



Review article

Nanostructured silver vanadate decorated with silver particles and their applicability in dental materials: A scope review



Murilo Rodrigues de Campos, André Luís Botelho, Andréa Cândido dos Reis *

Department of Dental Materials and Prosthodontics, Ribeirão Preto Dental School, University of São Paulo (USP), Ribeirão Preto, SP, Brazil

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ABSTRACT

Objectives: The present study aims to evaluate which studies evaluated the effectiveness of incorporating silver vanadate into dental materials and to analyze the influence of this incorporation on antimicrobial activity and material properties;

Data: This review was led by the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist and the JBI Briggs Reviewers Manual to answer the following question:

Does the nanostructured silver vanadate decorated with silver particles present anti-microbial activity when incorporated into dental materials without altering its mechanical properties?

Source: An electronic search without restriction on the dates or languages was performed in PubMed/MEDLINE, Web of Science, Lilacs, Scopus, and Embase up until 2020. The search was specified and limited to the use of the words "nanostructured silver vanadate" in double quotation marks.

Study selection: The initial search resulted in 55 articles. After an initial assessment and careful reading, 15 studies published between 2014 and 2020 were included in this review.

Conclusions: With the present scope review, it was possible to observe the good interaction between AgVO₃ and dental materials and have a clarity that it is possible to use them in different types of materials in order to reduce the probability of infections resulting from the biofilm that is installed in them.

1. Introduction

Through nanotechnology, the research group led by Alves [1] developed an antimicrobial agent called nanostructured silver beta vanadate (β -AgVO₃) decorated with silver particles (AgNPs). This nano-material has antimicrobial action and has been shown to be efficient in controlling bacterial infections transmitted by highly pathogenic microorganisms, such as Methicillin-Resistant Staphylococcus aureus (MRSA), which is resistant to drugs such as beta-lactams and other types of antimicrobials such as clindamycin and quinolones [2].

Silver nanoparticles (AgNP) exhibit antimicrobial activity due to the physical-chemical processes that occur when in contact with biomolecules or organic compounds. When cell molecules come into contact with the surface of AgNPs, a disturbance occurs in the cell walls that instill the growth of bacteria, promoting their antimicrobial activity. AgNPs can anchor and penetrate the cell membranes of bacteria due to the size and chemical surface, and release Ag⁺ ions through oxidative dissociation of AgNPs [3]. Vanadium, when in its oxidative state V⁵⁺ can

bind to thiol groups of cellular proteins and form stable complexes. When oxidation and reduction occur between V⁴⁺ and V⁵⁺ bacteria are led to oxidative stress that is responsible for the antimicrobial activity of the compound. These strong interactions with bacterial cell walls disrupt protein production, interfering with cellular metabolism [2].

Silver vanadate (AgVO₃) is the most common form of solid-state silver vanadate oxides. The AgVO₃ polymorphism can result from different properties for each compound. The β -AgVO₃ is a stable compound with a monoclinic spatial group. The α -AgVO₃ is considered a metastable phase, formed instantly below the melting point when it is slowly cooled and frozen quickly. Despite the scarcity of studies demonstrating the antimicrobial and microbiological properties of alpha vanadate, there are studies suggesting antimicrobial potential against *C. Albicans*, presenting fungistatic and fungicidal activity, according to a study by Da Silva Pimentel in 2020 [4].

Silver beta vanadate is a compound that has photoelectronic and chemical properties that can be altered, such as composition, size, shape, crystal structure, and surface. It has been extensively studied its

* Corresponding author.

E-mail address: andreatre73@yahoo.com.br (A.C. dos Reis).

usefulness in medical areas for the manufacture of cardio-vascular defibrillators, neurostimulators, and drug infusion devices [5]. In addition, the Silver Beta Vanadate promoted the stability of silver nanoparticles through the association with the lines of the vanadate, which prevents the agglomeration of particles [2, 6]. It is obtained by the precipitation reaction of ammonium nitrate and ammonium metavanadate. It has an antimicrobial effect due to the release of silver ions and vanadium that interact with thiol groups present in enzymes involved in the cell metabolism of bacteria, leading to cell death [1, 2].

Species of bacteria such as *E. faecalis*, *P. aeruginosa* and *E. coli* remain in the dental canals, even after filling due to the complexity of the anatomy of the canaliculi. Microorganisms such as *C. albicans*, *S. mutans*, *S. aureus* and *P. Aeruginosa* are adept at total and removable prosthesis bases while *S. mutans* attach to the ceramic surface, and thus can help in the development of diseases that present high severity, such as bacterial endocarditis, obstructive chronic lung disease, aspiration pneumonia, and generalized respiratory tract infections [7, 8, 9, 10, 11, 12, 13, 14].

The use of nanostructured silver vanadate decorated with silver nanoparticles is only possible thanks to its conformation that prevents agglomeration of silver nanoparticles, promoting increased surface contact with microorganisms and greater antibacterial efficacy [13].

The present study aims to evaluate which studies evaluated the effectiveness of incorporating silver vanadate into dental materials and to analyze the influence of this incorporation on antimicrobial activity and material properties.

2. Materials and methods

2.1. Protocols

This review was led by the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist and the JBI Briggs Reviewers Manual to answer the following question: Does the nanostructured silver vanadate decorated with silver particles present antimicrobial activity when incorporated into dental materials without altering its mechanical properties?

