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Materiais de reforço para polimetil metacrilato usados em bases de próteses dentárias: uma análise bibliométrica

Reinforcement materials for polymethyl methacrylate used in denture base: a bibliometric analysis

Materiales de refuerzo para polimetil metacrilato utilizados en la base de la dentadura: análisis bibliométrica

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RESUMO

Objetivo: Sintetizar a produção científica e a evolução dos materiais disponíveis para o reforço do polimetilmetacrilato usado bases de próteses dentárias. **Métodos:** A busca foi realizada na base de dados Web of Science em agosto de 2023, e foi utilizado um mapeamento bibliométrico no programa de software VOSviewer. Os dados incluídos dos artigos incluídos foram os termos do título e resumo, tipo de documento, número de citações, periódico de publicação, artigos mais citados e ano de publicação foram selecionados para análise. As variáveis, país dos autores correspondentes, tipo e tamanho de partícula, propriedades, tipo de estudo e resultados foram incluídos manualmente. **Resultados:** Um total de 410 estudos foram selecionados para análise. Os anos mais produtivos foram encontrados entre 2016 e 2022. 375 estudos in vitro (91,46%) e 371 artigos testando partículas inorgânicas (90,48%). A maioria das propriedades avaliadas foi mecânica, 198 estudos usaram partículas de tamanho nanométrico (48,29%), seguidos de 12 estudos em tamanhos micrométricos (2,92%). **Considerações finais:** O aumento global nos últimos sete anos de pesquisas sobre materiais de reforço ao PMMA, especialmente estudos in vitro com partículas inorgânicas e nanométricas, demonstra a necessidade de melhorar o PMMA nas propriedades mecânicas e antimicrobianas para aplicação como base de prótese.
Palavras-chave: Polimetil Metacrilato, Prótese Dentária, Bibliometria.

ABSTRACT

Objective: Synthesize the scientific production and the evolution of the materials available for the reinforcement of polymethyl methacrylate used in denture bases. **Methods:** The search was conducted on the Web of Science database in august 2023, and a bibliometric mapping in the VOSviewer software program was used. Data included from the included articles were title and abstract terms, type of document, number of citations, journal of publication, most cited articles and year of publication were selected for analysis. The variables, corresponding authors country, particle type and size, properties, study type and results were manually included. **Results:** A total of 410 were selected for analysis. The most productive years were found between 2016 and 2022. 375 in vitro studies (91.46%) and 371 articles testing inorganic particles (90.48%). Most of the properties evaluated were mechanical, 198 studies used nanometer-sized particles (48.29%), followed by 12 studies on micrometer sizes (2.92%). **Final considerations:** Global increase in the last seven years of research on PMMA reinforcements,

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especially in vitro studies with inorganic and nano-sized materials demonstrates there is a need to improve PMMA with better mechanical and antimicrobial properties for application as a denture base.
Keywords: Polymethyl Methacrylate, Dental Prosthesis, Bibliometrics.

RESUMEN

Objetivo: Sintetizar la producción científica y evolución de los materiales disponibles para refuerzo de polimetilmetacrilato utilizados como base para prótesis dentales. **Métodos:** La búsqueda se realizó en la base de datos Web of Science en agosto de 2023, y se utilizó mapeo bibliométrico en el programa VOSviewer. Los datos incluidos de los artículos incluidos fueron los título y resumen, tipo de documento, número de citas, revista de publicación, artículos más citados y año de publicación. Las variables, país de los autores correspondientes, tipo y tamaño de partícula, propiedades, tipo de estudio y resultados se ingresaron manualmente. **Resultados:** Se seleccionaron un total de 410 estudios para análisis. Los años más productivos se encontraron entre 2016 y 2022. 375 estudios in vitro (91.46%) y 371 artículos que probaron partículas inorgánicas (90.48%). La mayoría de las propiedades evaluadas fueron mecánicas, 198 estudios utilizaron partículas de tamaño nanométrico (48.29%), seguido de 12 estudios en tamaño micrométrico (2,92%). **Consideraciones finales:** El aumento global en los últimos siete años de investigación sobre materiales de refuerzo de PMMA, especialmente estudios in vitro con materiales inorgánicos y nanométricos, demuestra la necesidad de mejorar el PMMA con mejores propiedades mecánicas y antimicrobianas para su aplicación como base de prótesis.
Palabras clave: Polimetil Metacrilato, Prótesis Dental, Bibliometría**.**

