



Research trends in the study of biofilms related to periodontal disease: A bibliometric analysis

[Tendencias de investigación en el estudio de las biopelículas relacionadas con la enfermedad periodontal: Un análisis bibliométrico]

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Abstract

Context: The study of biofilms in the context of periodontal diseases is of paramount importance due to their central role in the pathogenesis of these oral diseases. Research has focused on understanding the formation, structure, and dynamics of biofilms, as well as developing therapeutic approaches for their eradication. However, there are still conceptual gaps in the scientific literature due to a lack of review studies.

Aims: To examine research trends in the study of biofilms related to periodontal diseases.

Methods: This study used a bibliometric analysis methodology of scientific literature based on the PRISMA-2020 statement.

Results: The results showed a remarkable increase in research activity in recent years. Prominent authors, influential journals, and emerging keywords such as "multispecies biofilm", "biofilm formation" or "periodontal therapy" were identified, reflecting the areas of greatest interest.

Conclusions: The need to balance the exploration of new areas with the consolidation of other key concepts is highlighted, as well as gaps in research that require more precise therapeutic approaches, longitudinal studies, and greater attention to underserved communities in developing countries.

Keywords: antimicrobial therapies; biofilm; oral microbiota; pathogenesis; periodontal disease; PRISMA-2020.

Resumen

Contexto: El estudio de las biopelículas en el contexto de las enfermedades periodontales es de suma importancia debido a su papel central en la patogénesis de estas enfermedades orales. La investigación se ha centrado en la comprensión de la formación, estructura y dinámica de las biopelículas, así como en el desarrollo de enfoques terapéuticos para su erradicación. Sin embargo, todavía existen lagunas conceptuales en la literatura científica debido a la falta de estudios de revisión.

Objetivos: Examinar las tendencias de investigación en el estudio de las biopelículas relacionadas con las enfermedades periodontales.

Métodos: Este estudio utilizó una metodología de análisis bibliométrico de la literatura científica basada en la declaración PRISMA-2020.

Resultados: Los resultados mostraron un notable incremento de la actividad investigadora en los últimos años. Se identificaron autores destacados, revistas influyentes y palabras clave emergentes como "biofilm multiespecie", "formación de biofilm" o "terapia periodontal", que reflejan las áreas de mayor interés.

Conclusiones: Se destaca la necesidad de equilibrar la exploración de nuevas áreas con la consolidación de otros conceptos clave, así como lagunas en la investigación que requieren enfoques terapéuticos más precisos, estudios longitudinales y una mayor atención a las comunidades desatendidas de los países en desarrollo.

Palabras Clave: biopelícula; enfermedad periodontal; microbiota oral; patogénesis; PRISMA-2020; terapias antimicrobianas.

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INTRODUCTION

Due to their fundamental role in the pathogenesis and development of these oral diseases, biofilms have received much attention in the context of periodontal diseases in recent years. Biofilms are highly organized microbial communities adhering to biological or abiotic surfaces, characterized by their extracellular matrix and their ability to resist conventional treatments. In the field of periodontal diseases, dental biofilms are known to be composed mainly of anaerobic bacteria and have been identified as an important etiological factor in periodontal disease and periodontal tissue loss (Colombo and Tanner, 2019).

They have conducted extensive research on periodontal biofilms to better understand their formation, structure, and dynamics and to develop therapeutic approaches to eradicate them. For example, recent studies have investigated the potential of near-infrared (NIR)-sensitive nitric oxide nanogenerators to eliminate periodontal biofilms and control the inflammatory response associated with these diseases (Qi et al., 2022). In addition, how to control periodontal pathogens by preventing biofilm formation using bioactive nanocomposites containing chlorine e6 was investigated (Zhang et al., 2019). *Staphylococcus aureus* strains isolated from periodontal lesions have also been studied to determine the frequency and expression of genes related to adhesion and biofilm formation, providing information on the molecular mechanisms underlying microbial colonization in this context (Uribe-García et al., 2021).

In biomedical research, the study of biofilms in relation to periodontal disease has gained importance. It has been shown that the pathogenesis and development of periodontal diseases are significantly influenced by these dental biofilms, which are formed by highly organized microbial communities. Recent studies have analyzed different aspects of this relationship using multidisciplinary methods to understand biofilms and their impact on oral health (Carli et al., 2021). They investigated how self-ligating orthodontic brackets affected dental biofilms and periodontal pathogens in adolescent subjects, highlighting the importance of biofilms in orthodontics.

In contrast, they studied quorum-sensitive molecules in oral biofilms *in vitro*, highlighting the ability of biofilms to control the gene expression of periodontal pathogens (Muras et al., 2020). The study of bioactive glass with zinc, which demonstrated antibiofilm properties against periodontal pathogens, is an example of important research that has been conducted on dental materials (Esfahanizadeh et al., 2018).

Innovative therapeutic strategies were also investigated to combat biofilms associated with periodontal disease: Tonon et al. (2022) evaluated periodontal biofilms for bacterial treatment using photosensitizers on superhydrophobic surfaces. Jungbauer et al. (2022) demonstrated the adaptability of emerging technologies by investigating the efficacy of an atmospheric plasma device against bacteria and biofilms associated with periodontal and peri-implant disease. Similarly, Parga et al. (2023) addressed the modification of periodontal biofilm formation by the enzyme Aii20J, highlighting the potential of quorum cooling in the control of oral infections.

The study of biofilms in the context of periodontal disease has shed important light on microbial interactions and the pathogenesis of these oral diseases. However, despite significant advances in this field, there are obvious gaps in the scientific literature that require a thorough bibliometric analysis. For example, the need to continue studying the immunological effects of periodontal biofilms, focusing on the alteration of the periodontal inflammatory response by dysbiotic biofilms (Herrero et al., 2018). In addition, they developed a polymicrobial biofilm model to evaluate the antimicrobial potential of a nisin biogel in the control of periodontal disease in dogs, emphasizing the lack of equivalent approaches for the study of periodontal disease in humans (Cunha et al., 2020). Finally, another study presented a new probiotic with anti-biofilm properties against harmful periodontal bacteria, raising doubts about the clinical utility of these strategies and their impact on human periodontal health (Widyarman and Theodora, 2022).