2.2. Electronic searches

The search was specified and limited to the use of the words "nanostructured silver vanadate" in double quotation marks in the databases of Pubmed, web of science, lilacs, Scopus, and Embase, the latter being the word used only in single quotation marks. This unique term was to specify and limit the number of references and focus only on nanostructured AgVO₃, which avoided a greater number of irrelevant references that would arise using other terms. The articles found with the search were exported to Men-delay, which consists of a reference management application.

2.3. Data charting process

Two phases were there to select this article. In phase one, three reviewers independently (M.R.C and A.L.B) screened titles and abstracts to identify eligible studies. At the other moment, phase two, after the selection excluded some references and there were potentially included articles, all collaborators read all full text. To final selection, the two reviewers had a discussion with the coordinator (A.C.R) to decide what articles could be included in the final list.

2.4. Screening process

The first stage was the reading of titles and abstracts to ascertain the important ones to answer the main question. For the scope review to be as homogeneous as possible, studies that did not specifically include "AgVO₃ decorated with silver nanoparticles", "which did not present the incorporation dental materials or in relation to dentistry", "without

antimicrobial, mechanical or optical analyses" and "studies that were in English" were excluded. If any article was not released for reading, this article was requested through e-mail to the authors.

2.5. Eligibility

Criteria such as the specific presence of nanostructured AgVO₃ incorporated into dental materials or with direct relation to dentistry were sought in the texts when performing the entire Reading, and antimicrobial, optical and mechanical analyses were used as inclusion criteria in this scoping review. Articles that presented Silver Vanadate, however, without being nanostructured or related to dentistry and its materials were excluded.

2.6. Data analysis

For a better understanding of the data, the studies that AgVO₃ was incorporated into the materials were separated into paragraphs and a table (Table 1). In total, there were 15 studies published between 2014 and 2020 which presented a total of 13 different analyses, including antimicrobial activity, cytotoxicity, radiopacity, Topographic, prey time, solubility, pH, compression, hardness, bending resistance, roughness, and plastic deformation. The results were narrated, demonstrating the type of analysis that was performed in each material to better understand the context (Figure 1).

3. Results

3.1. Acrylic resin

Kamimura et al., 2020 [17] evaluated the roughness, and hardness of acrylic resins incorporated with β-AgVO₃ with 2.5, 5 and 10% after immersion in artificial saliva for different times, 12 days, and 24 days. Drinks such as Coca-Cola, orange juice and red wine were used in conjunction with the immersions. After 12 days, there were statistical differences between the product that the resin was immersed in and the concentrations (P = 0.004). Coca-Cola showed the largest increase in roughness value for the group 2.5%. Regarding 24 days, there were also significant differences in the interaction between the product in which the resin was immersed in and the concentration of β-AgVO₃ (P = 0.008). For the control group, without the incorporation of the antimicrobial, there was a small decrease in surface roughness. For the hardness after 12 days, there were significant differences in the interaction between the solutions and the concentrations of β-AgVO₃ (P = 0.016). For the group, 2.5% Coca-Cola showed a slight loss of hardness, while wine and the saliva had a higher value of hardness loss. For the 10% group, Coca-Cola showed the greatest loss, while wine and saliva showed again (P < 0.05). At 24 days, it was demonstrated that the nanomaterial concentration factor influenced hardness after immersion.

De Castro et al., 2014 [7] evaluated the antimicrobial activity of β-AgVO₃ of acrylic resins and obtained results that the minimum inhibitory concentration was 31.25 µg/ml for staphylococcus aureus and pseudomonas aeruginosa strains, 62.5 µg/ml of Candida albicans, compared with 250 µg/ml of Streptococcus mutans. Regarding antimicrobial activity, it was observed that the largest inhibition area was observed when acrylic resin was added to 10% β-AgVO₃ compared to *S. aureus*. There were no significant differences when comparing the concentrations from 5 to 10% against *S. aureus*, *P. aeruginosa* and *C. Albicans*.

In another study, De Castro et al., 2017 [9] evaluated the dissociation into ions and the cytotoxicity of β-AgVO₃ incorporated into 0.5%, 1%, 2.5%, 5% and 10% in self-polymerized acrylic resins (PA) and polymerized term (HP). As for dissociation, all groups presented significant differences in relation to the dissociation of the Ions Ag and V compared to the group without the addition (P < .0001). Regarding the cytotoxicity of this incorporation, all groups showed significant differences compared to the control group (P < .0001). For AP resin, there was a significant

Table 1. The main results of the studies separated by author and year of publication, dental material incorporated with ANPs, the percentage used, and type of analysis performed.

