21**:445-451.
37. Makvandi, P., Gu, J.T., Zare, E.N., Ashtari, B., Moeini, A., Tay, F.R., *et al*. Polymeric and inorganic nanoscopical antimicrobial fillers in dentistry. *Acta Biomater*. 2020; **101**:69-101.
38. An, S., Evans, J.L., Hamlet, S. and Love, R.M. Overview of incorporation of inorganic antimicrobial materials in denture base resin: A scoping review. *J Prosthet Dent*. 2023; **130**:202-211.
39. Yin, I.X., Zhang, J., Zhao, I.S., Mei, M.L., Li, Q. and Chu, C.H. The antibacterial mechanism of silver nanoparticles and its application in dentistry. *Int J Nanomedicine*. 2020; **15**:2555–2562.
40. Rana, T. Prospects and future perspectives of selenium nanoparticles: An insight of growth promoter, antioxidant and anti-bacterial potentials in productivity of poultry. *J Trace Elem Med Biol*. 2021; **68**:126862.
41. Abdel-Moneim, A.E., El-Saadony, M.T., Shehata, A.M., Saad, A.M., Aldhumri, S.A., Ouda, S.M., *et al*. Antioxidant and antimicrobial activities of *Spirulina platensis* extracts and biogenic selenium nanoparticles against selected pathogenic bacteria and fungi. *Saudi J Biol Sci*. 2022; **29**:1197-1209.
42. Abbas, H.S., Abou, D.H. and Entesar, B. Cytotoxicity and antimicrobial efficiency of selenium nanoparticles biosynthesized by Spirulina platensis. *Arch Microbiol*. 2021; **203**:523-532.
43. Hamid, S.K., Al-Dubayan, A.A.H., Al-Awami, H., Khan, S.Q. and Gad, M.M. *In vitro* assessment of the antifungal effects of neem powder added to polymethyl methacrylate denture base material. *J Clin Exp Dent*. 2019; **11**:e170–178.
44. Kreve, S. and Reis, A.C. Influence of the electrostatic condition of the titanium surface on bacterial adhesion: A systematic review. *J Prosthet Dent*. 2021; **125**:416-420.
45. Zappini, G., Kammann, A. and Wachter, W. Comparison of fracture tests of denture base materials. *J Prosthet Dent*. 2003; **90**:578-585.
46. Alhotan, A., Yates, J., Zidan, S., Haider, J. and Silikas, N. Assessing fracture toughness and impact strength of PMMA reinforced with nanoparticles and fibre as advanced denture base materials. *Materials (Basel)*. 2021; **14**:4127
47. Faot, F., Costa, M.A., Del Bel Cury, A.A. and Rodrigues Garcia, R.C. Impact strength and fracture morphology of denture acrylic resins. *J Prosthet Dent*. 2006; **96**:367-373.
48. ISO 179-1:2010. Plastics—Determination of Charpy Impact Properties—Part 1: Non-instrumented Impact Test; ISO: Geneva, Switzerland, 2010.
49. ASTM D-256, Test for impact resistance of plastics and electrical insulating materials, Annual Book of ASTM Standards;1969.
50. Morris, A.S. and Salem, A.K. Surface engineered nanoparticles: considerations for biomedical applications. *Adv Eng Mater*. 2017; **19**:1–10.

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