INTRODUCTION

Polymethyl methacrylate (PMMA), despite being widely used in the manufacture of dental prostheses, has limitations, such as low thermal conductivity, increased water sorption, shrinkage in polymerization, insufficient ductility, low flexural strength, low modulus of elasticity and toughness, porosity, and insufficient hardness, making this material subject to clinical failures and fractures (GAD MM, et al., 2017; PRAJWALA N, et al., 2020). Furthermore, owing to the nature of the material itself, continuous exposure to a humid environment can lead to damage during the use of removable dentures causing pigment adhesion, color change, and aging fractures (WANG W, et al., 2015).

The denture base can act as a reservoir for microorganisms due to the porosity of PMMA, increasing the probability of bacterial and fungal infections, especially oral candidiasis, which is the most prevalent disease among these users, and is caused by Candida albicans (CHEN R, et al., 2017). In addition, microorganisms present in denture biofilms can degrade acrylic resin components through the biodeterioration process and increase their porosity. This microbial adhesion on the dental prosthesis compromises the health of the supporting tissues in these patients and may also be related to the increased risk of developing systemic diseases, such as aspiration pneumonia, infectious endocarditis, pulmonary candidiasis, and chronic obstructive pulmonary disease (PRZYBYŁOWSKA D, et al., 2014; PRZYBYŁOWSKA D, et al., 2016), particularly in bedridden long-term patients using removable dental prosthesis who face difficulties in sanitizing the prosthesis and immunocompromised like transplanted or under chemotherapy patients (CHEN R, et al., 2017; ZHANG K, et al., 2016).

Over the years, researchers have been studying alternatives utilizing reinforcement materials of different types, shapes, concentrations, and sizes in the polymeric chain of PMMA (GAD MM, et al., 2017). Filler materials found in the literature range from metallic oxides, such as zirconia, alumina, and titanium to other types of materials, such as nylon fibers, polyethylene, polyamide, glass, and antimicrobial agents (DE CASTRO DT, et al., 2016; MARRA J, et al., 2012; MIRIZADEH A, et al., 2018; ZHANG K, et al., 2016). In addition, hybrid materials combining different fibers, metal oxides and ceramics (ALHAREB AO, et al., 2015; ALHAREB AO, et al., 2016; MAH B e ALJAFERY AM, 2015; SAFARABADI M, et al., 2014), fibers and metal oxides (ISMAIL IJ, et al., 2018), or ceramics have been reported (ALHAREB AO e AHMAD ZA, 2011; SIHAMA SI, et al., 2015; ZHANG XY, et al., 2014). Owing to a large number of materials, several classifications have been proposed including, by material type: antimicrobial agents and drugs (YASSIN SA, et al., 2016), wires, plates, rubbers, tubes, organics or inorganics (BACALI C, et al., 2019), fibers, fillers, and hybrid materials (BACALI C, et al., 2019; GAD MM, et al., 2017) and

by particle size: macroparticles, microparticles, or nanoparticles (AHMAD N, et al., 2020; ALI SABRI B, et al., 2021; BACALI C, et al., 2019; COUTINHO IF, et al., 2018; GAD MM, et al., 2017).