Authors, year and reference number	Material incorporated with β -AgVO ₃	% of AgVO ₃ incorporated	Analysis of study	Results
De Castro et al., 2014 [7].	Acrylic Resin	0.5%, 1%, 2.5%, 5% and 10%	MIC and Microbiological analysis, Surface hardness, Compressive Strength	Antimicrobial effect against <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> and <i>Candida albicans</i> when incorporated with 10%. For the compressive strength and surface hardness, a statistically significant difference ($p < 0.05$) was observed only for the group with 0.5% of the nanostructured silver vanadate.
De Castro et al., 2016 [15].	Autopolymerizing dental and heat-polymerizing Acrylic Resin	0.5%, 1%, 2.5%, 5% and 10%	XTT reduction assay test, Confocal Laser Scanning Microscopy (CLSM). Surface hardness, Flexural Strength and Surface roughness	Antimicrobial effect against <i>Streptococcus mutans</i> and <i>Candida albicans</i> . Increase in surface hardness for SC with 0.5%. The flexural strength of both resins was reduced when 2.5% of AgVO ₃ was incorporated ($p = 0.446$).
De Castro et al., 2016 [16].	Autopolymerizing dental and heat-polymerizing Acrylic Resin	0.5%, 1%, 2.5%, 5% and 10%	XTT reduction assay test, CLSM, and impact strength	The concentration of 10% showed the greatest effect against <i>Pseudomonas aeruginosa</i> and <i>Staphylococcus aureus</i> . The percentage of 5% and 10% exhibited significant reductions in impact strength compared with the control group ($P < .001$).
De Castro et al., 2017 [9].	Autopolymerizing dental and heat-polymerizing Acrylic Resin	0.5%, 1%, 2.5%, 5% and 10%	Metal ions release and cell viability	All groups containing AgVO ₃ showed a significant difference in relation to the control group (0%) regarding the release of Ag and V ions ($P < .0001$). AP resin, the AgVO ₃ at concentrations of 0.5%, 1% and 2.5% presented a discrete cytotoxic effect. Concentrations of 5% and 10% for AP and 2.5% and 5% for HP were considered moderately cytotoxic and 10% for HP were considered severely cytotoxic.
De Castro et al., 2018 [10].	Heat-polymerizing Acrylic Resin	1%, 2.5% and 5%	PCR and 16S rDNA amplified by PCRI	After 7 days of incubation the genera <i>Enterobacter</i> , <i>Neisseria</i> and <i>Pseudomonas</i> increased significantly and the genera <i>Prevotella</i> and <i>Porphyromonas</i> were reduced.
Kamimura et al., 2019 [17].	Heat-polymerizing Acrylic Resin with immersion in Saliva, Coca-Cola, Orange juice and red wine	2.5%, 5% and 10%	Surface roughness, Hardness,	With the increasing in time, there was a reduction in the surface hardness and surface roughness.
Teixeira et al., 2017 [18].	Four endodontic sealers (AH Plus, Endofill, Sealapex and Sealer 26	2.5%, 5% and 10%	Radiopacity. Tooth color change and topographic analysis.	Sealer 26 with 2.5% presence higher radiopacity than the control group, and for the 2.5% AH Plus presence lower. The great color change is for Endofill with 2.5% incorporation. In topographic analysis, there was a topographical distribution pattern with dispersed smaller nanoparticles and agglomerations in random areas.
Teixeira et al., 2017 [19].	Four endodontic sealers (AH Plus, Endofill, Sealapex and Sealer 26	2.5%, 5% and 10%	Minimum inhibitory concentration (MIC), Agar diffusion method, flow and radiopacity	Antimicrobial effect against <i>Pseudomonas aeruginosa</i> , <i>Escherichia coli</i> and for <i>Enterococcus faecalis</i> . The incorporation of AgVO ₃ did not increase the antimicrobial activity of AH Plus against <i>E. faecalis</i> . The flow of AH Plus and Endofill reduced in proportion to the concentration of AgVO ₃ . For the radiopacity Endofill 2.5% and Sealapex 2.5% and 5% had lower radiopacity than their control groups.
Teixeira et al., 2019 [20].	Three endodontic sealers (AH Plus, Sealer 26 and Endomethasone N)	2.5%, 5% and 10%	Direct contact test (DCT), microscopy fluorescence, solubility and pH variation	Antimicrobial effect against <i>Enterococcus faecalis</i> . Endomethasone N sealer modified with 5% AgVO ₃ presented lower solubility in relation to the other groups ($P < 0.05$). All groups showing an acidic pH in relation to the initial pH.
Teixeira et al., 2019 [12].	Three endodontic sealers (AH Plus, Sealer 26 and Endomethasone N)	2.5%, 5% and 10%.	Antibacterial activity (DCT), Topographic, composition and setting time.	All endodontic sealers completely inhibited the growth of <i>Enterococcus faecalis</i> . The incorporation of AgVO ₃ altered the atomic proportions among components of the endodontic sealers. For the setting time, the sealers incorporated with AgVO ₃ of AH Plus presented a lower setting time than the control group. Sealer 26 and Endomethasone N increase time.

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Table 1 (continued)