The scientific literature contains significant conceptual voids due to gaps that mainly arise from the absence of comprehensive review studies integrating and synthesizing the current state of knowledge in the field of biofilms related to periodontal diseases. The lack of a unified overview hampers the identification of priority research areas and the determination of the direction of future investigations. Therefore, conducting a comprehensive literature review is crucial to addressing these gaps and establishing a strong foundation for advancing knowledge in this field. These research gaps underscore the importance of conducting a comprehensive bibliometric review to assess the current trajectory and trends in the study of biofilms related to periodontal disease.

The scientific literature on biofilms related to periodontal diseases is rich in research covering various aspects of the subject. Studies range from exploring the composition and structure of biofilms to investigating new therapeutic strategies for their control.

The literature reflects a continued and multifaceted interest in this field of study. However, there are significant gaps that require attention, such as the lack of in-depth studies that examine immunological interactions within periodontal biofilms and their impact on periodontal inflammation.

Therefore, the objective is to examine research trends in the study of biofilms in the context of periodontal disease with the purpose of guiding a research agenda for future studies. In turn, the following research questions are proposed, which allowed the study to be more robust in terms of achieving the stated objective:

- What are the years of greatest interest in the study of biofilms related to periodontal disease?

- What is the growth rate of the number of scientific articles on the study of biofilms related to periodontal diseases?

- What are the main research references on the study of biofilms related to periodontal diseases?

- What is the thematic evolution derived from the scientific production on the study of biofilms related to periodontal diseases?

- What are the main clusters of scientific associativity in the research on the study of biofilms related to periodontal diseases?

- What are the main thematic clusters in the study of biofilms related to periodontal diseases?

- What are the growing and emerging keywords in the field of research on the study of biofilms related to periodontal diseases?

- Which topics are positioned as protagonists for the design of a research agenda on the study of biofilms in the context of periodontal diseases?

Conducting a bibliometric analysis on this topic is essential for several reasons. Firstly, it will enable the quantification and objective evaluation of scientific production related to biofilms in the context of periodontal diseases. This will provide a clearer understanding of the quantity of research conducted, as well as the prominent thematic trends and identified research gaps in the field. Additionally, a bibliometric analysis can help identify areas that require further attention and exploration in future research.

MATERIAL AND METHODS

The present study used an exploratory methodology and adhered to the criteria established in the statement by performing a bibliometric analysis of the scientific literature on the topic of biofilms in the context of periodontal diseases. PRISMA-2020 (Page et

al., 2021). This method of systematic literature review was based on secondary research sources and allowed for a comprehensive and organized evaluation of previous research in this area. It was hoped that this method would provide a deeper understanding of this important area of oral health by identifying emerging trends, knowledge gaps, and areas of research that had received the most attention in the study of biofilms and periodontal disease.

Eligibility criteria

Titles and keywords were prioritized as essential metadata in the search and selection of documents, according to strict inclusion criteria established for the selection of relevant records. Focusing on the presence of key terms such as "biofilms" and "periodontitis" in these crucial parts of scientific papers ensured that the records selected were inextricably linked to the topic of interest. In addition, the combination of multiple citation styles for these terms was believed to ensure complete inclusion of relevant documents despite name variations.

Instead, the exclusion process was carried out in three successive stages to ensure the accuracy and usefulness of the records included in the bibliometrics. In the first phase, all records with incorrect indexing were discarded to ensure that the selected documents were correctly categorized and tagged. Since bibliometrics focused only on metadata analysis, the second phase of exclusion applied only to systematic literature reviews, and at this stage, all documents whose full text was not available were removed. Finally, in the third phase of exclusion, conference proceedings, texts that were not relevant to the research, and documents whose indexing was incomplete were eliminated, thus ensuring coherence and precision in the selection of records for bibliometric analysis.

Information sources

It was decided to use the Scopus and Web of Science databases when selecting databases to perform bibliometrics on the study of biofilms related to periodontal diseases. These databases were well known in the scientific community for their thoroughness in indexing academic literature, scientific journals, and conferences, thus ensuring the inclusion of a wide range of relevant and high-quality sources. In addition, both databases offered state-of-the-art tools for performing accurate and comprehensive bibliometric analyses. A comparative study supported this choice by highlighting that Scopus and Web of Science were two of the main databases used in bibliometric research due to their breadth and ability to provide

high-quality data, making them appropriate options for bibliometrics (AlRyalat et al., 2019).

Search strategy

Two specialized search equations were adapted to the previously established inclusion criteria, and the search characteristics of each platform were created to perform the bibliometric search in the two selected databases, Scopus and Web of Science. These equations were carefully constructed to ensure the identification of relevant data related to biofilm research in the context of periodontal disease. Specific keywords, synonyms, and Boolean operators were taken into account to optimize the completeness and precision of the search in each database, thus allowing a complete and representative data collection of the existing scientific literature in this research area. To ensure that relevant documents were accurately captured in both databases and to facilitate the analysis and evaluation of research in the area of interest, specialized search equations had to be carefully designed, which were:

For the Scopus database: (TITLE (periodontal) AND TITLE (biofilm))

For the Web of Science database: (TI= (periodontal) AND TI= (biofilm)).

Selection process

It was essential to disclose whether an internal automated classifier was used to expedite the study selection process and whether internal or external validation was performed to determine the risk of study loss according to the standards outlined in the PRISMA 2020 statement (Page et al., 2021). As an internal tool developed and selected by all researchers involved in the project, Microsoft Excel® was used in this study to implement automation tools. The use of this tool by each researcher independently during the application of inclusion and exclusion criteria in the selection of studies significantly reduced the risk of missing relevant studies or making incorrect classifications, thanks to the convergence of results and validation. This strategy helps maintain the reliability and accuracy of bibliometrics by ensuring that studies are rigorously and consistently selected and categorized according to predetermined inclusion criteria.