The ability to reduce physical, mechanical, and biological limitations (AN S, et al., 2018; ERGUN G, et al., 2018; GAD MM, et al., 2016; HAO Y, et al., 2018), among others, clinically reflects on higher longevity of the dental prosthesis and the oral and systemic health of the user. Thus, considering the range of materials available to reinforce the PMMA used for denture bases, the purpose of this review was to perform a bibliometric analysis and evaluate the evolution of materials available for the reinforcement of polymethyl methacrylate used in dentures bases.

METHODS

The search was conducted on the Web of Science database (WoS) (CHEN Y, et al., 2021; KOKOL P e VOŠNER HB, 2018) in august 2023 with no filter applied. A combination of free uniterms and MeSH descriptors was used with the boolean operators AND and OR: "((incorporation OR reinforcement OR filler OR impregnated OR particles OR nanoparticles OR enhancement) AND (acrylic resin OR PMMA OR reinforced acrylic OR polymethyl methacrylate OR poly methyl methacrylate) AND (complete denture OR removable dental prosthesis OR denture base OR oral rehabilitation OR denture)) (All Fields)". An initial scan was conducted to select articles that provided the focus of this review: reinforcement materials used in PMMA specific to denture bases. Thus, articles where the full text was not available, studies that presented coated materials and copolymers, or studies where materials were not evaluated as a reinforcement/filler in PMMA for denture bases were excluded.

The WoS search was conducted, and all results were exported in Excel format, selecting the "full records" option. The exported file was managed in Excel (Microsoft Corp), and the categories selected for analysis were document type, number of citations, journal of publication, most cited articles, and year of publication.

In addition, the country of the corresponding author, type of particle (organic or inorganic), particle size, properties, type of study, and results were manually included by the researchers (B.R.N., R.T.F.C.). Bibliometric mapping in the software program (VOS viewer; Leiden University) that is designed for visualizing and analyzing bibliometric networks. It can then create visualizations based on the co-occurrence of authors, keywords, or documents in the dataset. The program offers various clustering methods and filtering options to customize the visualizations and highlight the important nodes and clusters (VAN ECK NJ and WALTMAN L, 2010).

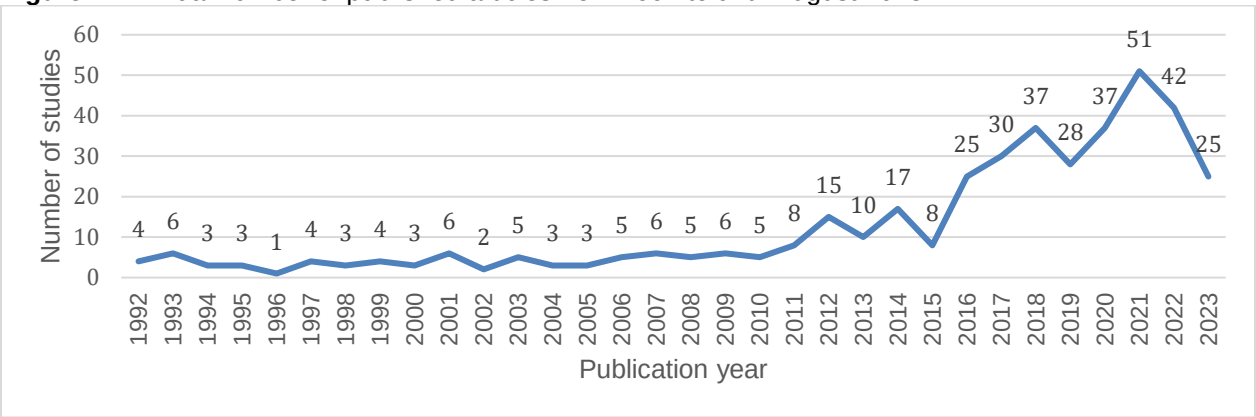
This analysis was used for data extraction and identify a relevant combination of title and abstract terms. These terms were obtained from the network visualization, consisting of the following items: circles representing the term; the size of the circle indicating frequency, thus, the greater the size, the greater its occurrence; colors determined by the cluster to which it belongs; and lines representing links, thus, words that occur simultaneously. Link thickness indicated the number of times words occur simultaneously.