Authors, year and reference number	Material incorporated with β -AgVO ₃	% of AgVO ₃ incorporated	Analysis of study	Results
Teixeira et al., 2020 [14].	Three endodontic sealers (AH Plus, Sealer 26 and Endomethasone N).	2.5%, 5% and 10%.	Cell viability and release of metal ions.	AH Plus was moderated cytotoxic. The release of Ag ⁺ and V ⁴⁺ /V ⁵⁺ was proportional to the concentration of AgVO ₃ incorporated in the sealers.
De Castro et al., 2019 [21].	Irreversible hydrocolloid.	2.5%, 5% and 10%	Agar diffusion method, gelation time and flow capacity.	Antimicrobial effect against <i>Candida albicans</i> , <i>Pseudomonas aeruginosa</i> , <i>Escherichia coli</i> , <i>Staphylococcus aureus</i> and for <i>Streptococcus mutans</i> . No difference at gelation time was found. The flow capacity was significantly lower for the group 5% compared to the control ($p = 0.034$).
Kreve et al., 2019 [22].	Soft denture liner.	1%, 2.5%, 5% and 10%.	Agar diffusion method, adhesion properties, hardness and roughness.	Antimicrobial effect against <i>Pseudomonas Aeruginosa</i> , <i>Candida albicans</i> and <i>Enterococcus faecalis</i> . For hardness values, 1, 2.5% and 10% promoted a decrease. For roughness, the values are not affected significantly. Relation to the adhesive failure, 10% group presented the higher failures.
Oliscovicz et al., 2018 [11].	Substrate surfaces found in the dental implant (Polytetrafluoroethylene, Polyacetal and acrylic resin).	2.5%, 5% and 10%.	Antimicrobial activity, surface roughness, hardness scanning electron microscopy.	Antimicrobial effect against <i>Enterococcus faecalis</i> , <i>Escherichia coli</i> , <i>Pseudomonas aeruginosa</i> , <i>Staphylococcus aureus</i> and <i>Streptococcus mutans</i> . For surface roughness, no difference was found. For hardness the group with 10% of PTFE had increased values. The scanning electron microscopy showed that the increase with AgVO ₃ films provided heterogeneous surfaces.
Ferreira et al., 2020 [13].	Dental porcelain (IPS InLine, Ivoclar Vivadent AG).	2.5%, 5% and 10%.	Microbiological, roughness and Vickers microhardness.	All groups presented an inhibition zone against <i>Streptococcus mutans</i> . No difference was observed for Vickers microhardness. For roughness, only the group with 10% was statistically different ($P < .001$).

decrease when incorporated with 5 and 10% of β -AgVO₃ ($P < .0001$). For HP resin, a reduction in cell viability was observed when incorporated with 2.5% ($P < .0001$).

De Castro et al., 2016 [15] evaluated self-polymerized acrylic resins (AP) and thermopolymerized (HP) incorporated in 0.5, 1, 2.5, 5 and 10% AgVO₃. Regarding biofilm activity, the absorbance values using XTT showed that for *C. albicans* there was a significant reduction when

incorporated in 5 and 10% ($p < 0.05$). However, for *S. mutans* there was only a good reduction when incorporated with 10% ($p = 0.023$).

De Castro et al., 2016 [15] also evaluated the mechanical properties of resins, incorporated in 0.5, 1, 2.5, 5 and 10% of β -AgVO₃. Regarding surface hardness, there was a significant increase in CS when incorporated to 0.5%. For RT, there were no significant changes. For bending resistance, both resins showed reduction when incorporated with 2.5% ($p = 0.446$), followed by 5 and 10%. Regarding surface roughness, there were no significant changes between the groups compared to the control group ($p = 0.751$). Differing from the results of De Castro et al., 2014, we found statistical differences for the group with 0.5% of β -AgVO₃.

De Castro et al., 2016 [16] incorporated in β -AgVO₃ 0.5, 1, 2.5, 5 and 10% in two acrylic resins, one self-curing (PA) and other thermo polymerizable (HP). Two-way ANOVA showed no influence of β -AgVO₃ concentration on metabolic activity of *S. aureus* with the XTT method ($P = .108$). However, there were differences in the metabolic activity of *P. aeruginosa* and the number of forming colony units ($P < .001$). In addition, HT resin showed a greater reduction for *P. aeruginosa* compared to AP ($P = .009$). Furthermore, concentrations of 5 and 10% promoted a higher antimicrobial activity.

3.2. Endodontic cement

Several studies have evaluated the effect of the incorporation of nanostructured silver vanadate decorated with silver particles to endodontic cement [14, 18, 19, 20, 21]. Teixeira et al., 2019 [20] found that after modifying sealer, Endomethasone N and AH-Plus endodontic cement with the addition of 2.5, 5 and 10% β -AgVO₃, there was better inhibition for the groups of 5 and 10% for Sealer, 2.5, 5 and 10% for Endomethasone, while AH-Plus presented similar results to the control group. In another study by Teixeira et al., 2019 [12] in which he added the same proportions to the same materials previously mentioned, there

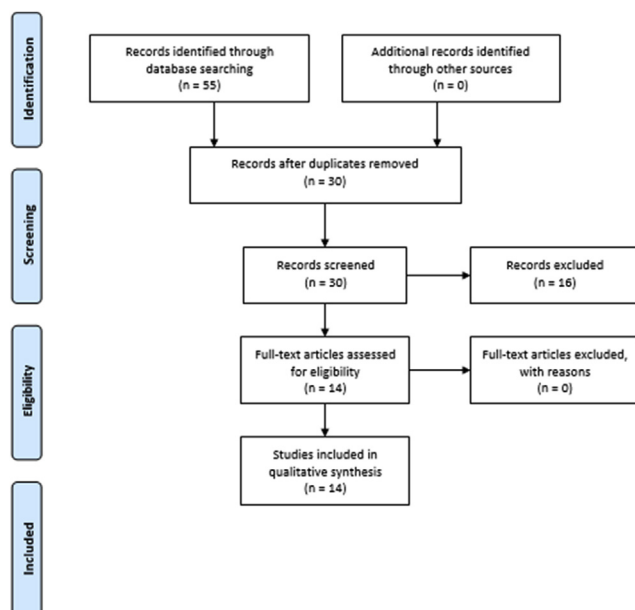


Figure 1. Organization chart of the selection of articles in the databases.