Data management

Microsoft Excel® was used to effectively extract, store, and process the data obtained from each of the databases selected to carry out this bibliometric study focused on the study of biofilms related to periodontal disease. This application was utilized to sort bibliographic data and perform calculations related to important bibliometric indicators, ensuring the preci-

sion and consistency of the analysis. Next, the free software VOSviewer®, a well-known tool in the field of bibliometrics, was employed for the visualization and graphical presentation of the bibliometric results (Van Eck and Waltman, 2010). Graphs and maps were created using VOSviewer® and Microsoft Excel® to effectively represent the trends, relationships, and patterns found in the scientific literature on biofilms and periodontal disease. These tools were extremely important in helping us make meaningful inferences and visualize the key findings of this bibliometric review.

Data collection process

The methods used to collect data from bibliometric reports to comply with the recommendations were described in detail (Page et al., 2021). For the data collection process in this study, reports obtained from the two selected databases, Scopus and Web of Science, were entered into Microsoft Excel® as an automation tool. It should be noted that all study authors assumed the role of reviewers during the compilation process, independently evaluating each report using predetermined inclusion criteria. The results of the authors' individual assessments were then compared and discussed by the group as a whole, and the process continued until absolute convergence of the collected data was achieved. This methodology contributed to the integrity and quality of the bibliometrics performed on the study of biofilms related to periodontal disease by ensuring a rigorous review and an accurate and consistent data collection process.

Data items

An exhaustive search was conducted to collect information from each article that addressed the research objective. This required reviewing all articles that specifically mentioned the study of biofilms in relation to periodontal disease, taking into account all measurements, time points, and analyses available in each identified study. However, strict standards were applied in the selection process to eliminate data considered to be contained in "non-relevant texts". These texts did not fit the purpose and scope of the research because they did not provide an adequate understanding of the body of knowledge on the topic. In order to ensure consistency in the selection of studies and to ensure that only relevant, high-quality records were included in the bibliometrics, it was necessary to exclude studies with unclear or insufficient information.

Study risk of bias assessment

As the data collection process was carried out jointly by all authors, the risk of bias was assessed in

the same way in the included studies. This ensured that the risk of bias assessment was rigorous and consistent. This was done using the same automated tool, Microsoft Excel®, that was used for data collection. Because the methodology was applied collectively and according to an established procedure, the accuracy and reliability of the results could be guaranteed. This contributed to the validity and reliability of the conclusions drawn from the bibliometric analysis by ensuring an unbiased and consistent assessment of the studies included in the bibliometrics.

Effect measures

It was important to note that although hazard ratios and mean differences were the most commonly used measures of effect in primary research, this study used different measures based on secondary research sources. Instead of specific effect measures, bibliometric indicators such as the number of publications and the number of citations, which provided information about the production and influence of scientific literature in the field, were analyzed. In addition, the temporality of the use of each keyword was evaluated, providing information about long-term trends in research. These analyses were carried out using software such as VOSviewer®, which made it possible to determine thematic association by visualizing nodes in scientific knowledge networks, and Microsoft Excel®, which simplified data collection and processing. To understand the dynamics and evolution of the field of study of biofilms in periodontal diseases from secondary research sources, it was essential to understand these measurements and methodologies.

Synthesis methods

In the course of this bibliometric study on biofilms in periodontal diseases, several procedures were carried out to evaluate the eligibility of the studies and to prepare the data for analysis and synthesis. All retrieved documents were first subjected to inclusion and exclusion criteria, which involved a thorough examination of the characteristics of the document and its compatibility with the objectives of the study. In addition, bibliometric indicators of quantity, quality, and structure of quality measures in scientific publications were carried out according to the guidelines described (Durieux and Gevenois, 2010). These indicators were automatically applied, using Microsoft Excel®, to all documents that passed the three exclusion stages described above. This facilitated the presentation and synthesis of the results in a convincing and effective manner and allowed an objective and systematic evaluation of the scientific production related to biofilms and periodontal disease.

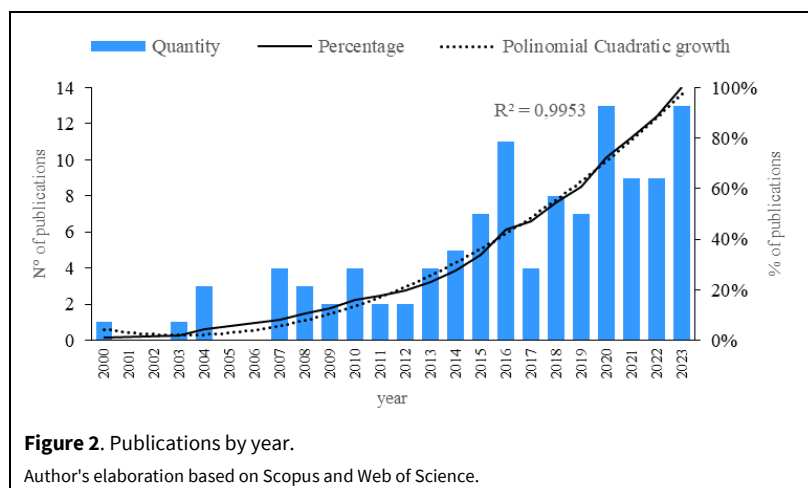
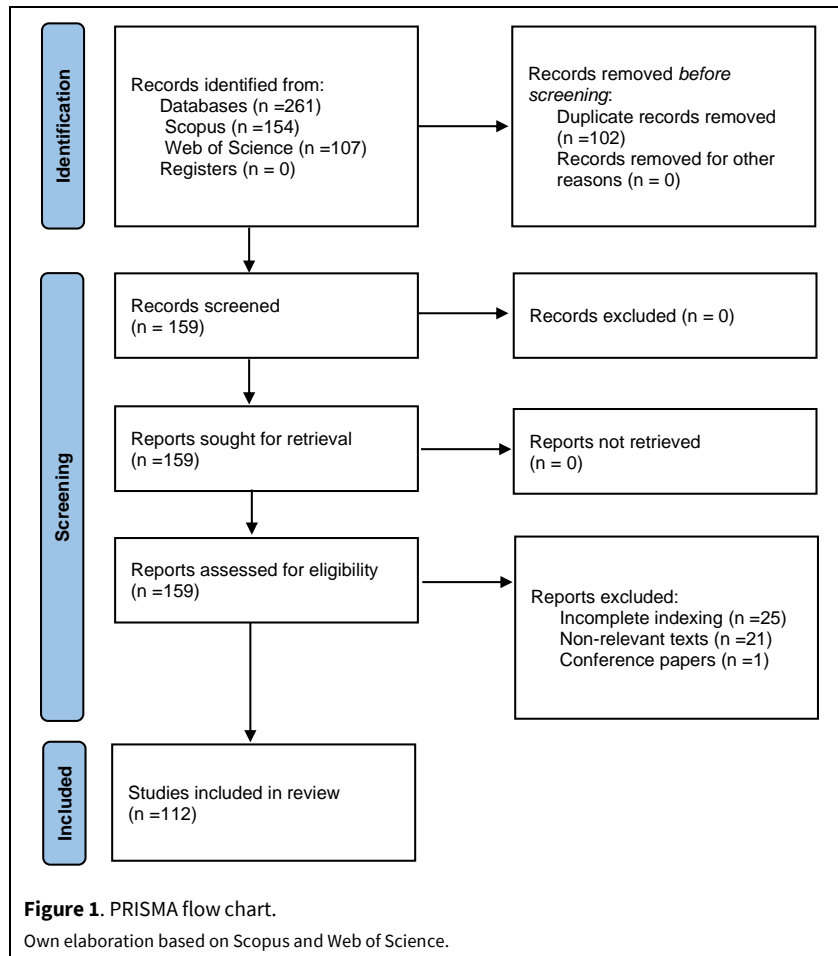
Reporting bias assessment