RESULTS

A total of 769 studies were identified, of which 355 were excluded because they did not meet the inclusion criteria of this study, and 4 full text was not available; thus, 410 articles were selected for analysis. According to the years of publication, 18.78% of the studies were published between 1992 and 2010, the year 1996 had the lowest number of publications (one record), and the years 1993, 2001, 2007, and 2009 had six records (the highest number).

Between 2011 and 2015, significant variations were observed in the number of studies, and the most productive years were 2016 and 2022. The largest number of studies were conducted in 2021, with 51 published studies, following 42 studies in 2022 (**Figure 1**).

Figure 1 - Annual number of published articles from 1992 to until August 2023.



Source: Neves BR, et al., 2023.

With reference to the type of document, articles were the most common, with a total of 369 (90.00%) articles. Following this were reviews and proceedings papers with 27 (6.58%) and 13 (3.17%), respectively. Finally, one (0.24%) study was classified as “other”. With regard to the type of study, there were 375 in vitro studies (91.46%), 4 clinical studies (0.97%), and 31 reviews (7.56%). Regarding the reinforcement material, the most studied materials were inorganic particles 371 (90.48%), followed by organic particles 26 (6.34%) (SHAKERI F, et al., 2018), six studies that evaluated both (1.46%), and the remaining seven (1.70%) were not applicable because they did not specify the type of material. Several properties were evaluated in the studies, the majority studies (267) evaluating mechanical properties, and the smallest number of studies (104) evaluating antimicrobial properties. Finally, according to particle size, 198 (48.29%) studies used nanometer-sized particles, 12 (2.92%) studies used micrometer-sized particles, 12 studies (2.92%) evaluated both types, and 188 studies (45.85%) did not report particle size (**Table 1**).

Table 1 - Characteristics of included articles.

Type of study		**%**
Clinical	4	0.97%
Review	31	7.56%
In vitro study	375	91.46%
Type of document		
Article	369	90.00%
Proceedings paper	13	3.17%
Review	27	6.58%
Other	1	0.24%
Type of material		
Inorganic	371	90.48%
Organic	26	6.34%
Organic and inorganic	6	1.46%
Not applicable	7	1.70%
Particle size		
Micro	12	2.92%
Nano	198	48.29%
Micro and nano	12	2.92%
Not reported	188	45.85%
Properties evaluated		
Mechanical	267	-*
Antimicrobial	104	-
Others	144	-

Subtitle: *Not possible perform percentage due to studies evaluated many properties.
Source: Neves BR, et al., 2023.

A total of 42 countries or regions were analyzed and the articles frequency were distributed by countries or regions of publication: Saudi Arabia 38 studies, Turkey (36), India (32) Brazil (28), Iraq (25), China (25), Romania (22), Malaysia (21), Japan (20), United Kingdom (19), United States (16), Finland (15), Poland (13), Iran and Egypt (11), Republic of Korea and Serbia (9), Thailand (6), Mexico (5), Australia, Hong Kong, Libya and Indonesia (4), Norway, Pakistan, Croatia, Slovenia and South Africa (3), South Korea, Italy and Taiwan (2), lastly Bosnia, Czech Republic, England, Germany, Hungary, Nigeria, Chile, Spain, Ukraine, Switzerland and Portugal (1). Regarding the result of the studies, most of the articles showed some positive results in properties (354), with 24 articles showing negative results, 1 study showing inconclusive results, and the rest (31) not showing direct results because they were reviews.

The analysis showed the distribution of the articles in journals with their impact factor, and country of origin. The five journals with the highest number of published studies were the Journal of Prosthetic Dentistry with 27 studies, followed by Materials with 18 studies, Dental Materials Journal and Journal of Prosthodontics-Implant Esthetic and Reconstructive Dentistry with 17 studies each, and Polymers with 16 studies, as shown in **Chart 2**. **Chart 3** shows a list of the 8 most-cited articles and the year of publishing along with the journal and total number of citations, with a total of 1,010 citations.