Dental materials incorporated with β -AgVO₃

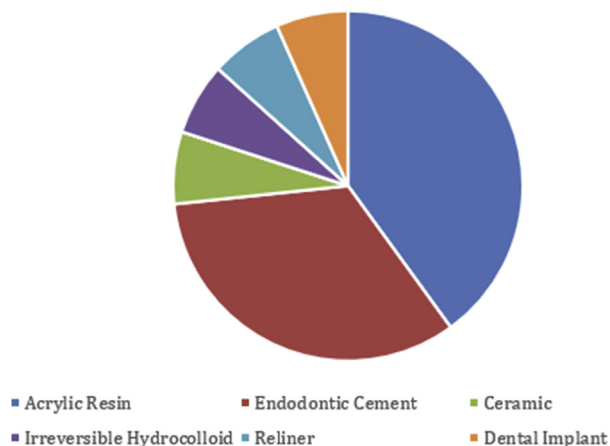


Figure 2. Studies with the incorporation of β -AgVO₃ in dental materials.

was complete inhibition of the growth of *E. Faecalis*, however, without significant differences between the groups, including control. In another study by Teixeira et al., 2017 [19], the incorporation of β -AgVO₃ did not increase the antimicrobial activity of AH Plus against *E. Faecalis*. For Endofill, there was an increase in antimicrobial activity when incorporated with 2.5% ($P < 0.05$), however, a higher activity when incorporated with 5%. For sealer 26 there was an increase when incorporated with 5%. For Sealapex the inhibition zone was increased according to the proportion of β -AgVO₃ concentration ($P < 0.01$). Against *P. aeruginosa*, only AH Plus and Endofill with 10% inhibited the formation zone ($P < 0.01$). Endofill showed increased antimicrobial activity according to the proportion of incorporation with β -AgVO₃ versus *E. coli*. Sealer 26 with the addition of 10% off β -AgVO₃ and Sealapex with 5 and 10% promoted antimicrobial activity against *E. coli*.

Teixeira et al., 2020 [14] evaluated the cytotoxicity of the addition of β -AgVO₃ at concentrations of 2.5, 5 and 10% to three different trademarks of endodontic cement (AH Plus, Endomethasone N and Sealer 26). All groups presented reduced cell viability compared to the control group ($p < 0.05$). The Endomethasone N and Sealer 26 groups showed a reduction of more than 95% in HGF of cell viability regardless of treatment time. While AH Plus presented 55.17% of cell viability after 24h. However, after 7 and 14 days, there was a reduction of more than 95% in HGF cell viability. The release of silver and vanadium ions in the period of 24 h was also evaluated. While Endomethasone N and Sealer 26 showed high concentrations, especially when incorporated with 10% β -AgVO₃.

Teixeira et al., 2017 [18], demonstrated that in relation to differences in radiopacity of endodontic cement modified with β -AgVO₃, Endofill and Sealapex did not present significant differences. While Sealer 26 presented higher radiopacity with the group 2.5% in relation to the others. On the other hand, AH Plus presented higher radiopacity for groups 2.5 and 5% in relation to the others, differing from another study by Teixeira et al., 2017 [19], where Endofill 2.5% and Sealapax 2.5% and 5% presented lower radiopacity than their control groups. Changes in tooth color were also observed in the study by Vileta et al., 2017 [18], where it showed that the greatest alterations occurred in Endofill with 2.5%, AH Plus with 2.5 and 10%, Sealapex 5 and 10% and Sealer 26 with 10%. In topographic analysis, modifications were found in all groups with different concentrations, where it was possible to visualize the small, scattered nanoparticles and agglomerations in random areas. In another study, Teixeira et al., 2019 [12] demonstrated that the incorporation of nanomaterial alters the molecular interactions between cement components and that the addition of β -AgVO₃.

Teixeira et al., 2019 [20] found as results that the addition β -AgVO₃ did not significantly alter the solubility of AH Plus and Sealer 26 cement.

Endomethasone N incorporated with 5% showed a reduction in solubility compared to other groups. Regarding the pH over time, AH Plus showed a reduction in pH after 30 days in all concentrations. Sealer 26 there was an increase in pH over time, with a significant difference at 6h in relation to the other periods 7, 14, and 30 days. For endomethasone N, a small increase in pH was observed over time.

3.3. Irreversible hydrocolloid

De Castro et al., 2019 [21] evaluated the effect of the incorporation of β -AgVO₃ in 2.5, 5 and 10% in an irreversible hydrocolloid and obtained results that the addition demonstrated antimicrobial effects and dependent dose, except for *P. aeruginosa* and *Streptococcus aureus*. Regarding the time of gelatinization of the material, there were no significant differences in relation to the control group. The flow capacity showed significant differences in the 5% group in relation to the control ($p = 0.034$), and the group was 5% less fluid. The concentrations of 5 ($p = 0.010$) and 10% ($p < .001$) had an increase in the values of plastic deformation of the material in relation to the control.