In the context of this bibliometric study of biofilms in periodontal disease, it was important to discuss the assessment of the risk of bias related to the lack of results in a synthesis, which might have resulted from reporting bias. The inclusion criteria, search approach, and data collection in this study had the potential to be biased in favor of specific synonyms found in thesauri, such as the Institute of Electrical and Electronics Engineers (IEEE). This might have resulted in the exclusion of relevant studies that discussed the topic using unusual or different jargon. Furthermore, there was a risk of omitting important data that could have significantly improved our understanding of biofilms and periodontal disease when applying exclusion criteria, such as removing conference proceedings or documents with incomplete indexing. Because it was critical to address this potential bias, a comprehensive search strategy and strict inclusion and exclusion criteria were employed to reduce its impact.

Certainty assessment

The assessment of certainty in the body of evidence is thoroughly addressed in the context of this bibliometric investigation into the study of biofilms in periodontal disease. Unlike primary studies, which assess certainty separately, this approach assesses certainty broadly by independently applying inclusion and exclusion criteria and defining bibliometric indicators that reflect the caliber and applicability of the selected studies. In addition, they provide a detailed explanation of any potential bias previously identified in the methodological design of the research, and the limitations of the study are acknowledged and addressed in the discussion phase. This comprehensive strategy makes it possible to assess the level of confidence in the body of knowledge produced by bibliometrics and provides a solid framework for interpreting and contextualizing the results of bibliometric analysis. In summary, in Fig. 1, the flow chart recommended by PRISMA-2020 is presented to summarize the methodological design.

Records were identified in the initial phase of this bibliometrics on the study of biofilms related to periodontal disease based on the search strategy implemented in each of the selected information sources. To ensure the integrity of the database, a significant amount of duplication was carried out. The three phases of exclusion mentioned above were then carried out: records with incorrect indexing, documents that could not be read in their entirety, and records that did not meet the predetermined relevance criteria. A total of 112 articles constituted the main corpus



of this bibliometric study, once the selection and exclusion process were completed, providing a solid basis for the analysis of the study of biofilms in relation to periodontal disease.

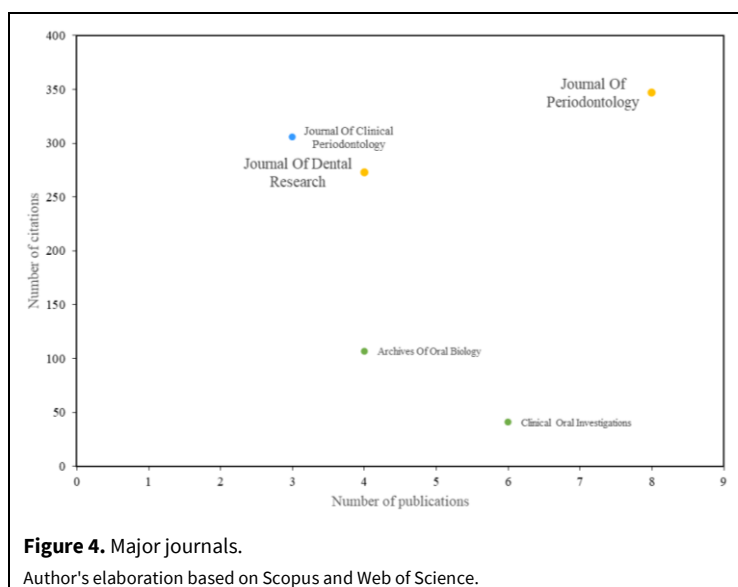
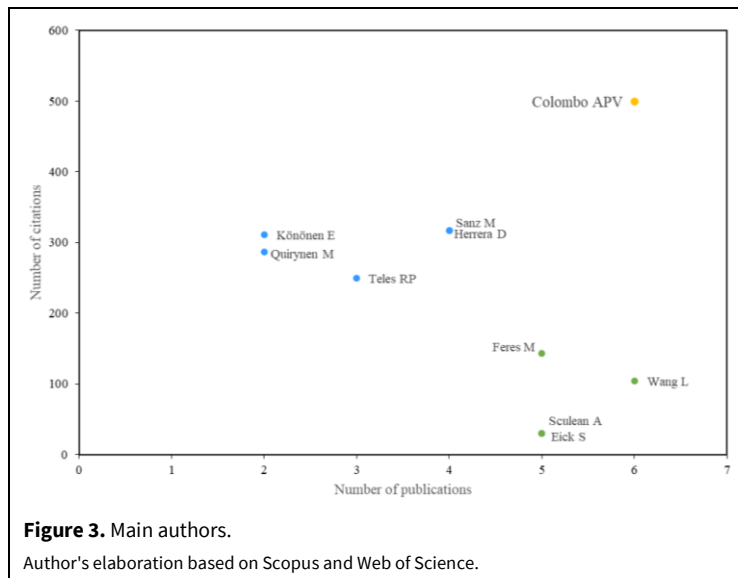
RESULTS