Chart 2 - Distribution of the number articles in journals and corresponding journal metrics.

Name of the journal	No. of articles	Journal Metrics (IF: X)	Country
The Journal of Prosthetic Dentistry	27	IF: 4.6	United States
Materials	18	IF: 3.4	Switzerland
Dental Materials Journal	17	IF: 2.5	Japan
Journal of Prosthodontics-Implant Esthetic and Reconstructive Dentistry	17	IF: 4.0	United States
Polymers	16	IF: 5.0	Switzerland
Dental Materials	14	IF: 5.0	United Kingdom
Nanomaterials	10	IF: 5.3	Switzerland
Journal of Advanced Prosthodontics	10	IF: 2.6	South Korea
Journal of Oral Rehabilitation	10	IF: 2.9	United Kingdom
Journal of Applied Polymer Science	9	IF: 3.0	United States
International Journal of Nanomedicine	8	IF: 8.0	New Zealand
Gerodontology	7	IF: 2.0	Denmark
Revista de Chimie	7	IF: 1.7	Romania
Journal of The Mechanical Behavior of Biomedical Materials	7	IF: 3.9	Netherlands
Journal of Dentistry	6	IF: 4.4	Netherlands
Contemporary Clinical Dentistry	6	IF: 1.2	India
Materiale Plastice	6	IF: 0.7	Romania
Others*	201	-	-

Subtitle: No, numbers; IF, impactor factor; * Journals with ≤ 5 articles grouped in category others.
Source: Neves BR, et al., 2023.

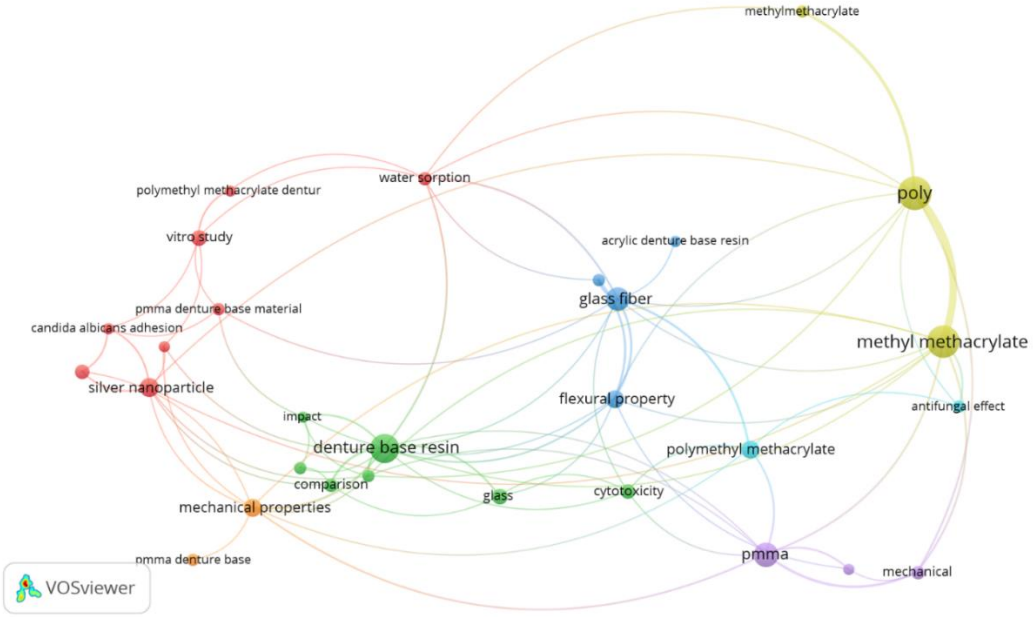
Chart 3 - List of most cited articles.