3.4. Soft denture liner

Kreve et al., 2019 [22] evaluated the incorporation with β -AgVO₃ 1, 2.5, 5 and 10% in soft denture liner. When incorporated with 1 and 2.5%, there was no antimicrobial activity for *P. Aeruginosa* and *C. Albicans*. However, at concentrations of 5 and 10% they were effective for *P. aeruginosa* and *C. Albicans* with 10% being more effective for *P. Aeruginosa*. For *E. Faecalis*, all concentrations were effective, with greater efficacy when the concentration increased, with 10% being the most effective. Still, for *S. aureus*, no concentration was effective. Regarding the mechanical properties, the incorporation of 1, 2.5, and 10% promoted a decrease in the values of Shore A hardness ($p < 0.001$) since the concentration of 5% there were no changes. For surface roughness, there were no significant changes. For HT resin there was a better rebase strength when incorporated with 2.5% ($p < 0,001$) and 10% ($p = 0.042$). For PA, there were no significant differences. Regarding the failure in the soft denture liners addition to the resins, there was a significant difference for HT with 2.5% with 50% of failures and for the 10% group with 60% of adhesive failures. For AP, there was a difference only for the 10% group, with 80% of adhesive failures ($p = 0.007$).

3.5. Dental implant

Oliscovicz et al., 2017 [11] proposed the addition β -AgVO₃ to the surface treatment of dental implants. β -AgVO₃ at concentrations of 5% and 10% promoted antimicrobial activity in substrates that present potential utility as dental implants. As for SME analysis, a more heterogeneous surface was observed detectable irregularities and a greater amount of nanomaterial. For hardness, there were no differences compared to the control group independent of the substrate. For roughness there were no statistical differences between the different substrates.

3.6. Ceramics

Ferreira et al., 2020 [13] incorporated β -AgVO₃ in dental ceramics and found that with the percentages of 2.5%, 5% and 10% there were halo inhibitions against *Streptococcus mutans*, with the highest value for the 10% group (30mm). Regarding roughness, only the 10% group presented significant differences in relation to all others ($p < .001$). Microhardness did not present differences between groups.

4. Discussion

The present scope review brought several studies in which there was the incorporation of dental materials with the β -AgVO₃, reaching the

objective of this study. The results showed that the incorporation was successfully performed, evidencing the antimicrobial activity of β -AgVO₃ differing from the control groups studied that did not present the incorporation. The largest number of studies was the incorporation of β -AgVO₃ into acrylic resin, contemplating 6 studies of the present review [7, 9, 10, 15, 16, 17], followed by 5 studies that presented the incorporation in endodontic cement [12, 14, 18, 19, 20], 1 in irreversible hydrocolloid [21], 1 in soft denture liner for prostheses [22], 1 in substrates that can be used for dental implant surface [11], 1 in ceramics [13] (Figure 2). The studies that presented a single specimen hinder the evaluation and possible divergence between authors regarding the difference of results regarding the incorporation in these specimens. The articles are well structured and include complete analyses for the conclusion of the results, as well as were published in journals of selective editorial policy. Among the favorable questions about the study, it is found that the concentrations of β -AgVO₃ incorporated in the different materials were almost their entirety equal, which makes the discussion between the favorable results and the study more homogeneous, demonstrates the effectiveness and stability of action of materials at certain concentrations.

In the case of acrylic resins, the analyses studied for characterization and development of materials are hardness [7, 15, 17], compression [7], surface roughness [15, 17], impact resistance [16], bending resistance [15] and antimicrobial activity [7, 10, 15, 16]. The articles include these analyses because they present results for all these tests demonstrating that for hardness, there was a significant difference for resins incorporated with 0.5%, with an increase for most studies. For compression, there was a significant increase only for the incorporated group with 0.5%. Surface roughness did not present significant differences in relation to the control groups. Regarding impact resistance, only one study evaluated this analysis, obtaining that the groups incorporated with 5% and 10% presented significant reductions ($P < .001$). For bending resistance, only one study evaluated this variable and there was a reduction in values for the incorporated group with 2.5% ($p = 0.446$).

In addition to the observance of the non-significant alteration of the chemical and mechanical physical properties, it was possible to achieve the main objective of antimicrobial activity of incorporation, and this analysis obtained as results that demonstrated inhibitions of different species of bacteria, as well as fungi, presenting results with higher values the groups incorporated with 5% and 10% of β -AgVO₃.

For cement, which includes together with acrylic resins the largest number of studies in this review, the main analyses for evaluation of properties are radiopacity [18, 19], color change in teeth [18], topographic analysis [12, 18], flow [19], solubility [20], pH [20], prey time [12], cell viability and dissociation of ions [14] and antimicrobial activity [12, 19, 20]. Sealer 26 cements presented higher radiopacity when incorporated with 2.5%, while AH Plus decreased radiopacity to the same concentration. The biggest color change was for Endofill cement incorporated also with 2.5%. For topographic analysis, we observed a distribution pattern with lower dispersion of nanoparticles and agglomerations in random areas. The cement that presented the most alterations were Sealer and AH Plus, which presented the atomic percentage of Calcium and Tungsten modified with β -AgVO₃. As for the flow, the AH Plus and Endofill cements showed reductions in the flow in proportion to the concentration of the incorporation. The solubility of most cements did not present significant change, with solubility within the standards recommended by the American National Standards Institute/American Dental Association (ANSI/ADA, specification 57, 2000), except only for the incorporated Endomethasone N with 5%. The pH of all cements after 30 days was more acidic than the initial one, but without compromising their antimicrobial activity. The prey time of AH Plus cement was shorter, while for sealer 26 and Endomethasone N increased. All groups showed reduced cell viability in relation to treatment time and Concentration of β -AgVO₃. The dissociation of ag^+ and $v4^+/v5^+$ ions are also dependent and

proportional to the concentration of β -AgVO₃ incorporated into the cements. The antimicrobial activity of the incorporated cements has been shown to be effective by all concentrations presenting zones of antimicrobial inhibitions.