Fig. 2 shows a quadratic polynomial growth of 99.53 percent, illustrating the significant results of the current bibliometrics. This result suggested that the

amount of research conducted on biofilms in relation to periodontal diseases had increased steadily and rapidly in recent years. It was crucial to note that most of the articles on this topic were published in the years 2020, 2023, and 2016, indicating a significant amount of interest and notable research activity in these years. These results provided an in-depth look at the development and vitality of the subject area under consideration and could be used as a basis for further studies and bibliometric analyses in the field.

The analysis of the main authors of this bibliometric study on the study of biofilms in periodontal disease revealed three different groups. First, a group of authors led by Colombo APV stood out as exceptional both in terms of their scientific production and their impact on citations. Secondly, a group of authors, including Kononen E, Sanz M, and Herrera D, achieved a significant impact in their work despite having a lower level of scientific productivity, which indicated the importance of their research. There was a third group of authors for whom scientific productivity was the main factor. In this group, names such as Wang L. and Feres M. stood out, although their impact in terms of citations may have been relatively low compared to other groups. These results demonstrated the diversity of authors' contributions to the field and emphasized the value of both quantity and quality in the production of scientific literature on biofilms and periodontal diseases (Fig. 3).

The analysis of the main journals included in this bibliometric study on the study of biofilms related to periodontal diseases allowed us to distinguish three different groups. First, there were the most important journals, such as the Journal of Periodontology and the Journal of Dental Research, which stood out both for their scientific productivity and for their impact in terms of citations. The Journal of Clinical Periodontology, for example, was one of the journals that, despite having a lower level of scientific production, had a significant impact on the field of science. The third group of journals, which focused on clinical oral research, was characterized by a high level of scientific productivity. These results demonstrated the diversity of journals that contributed to the field of study and emphasized the importance of quantity and quality in the production of scientific literature on biofilms and periodontal diseases (Fig. 4).



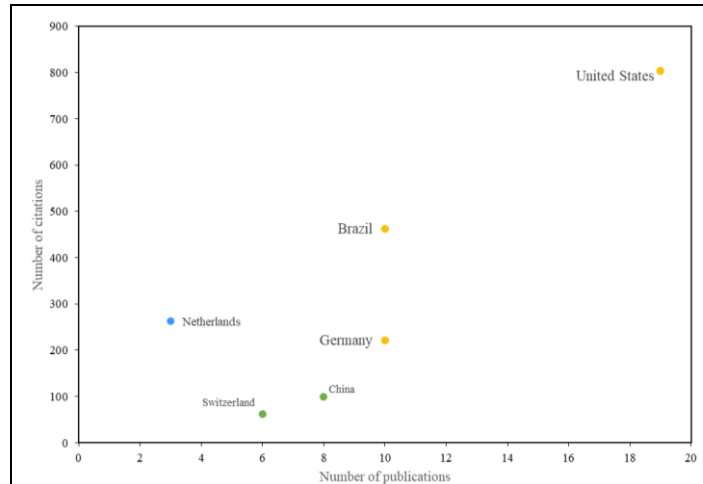


Figure 5. Main countries.
Own elaboration based on Scopus and Web of Science.