	Article title / Publication year	Journals	No. of citation
1	Medical and Dental Applications of Titania Nanoparticles: An Overview /2022	Nanomaterials	369
2	Prospects on Tuning Bioactive and Antimicrobial Denture Base Resin Materials: A Narrative Review / 2023	Polymers	125
3	PMMA-Based Nanocomposites for Odontology Applications: A State-of-the-Art / 2022	International Journal of Molecular Sciences	113
4	Antimicrobial Properties of Silver-Modified Denture Base Resins / 2022	Nanomaterials	100
5	Effects of silver nanoparticle-based antimicrobial formulations on the properties of denture polymer: A systematic review and meta-analysis of in vitro studies / 2023	Journal of Prosthetic Dentistry	92
6	Nanoparticle-modified PMMA to prevent denture stomatitis: a systematic review / 2022	Archives of Microbiology	75
7	Development of novel antimicrobial acrylic denture modified with copper nanoparticles / 2023	Journal of Prosthodontic Research	68
8	Antibacterial Effect of Polymethyl Methacrylate Resin Base Containing TiO2 Nanoparticles / 2022	Coatings	68

Subtitle: No, Numbers. **Source:** Neves BR, et al., 2023.

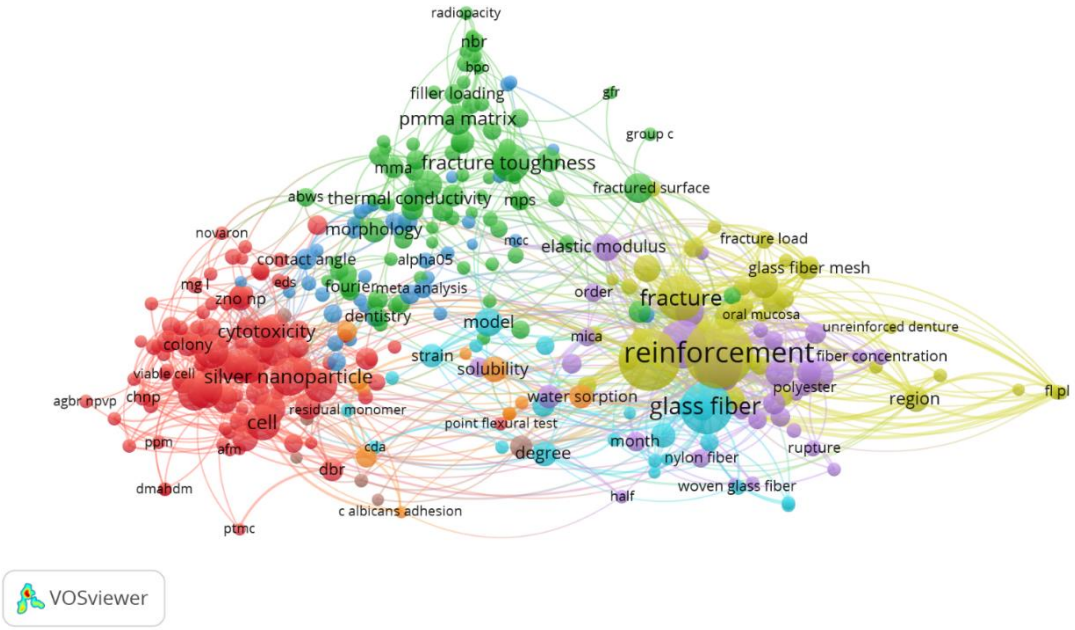
The network view shows the cooccurrence of terms in the titles (**Figure 2**) and abstracts (**Figure 3**) of the selected studies, with five being the minimum occurrences of a term. A correlation was found among 29 terms in the titles, highlighting “poly methyl methacrylate”, “denture base resin”, “glass fiber, and “pmma” because of the frequency represented by size and some tests, such as “impact”, “water sorption”, “Candida albicans adhesion, and “flexural property”. In the abstract, 346 terms were correlated, highlighting “reinforcement,” “fracture,” and “glass fiber,” in addition to other tests, such as “fracture toughness,” “thermal conductivity,” “cytotoxicity,” and “radiopacity” and reinforcement, such as “silver nano,” “zno,” “nylon fibers,” and “polyester”.