With only one article for each material, including irreversible hydrocolloid [21], it presented the highest antimicrobial inhibition with the incorporation of 2.5%. The gelatinization time of the material was not changed, and the yield capacity was slightly lower for the group of 5%. Regarding the soft denture liner [22], those incorporated with 5% and 10% presented higher antimicrobial activity. Concentrations of 1%, 2.5% 10% promoted a decrease in hardness values. While the roughness has not changed with the incorporations. The adhesivity that is necessary for the union with the prosthesis base presented a higher number of failures with the group incorporated with 10%. Finally, the last study, which consists of different substrates likely to be used on implant surfaces [11], showed as results that the type of substrate did not influence antimicrobial activity, however, there was antimicrobial activity when incorporated into β -AgVO₃. There were no differences in roughness after incorporation, and hardness increased when incorporated by 10% for PTFE substrate. As for scanning electron microscopy, it was demonstrated that the incorporation of β -AgVO₃ promoted heterogeneous surfaces with more irregularities in the surface of the specimens, with a greater amount of nanomaterial.

Thus, the articles studied include several analyses on the properties of materials before and after incorporation with several concentrations of β -AgVO₃. Most of the analyses made for all materials had positive results, with small changes and most of them within the acceptable parameters in the literature, such as the results of compression, hardness and roughness for acrylic resins, solubility, radiopacity and pH for cements, gelatinization and flow for reversible hydrocolloid, roughness for the refiller and substrates for dental implants, as well as hardness, which only increased significantly for a specific substrate and with a concentration of 10% incorporation.

However, it was also possible to observe through the negative aspects related to the incorporated materials, such as the fall in the values of impact resistance and the bending for acrylic resins, which increases the chances of fractures of prosthetic devices in situations of accidents or parafunction such as bruxism [23]. This decrease may be caused due to the mode of dispersion and formation of β -AgVO₃ agglomerates in the structure of the resins [15]. A negative point in relation to endodontic cements is the change in tooth color when treated with cement, which can directly affect the aesthetics of the smile, especially when it comes to anterior teeth [18].

However, properties of high relevance, such as low cytotoxicity of modified materials, since silver ions have low toxicity to human cells and long shelf life against bacteria, should be taken into account, because they are advantageous compared to other antimicrobials in the market [6]. In addition, the main focus of the incorporation of β -AgVO₃ in dental materials is its antimicrobial property and the studies presented there is a great possibility in its use, since they demonstrated promising results against gram-positive and negative bacteria species such as MRSA and *E. faecalis* [2], in addition to *S. mutans* [13], *P. aeruginosa*, *C. albicans* [7, 15, 22] and *E. coli* [19]. It should be noted that in Holtz's the study, 2012 [2], although it is not a direct dental application, β -AgVO₃ was incorporated into water-based paints for tissues and hospital materials, used in sanitary spaces, kitchens, and offices. The study is of great importance, since infections associated with biofilm present in dental materials and hospital areas can cause serious health problems [2, 24, 25], such as opportunistic infections such as oral candidiasis and bacterial endocarditis, respiratory tract infections and pneumonia that can cause the patient to die [26, 27, 28, 29].

5. Conclusions

With the present scope review, it was possible to observe the good interaction between β -AgVO₃ and dental materials and have a clarity that

it is possible to use them in different types of materials in order to reduce the probability of infections resulting from the biofilm that is installed in them. Therefore, the study of the incorporation of β -AgVO₃ in dental materials is of great importance and needs to be researched in depth. New projects should propose the addition of nanomaterial to other materials to reduce the risk of infections, maintaining the mechanical and chemical properties of the materials so that the treatment always has the desired longevity. Thus, the modified material can also act as a preventive material against various types of diseases caused by microorganisms. The limitation of this study is related to the material being recent, innovative, and patented. Thus, few groups still study its advantages and disadvantages, which tend to be expanded by the great potential presented by the antimicrobial.