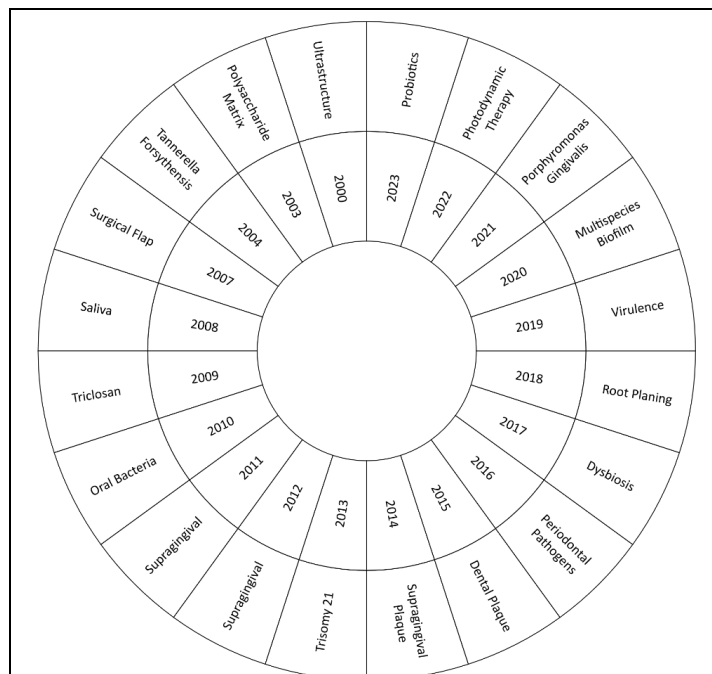
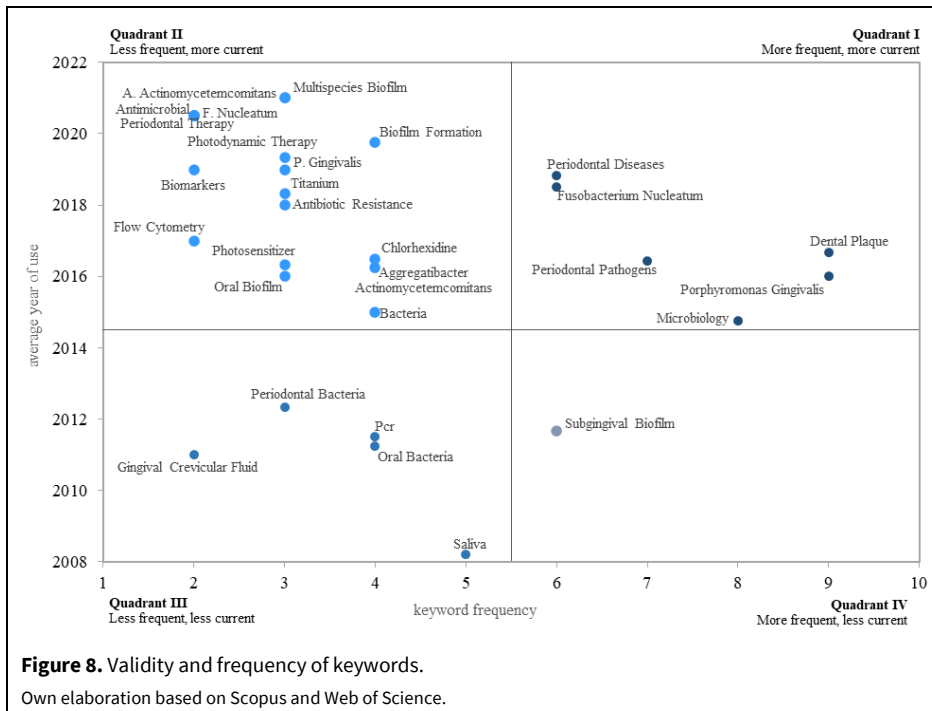
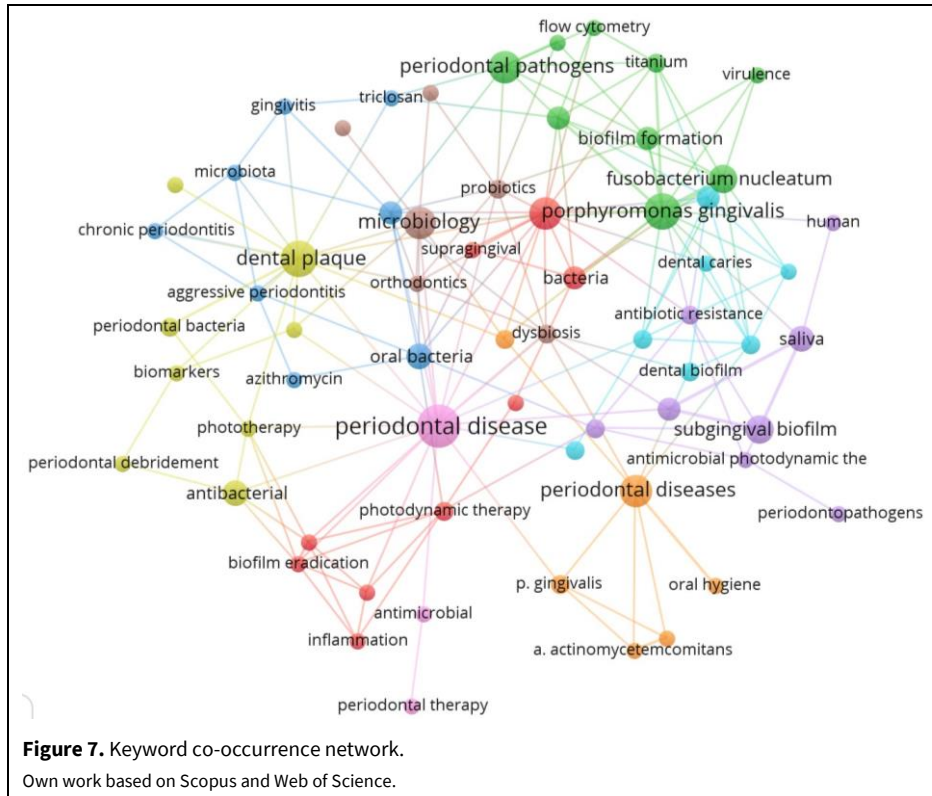


Figure 6. Thematic development.
Own elaboration based on Scopus and Web of Science.

By analyzing the most important nations involved in biofilm research related to periodontal disease, three different groups were identified. First, there were the most important nations, which stood out for both their scientific productivity and their impact in terms of citations. Examples included the United States, Brazil, and Germany. Second, there were nations such as the Netherlands, which had a low level of scientific productivity but a high level of scientific impact. Finally, there was a third group of countries, led by China, where scientific productivity was the key factor. These results demonstrated the geographical diversity of research on biofilms and periodontal diseases and underlined the importance of quantity

and quality in global scientific production in this field (Fig. 5).

In the current study, as shown in Fig. 6, we examined the most popular keyword each year from 2000 to 2023 to analyze the thematic evolution in the literature related to biofilms in the context of periodontal diseases. As a starting point, it can be noted that in the year 2000, terms related to "ultrastructure" stood out. Recently, the focus of research has changed, and more emphasis has been placed on topics such as "probiotics", "photodynamic therapy", "*Porphyromonas gingivalis*", "multispecies biofilms", and "virulence".



As shown in Fig. 7, this bibliometric study presented the main network of keyword co-occurrence across a total of 9 thematic clusters. In terms of conceptual affinity, the green group, composed of terms such as "*Porphyromonas gingivalis*", "*Fusobacterium nucleatum*", "biofilm formation", "virulence", "titanium", "periodontal pathogens", and "flow cytometry", stood out as the most significant. This was followed

by the yellow group, which contained words such as "plaque", "periodontal bacteria", "biomarkers", "phototherapy", "periodontal debridement", and "antibacterial".

As shown in Fig. 8, a Cartesian plane diagram was used to evaluate the frequency of keyword usage. Declining concepts, represented by keywords such as

"subgingival biofilm," which became less relevant over time, fell into the fourth quadrant. In quadrant 2, terms such as "biofilm multispecies," "antimicrobial," "periodontal therapy," and "*F. nucleatum*" were identified as emerging terms in research because they were uncommon but significantly current, such as "*F. nucleatum*" and "biofilm formation."