Figure 2 - Co-occurrence of title terms of included studies.



Source: Neves BR, et al., 2023.

Figure 3 - Co-occurrence of abstract terms of included studies.



Source: Neves BR, et al., 2023.

DISCUSSION

The general increase in research on the reinforcement of PMMA, particularly in the last 7 years, has reinforced the need to consolidate a material that brings structural and biological improvements to PMMA. The growth of studies seems to be associated with nanometric inorganic particles since the first analysis of these materials began in 2011 (GAD MM, et al., 2017). The interaction between nanometric particles and PMMA has been shown to be promising because of the index of positive results also in antimicrobial, physical, and chemical properties (AHMAD N, et al., 2020; ALI SABRI B, et al., 2021; COUTINHO IF, et al., 2018). Nano-fillers are another type of reinforcement material that can be added to PMMA to improve mechanical properties, such as strength, stiffness, and wear resistance. Can also enhance the esthetic properties of the denture base by increasing its translucency and reducing the surface roughness. However, the use of nano-fillers may increase the processing time and affect the handling properties of the PMMA resin (DÍEZ-PASCUAL AM, 2022).

Inorganic particles comprised most of the tested particles in these studies; however, in recent years, more attention has been given to organic particles, probably because they have some advantages in certain applications as their biocompatibility, low toxicity, antimicrobial activity, biomedical applications, biodegradability (SHAKERI F, et al., 2018) and cost-effective. Thus, it is expected that innovations in this area will be tested in the coming years.

Research on the reinforcement of PMMA with both inorganic and organic particles has been conducted in many countries around the world. Regarding the country of origin of this bibliometric analysis, Turkey stands out with at least 2% of the world's scientific publications and Brazil with 7%, both in the field of dentistry. Saudi Arabia has also contributed to an increase in the global production of dental research (GRACIO MCC, et al., 2013); thus, being considered a representative country on the international scene (SHAKERI F, et al., 2018).

Although the topic investigated in this analysis has been studied since the 1990s (CHOW TW, et al., 1992), in vitro studies continue to dominate because of the variety of particles and different reinforcement forms. Also, despite positive results in some tests, other tests with the same material may not present favorable results due to the lack of standardization in particle size and concentration, which promotes the development of new laboratory

research (GAD MM, et al., 2017). As a set of ideal characteristics has not yet been found, in vitro studies are necessary as they represent an important step to support future clinical studies (GAD MM, et al., 2017), also less expensive, and less time-consuming than in vivo studies; allow researchers to control the experimental conditions more precisely; test the safety and toxicity before they are tested in animals or humans and can help researchers understand the mechanisms between the materials.

Most studies have focused on mechanical tests because different types of mechanical tests measure different properties of a material, such as its tensile strength, compressive strength, and hardness. In addition, can determine the optimal concentration of the reinforcement e compare the results with existing standards. These tests are frequently used due to their great cost benefit, high performance, and the safety measures required according to the need and utility of each material (ERGUN G, et al., 2018). However, there are also other tests that can be used to assess the performance of PMMA in specific applications taking significant aspects of denture base tests include water sorption, cytotoxicity, surface hardness and roughness, dimensional stability, thermal changes, polish ability, radiopacity, color changes, stiffness, electric conductivity (ZAFAR MS, 2020).