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References

- [1] R.D. Holtz, A.G. Souza, M. Brocchi, D. Martins, N. Duran, O.L. Alves, Development of nanostructured silver vanadates decorated with silver nanoparticles as a novel antibacterial agent, *Nanotechnology* 21 (18) (2010 May 7) 185102.
- [2] Raphael D. Holtz, et al., Nanostructured silver vanadate as a promising antibacterial additive to water-based paints, *Nanomedicine* 8 (6) (2012 Aug) 935–940.
- [3] J.R. Koduru, et al., Phytochemical-assisted synthetic approaches for silver nanoparticle antimicrobial applications: a review, *Adv. Colloid Interface Sci.* 256 (2018 Jun) 326–339.
- [4] B.N.A. Da Silva Pimentel, et al., Antifungal activity and biocompatibility of alpha-AgVO₃ microcrystals: a promising material against oral Candida disease, *Mater. Sci. Eng. C Mater. Biol. Appl.* 108 (2020 Mar) 110405.
- [5] A.P.M. Monteiro, et al., Nano silver vanadate AgVO₃: synthesis, new functionalities and applications, *Chem. Rec.* 18 (7-8) (2018 Jul) 973–985.
- [6] J.M. Corrêa, M. Mori, H.L. Sanches, A.D. da Cruz, E. Poiate Jr., I.A. Poiate, Silver nanoparticles in dental biomaterials, *Int. J. Biomater.* (2015) 1–9, 2015.
- [7] Castro Denise Tornavoi de, et al., Development of a novel resin with antimicrobial properties for dental application, *J. Appl. Oral Sci.* 22 (5) (Sep-Oct 2014) 442–449.
- [8] V.V. Nair, G.N. Karibasappa, A. Dodamani, V.K. Prashanth, Microbial contamination of removable dental prosthesis at different intervals of usage: an in vitro study, *J. Indian Prosthodont. Soc.* 16 (2016) 346–351.
- [9] D.T. de Castro, M.L.C. Valente, C.P. Aires, O.L. Alves, A.C. Reis, Elemental ion release and cytotoxicity of antimicrobial acrylic resins incorporated with nanomaterial, *Gerodontology* 34 (3) (2017 Sep) 320–325.
- [10] de Castro, Denise Tornavoi, et al., Analysis of the oral microbiome on the surface of modified dental polymers, *Arch. Oral Biol.* 93 (2018 Sep) 107–114.
- [11] Oliscovicz, Nathalia Ferraz, et al., Surface treatment of implant materials with antimicrobial nanoparticles, *Gen. Dent.* 66 (1) (Jan-Feb 2018) 66–73.
- [12] Ana Beatriz Vilela Teixeira, et al., Endodontic sealers modified with silver vanadate: antibacterial, compositional, and setting time evaluation, *BioMed Res. Int.* 2019 (2019 May 9) 4676354.
- [13] Izabela Ferreira, et al., Effect of nanomaterial incorporation on the mechanical and microbiological properties of dental porcelain, *J. Prosthet. Dent.* 123 (3) (2020 Mar), 529.e1-529529.e5.
- [14] Ana Beatriz Vilela Teixeira, et al., Cytotoxicity and release ions of endodontic sealers incorporated with a silver and vanadium base nanomaterial, *Odontology* 108 (4) (2020 Oct) 661–668.
- [15] de Castro, T. Denise, et al., Evaluation of antibiofilm and mechanical properties of new nanocomposites based on acrylic resins and silver vanadate nanoparticles, *Arch. Oral Biol.* 67 (2016 Jul) 46–53.
- [16] de Castro, T. Denise, et al., In vitro study of the antibacterial properties and impact strength of dental acrylic resins modified with a nanomaterial, *J. Prosthet. Dent.* 115 (2) (2016 Feb) 238–246.
- [17] Kamimura, Mm Marian, et al., Effect of saliva and beverages on the surface roughness and hardness of acrylic resin modified with nanomaterial, *Am. J. Dent.* 33 (4) (2020 Aug) 191–195.
- [18] Teixeira, Vilela Ana Beatriz, et al., Effect of incorporation of a new antimicrobial nanomaterial on the physical-chemical properties of endodontic sealers, *J. Conserv. Dent.* 20 (6) (Nov-Dec 2017) 392–397.
- [19] Teixeira, Vilela Ana Beatriz, et al., Incorporating antimicrobial nanomaterial and its effect on the antimicrobial activity, flow and radiopacity of endodontic sealers, *Eur. Endod. J.* 2 (1) (2017 Jul 6) 1–6.
- [20] Teixeira, Vilela Ana Beatriz, et al., Influence of adding nanoparticles of silver vanadate on antibacterial effect and physicochemical properties of endodontic sealers, *Iran. Endod. J.* 14 (1) (2019) 7–13.
- [21] de Castro, T. Denise, et al., Development of an impression material with antimicrobial properties for dental application, *J. Prosthodont.* 28 (8) (2019 Oct) 906–912.
- [22] Simone Kreve, et al., Influence of AgVO₃ incorporation on antimicrobial properties, hardness, roughness and adhesion of a soft denture liner, *Sci. Rep.* 9 (1) (2019 Aug 15) 11889.
- [23] A.L. Machado, A.D. Puckett, L.C. Breeding, A.F. Wady, C.E. Vergani, The effect of thermocycling on the flexural and impact strength of urethane-based and high-impact denture base resins, *Gerodontology* 29 (2012) e318–e323.
- [24] Tolker Nielsen, Tim, Biofilm development, *Microb. Biofilms* (2015) 51–66.
- [25] K. Ikeya, et al., Inhibition of denture plaque deposition on complete dentures by 2-methacryloyloxyethyl phosphorylcholine polymer coating: a clinical study, *J. Prosthet. Dent.* 119 (1) (2018 Jan) 67–74.
- [26] H. Egusa, T. Watamoto, K. Abe, et al., An analysis of the persistent presence of opportunistic pathogens on patient-derived dental impressions and gypsum casts, *Int. J. Prosthodont.* (IJP) 21 (2008) 62–68.
- [27] F.L. Mayer, D. Wilson, B. Hube, Candida albicans pathogenicity mechanisms, *Virulence* 4 (2013) 119–128.
- [28] C.D. Van der Maarel Wierink, J.N. Vanobbergen, E.M. Bronkhorst, J.M. Schools, C. de Baat, Oral health care and aspiration pneumonia in frail older people: a systematic literature review, *Gerodontology* 30 (1) (2013 Mar) 3–9.
- [29] L.E. O'Donnell, et al., Dentures are a Reservoir for respiratory pathogens, *J. Prosthodont.* 25 (2) (2016 Feb) 99–104.