Finally, in quadrant 1, the consolidated and growing concepts, such as "periodontal diseases", "*Fusobacterium nucleatum*", "dental plaque", "periodontal pathogens", "microbiology", and "*Porphyromonas gingivalis*", maintained their relevance over time and were fundamental in the literature on the study of biofilms related to periodontal diseases. This method allowed for a deeper understanding of the dynamics of research in this field.

DISCUSSION

The discussion section plays a fundamental role in this bibliometric study of biofilms related to periodontal disease. This section comprehensively analyzes the results, highlighting trends, patterns, and key findings. The practical implications of these findings for periodontal research and clinical practice are also explored. Methodological limitations are discussed, and a keyword classification is provided that takes into account how each keyword is used in the literature. They also identified the main research gaps that emerged from the bibliometric analysis and proposed a research agenda to guide future studies in this area, contributing to the enrichment of knowledge on the relationship between biofilms and periodontal disease.

General interpretation of the results

During the years 2016, 2020, and 2023, an increase in the amount of research related to the study of biofilms in the context of periodontal diseases was observed (Colombo and Tanner, 2019). They conducted a study on the role of bacterial biofilm in dental caries and periodontal and peri-implant diseases. Their findings indicated that the view of the etiology of dental caries and periodontal diseases has broadened over time.

Qi et al. (2022) conducted a study in China where they investigated antibacterial photodynamic therapy, photothermal therapy, and gas therapy loaded with S-nitrosothiols (SNO) and ICG in mesoporous silica-gold-coated nanorods to evaluate their antibacterial and anti-inflammatory functions in deep periodontal lesions. It was shown that SNO molecules could be thermally activated to release nitric oxide (NO) molecules in the area affected by periodontal disease. This would help reduce inflammation by blocking the

formation of pro-inflammatory factors and the NLRP3 inflammasome. In addition, this nanotechnology platform could be effective in fighting pathogenic bacterial biofilms and regulating the immune response, leading to beneficial therapies in animal models of periodontal disease.

Zhang et al. (2019) conducted an investigation to evaluate the anti-biofilm properties of infrared excitation upconversion fluorescent nanomaterials containing chlorine E6 against periodontal pathogens. Ce6 photosensitizing molecules were combined with upconversion nanoparticles (UCNPs). These Ce6-containing UCNP particles, which emit red upconversion light, show a striking therapeutic effect against *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Fusobacterium nucleatum* bacteria and associated biofilms when exposed to 980 nm radiation. This suggests a great potential for its use in the treatment of periodontal disease.

The author Colombo APV has stood out for his remarkable scientific production and impact in the field of research in citations related to periodontal diseases. His research, titled "The role of bacterial biofilms in dental caries and periodontal and peri-implant diseases: a historical perspective," demonstrated that current studies on the microbiome suggest that caries or periodontitis/peri-implantitis are not always directly caused by microorganisms. Instead, these diseases appear to develop due to an imbalance in the dynamic interactions between the bacterial biofilm, the host, and the microbial environment (Colombo and Tanner, 2019).

Könönen E, Sanz M, and Herrera D are a second group of authors who, despite having a lower level of scientific productivity, achieved a significant impact in their work. In their study "Role of microbial biofilms in the maintenance of oral health and in the development of dental caries and periodontal diseases. Consensus report of group 1 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal disease", they investigated the ecological interactions in dental biofilm in health and disease, as well as the role of microbial communities in the pathogenesis of periodontitis and caries and the innate host (Sanz et al., 2017). They showed that the current state of knowledge suggests that the etiologies of caries and periodontal disease are independent of each other and that the elements of innate immunity that seem to contribute to resistance to both are somewhat coincidental.

A third group of authors is also recognized, among which names such as Wang L. and Feres M. stand out, who have carried out various studies, including "Targeting pathogenic biofilms: Newly de-

veloped superhydrophobic coating favors a host-compatible microbial profile on the titanium surface" (Souza et al., 2020) and "Metronidazole alone or with amoxicillin as adjuncts to non-surgical treatment of chronic periodontitis: a secondary analysis of the microbiological results of a randomized clinical trial" (Soares et al., 2014). Although the impact in terms of citations is small, his work covers a larger field of study of biofilms and periodontal disease.

Scientific journals are essential to the dissemination of information and the advancement of research in many fields, including biofilms and periodontal disease. "The Journal of Periodontology" and the "Journal of Dental Research" have been important journals in this regard in terms of productivity and impact. It is clear that "The Journal of Periodontology" is the leading journal in periodontics and one of the most important journals in dentistry, which has contributed significantly to the research of biofilms related to periodontal diseases.

In terms of scientific research on biofilms and periodontal disease, the United States and Brazil are the nations that have significantly distinguished themselves and made important contributions to the body of knowledge in this field. In the case of the United States, research has focused on the study of various biofilms, periodontal pathogens, and treatment alternatives (Herrera et al., 2020), while Brazil stands out for its research on biofilms and periodontal disease (Vieira Colombo et al., 2016).

In third place is Germany, which has made a significant impact in the field of science with less scientific production. Research such as "A novel technique for monitoring the development of bacterial biofilms in human periodontal pockets" (Wecke et al., 2000) highlights the importance of analyzing the growth of periodontal biofilms.

Early research on periodontal biofilms was largely based on the basic idea of the pathogenesis and development of these oral diseases; biofilms have received much attention in recent years in the context of periodontal diseases in order to understand the importance of studying the formation of these microbial communities in the oral health of the population (Colombo and Tanner, 2019).

This initial strategy helped to contextualize and highlight the close relationship between the formation and organization of biofilms and the development of periodontal disease, laying the foundation for subsequent studies that have contributed to our understanding of the topic.

The terms "biofilm", "biofilm formation", and "periodontal therapy" have become more relevant in recent research on the topic, which greatly helps in understanding the study. The study of biofilms in relation to periodontal disease has shed important light on microbial interactions and the pathogenesis of these oral diseases. However, despite significant advances in this field, there are obvious gaps in the scientific literature that require a thorough bibliometric analysis. Similarly, a polymicrobial biofilm model approach has been developed to evaluate the antimicrobial potential of periodontal diseases, highlighting the lack of equivalent approaches for the study of periodontal diseases (Cunha et al., 2020).