Moreover, the search for better antimicrobial properties also stands out. Fungal growth on the surface of PMMA can cause discoloration and staining and Candida is a type of fungal microorganism most founded in dentures that can colonize on the surface of polymeric materials, and cause infection. The incorporation of nanoparticles as reinforcement materials in PMMA can enhance fungicidal properties, potentially inhibiting the growth of Candida (GLIGORIJEVIĆ N, et al., 2022). For example, the incorporation of silver nanoparticles into PMMA has been shown to have a potent antifungal effect against Candida, which is attributed to the release of silver ions from the nanoparticles. The silver ions can penetrate the cell wall of the Candida and disrupt its metabolic processes, resulting in the inhibition of its growth. In addition to silver nanoparticles, other types of nanoparticles, such as zinc oxide and titanium dioxide, have also been shown to have an inhibitory effect on the growth of Candida (BANGERA MK, et al., 2021).

The effectiveness of nanoparticles against Candida can be influenced by several factors, such as their size, shape, concentration, and surface chemistry, as well as the type of Candida strain. Therefore, it is important to optimize the nanoparticle properties and concentration in PMMA to achieve optimal antifungal efficacy.

Furthermore, various biocidal agents can be incorporated into PMMA as reinforcement materials to impart fungicidal properties. However, it is important to consider the potential toxicity of these agents and their impact on human health and the environment. Careful consideration should be given to the selection and processing of both the PMMA and reinforcement material to ensure that the final product is both functional and biocompatible. Materials that are not biocompatible can cause inflammation, infection, or other types of tissue damage, which can compromise the success and patient health.

In addition, cases of dental prosthesis repairs are a common practice in dental clinics, and often involves the use of polymethyl methacrylate (PMMA) as a repair material. This repair with addition of particles has been studied and performed with an interesting strategy to maintain the original strength of the prosthesis or improve their mechanical properties and increase their longevity doing the bond strength between the repair material and the existing denture base, however, due to the limited number of studies, further investigations are needed before recommendations for clinical applicability (GAD MM, et al., 2016).

Reviews and studies of nanometric materials are the most cited articles because they provide a comprehensive summary of a particular research area, including a critical analysis of the existing literature being written by experts in the field, which qualify the topic of interest amid the research conducted (ALI SABRI B, et al., 2021). In addition, journals in the areas of dentistry, dental prosthetics, and polymers had the largest number of publications. The terms in the titles with more prominence and connections express those studies that have shown development in these fields, and the abstract terms demonstrate a correlation with more topics, such as tests used and particles analyzed, that can be explained by the growing progress of research in these areas.

Overall, while bibliometric analysis is a useful tool for evaluating the impact of research, it is important to consider the limitations: may not capture other forms of research output, does not provide complete research in a particular field and the analysis does not showing all the details about the publications that are being analyzed. In addition, this bibliometric analysis was that it only included articles from the WoS electronic database, which however, does have a larger selection of articles than other databases and is a powerful resource for academic research, providing access to a vast collection of literature (KOKOL P e VOŠNER HB, 2018). Although the search in different databases for extraction and visualization of the data was still an obstacle for bibliometric analysis (CHEN Y, et al., 2021), finally, with the progress of research, it is expected that in the next few years, the modification of PMMA will be achieved providing support for clinical research on removable denture bases and benefiting the health of these users.

FINAL CONSIDERATIONS

Bibliometric analysis is an important method for analyzing large volumes of scientific data that can provide a comprehensive assessment of a researcher and identify emerging areas of research being a useful tool for understanding the impact and influence of a particular search. This analysis indicate the global increase in the last 7 years of research on PMMA reinforcements, especially in vitro studies with inorganic and nanosized materials, demonstrates the need to improve PMMA with better mechanical and antimicrobial properties for application as a denture base, thus allowing the advancement of clinical studies to evaluate the effectiveness of these reinforcements in denture users. Furthermore, this research demonstrates the importance of multidisciplinary collaborations and innovation in materials science, dentistry, and biomaterials, as researchers strive to enhance the quality of dental prosthetics and improve the overall oral health of patients. The reinforcement techniques indicate great promise in revolutionizing denture fabrication and patient care in the coming years.

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