Innovative therapeutic strategies have also been investigated to combat biofilms associated with periodontal diseases (Tonon et al., 2022), evaluating periodontal biofilms for bacterial treatment, thus demonstrating the adaptability of emerging technologies against bacteria and biofilms associated with periodontal diseases.

The main keyword co-occurrence network of this bibliometrics reveals thematic affinity in terms of groups. With keywords such as "subgingival biofilm", "multispecies biofilm", "antimicrobial" and "periodontal therapy", they are identified as emerging terms in research because they are uncommon but significantly current, such as "nucleatum" and "biofilm formation". The importance of understanding the relationship between periodontal conditions has shed important light on microbial interactions and the pathogenesis of these oral diseases (Herrero et al., 2018).

Finally, there are consolidated and growing concepts, such as "periodontal disease", "*Fusobacterium nucleatum*", "dental plaque", "periodontal pathogens", "microbiology" and "*Porphyromonas gingivalis*", which maintain their relevance over time and are fundamental in the literature on the study of biofilms related to periodontal disease. This method allows a deeper understanding of the dynamics of research in this field.

The term "oral biofilm" is located in quadrant 2 of the Cartesian plane, where it is used less frequently than in the past in the scientific literature on biofilm formation in periodontal diseases. This concept mainly referred to the fundamental role of the formation and organization of biofilms acquired during the development of periodontal diseases.

The study has gained interest and importance in relation to periodontal diseases. It has been shown

Table 1. Classification of keywords according to their function.

Keyword	Associated tools	Applications	Characteristics
Multispecies biofilm	Confocal microscopy, antibacterial agents, antimicrobial peptides, photodynamic therapy	Assessment of biofilm structure and composition, control of microbial population in biofilms, and selective elimination of microorganisms in biofilms.	It allows the three-dimensional observation of biofilms composed of various bacterial species.
Antimicrobial	Antibacterial agents, antimicrobial peptides, photodynamic therapy	Control of the microbial population in biofilms, selective elimination of microorganisms in biofilms.	Inhibition or elimination of pathogenic microorganisms in biofilms. It uses light and photosensitizers to damage bacterial cells.
Periodontal therapy	Dental irrigators, antibiotics, periodontal surgery	Non-invasive therapy for the treatment of periodontal disease, selective removal of infected tissue, and surgical intervention on periodontal tissue.	Facilitates cleaning of periodontal pockets and delivery of antimicrobial agents. Surgical intervention in periodontal tissues.
<i>F. nucleatum</i>	Real-time PCR, bacterial culture techniques, oral microbiota	Identification and quantification of <i>F. nucleatum</i> in biofilms, interactions with other bacterial species in biofilms.	Sensitive and specific method for the detection of <i>F. nucleatum</i> . Contributes to the formation of complex periodontal biofilms.
Biofilm formation	Scanning electron microscopy, bacterial adhesion assays, surface biochemistry	Study of biofilm morphology and formation, study of factors involved in adhesion.	Provides detailed visualization of the structure and formation of biofilms. Analyzes the surface properties of surfaces associated with biofilms.

that the pathogenesis and development of periodontal diseases are significantly influenced by these dental biofilms, which are formed by highly organized microbial communities. Recent studies have investigated various aspects of this relationship using multidisciplinary methods to understand biofilms and their impact on oral health (Carli et al., 2021). Although these ideas may not have been as prevalent in the recent literature, their impact on our understanding of biofilm in periodontal disease remains important in advancing our knowledge in this area.

The terms "multispecies biofilm" are included in quadrant 2 of the Cartesian plane, which represents new ideas for studying isolated species of periodontal lesions to determine the frequency and expression of genes related to adhesion and biofilm formation, providing information on the molecular mechanisms underlying microbial colonization in this context (Uribe-García et al., 2021).

On the other hand, the term "periodontal therapy" refers to the fact that innovative therapeutic strategies have also been investigated to combat biofilms associated with periodontal disease (Tonon et al., 2022), demonstrating the adaptability of emerging technologies.

This method allows a deeper understanding of the dynamics of the disease and helps to discover more effective preventive and therapeutic measures with a

focus on promoting the study of biofilms acquired during periodontal disease. These emerging concepts represent a promising direction for research and clinical practice in the field of periodontics.

Classification of keywords in the study of biofilms related to periodontal diseases according to their function

Table 1 presents a classification of the most important emerging and expanding terms in the study of biofilms related to periodontal diseases according to their function and with a description of their main characteristics and uses. This classification allows for a deeper understanding of the diversity of key concepts in this field of research.

Based on their usage, the keywords have been grouped into several categories. These categories include words such as "structure and composition," "microbial population," "biofilm formation," which are important to understand the scope of the topic because they relate to the study of periodontal biofilms. Other keywords emphasize the value of successful public health and clinical care initiatives by highlighting aspects of prevention and control, such as "periodontal therapy". The inclusion of terms such as "identification and quantification" emphasizes the importance of research in developing sensitive and spe-

cific methods for identifying and studying periodontal biofilms.

Implications

Decision-making on oral health and public health policies will be significantly influenced by the implementation of bibliometrics on biofilm research trends in periodontal disease. A shift in the research focus of the field is indicated by the thematic evolution from the study of socioeconomic status to more modern ideas such as survival analysis, oral hygiene habits, and prevalence. This indicates that researchers are placing more emphasis on the study of biofilm formation in periodontal disease, which in turn may lead to more effective prevention and treatment methods.

The discovery of the main thematic group, composed of the keywords multispecies biofilm, antimicrobial, periodontal therapy, biofilm formation, reveals the conceptual affinities around the quality of life and dental care of the population. By emphasizing the importance of addressing these related issues comprehensively, this information may be useful to health professionals and policy planners. The appearance of these terms indicates that these aspects are gaining in importance in the scientific literature. At the same time, it suggests a greater emphasis on these issues, which may have implications for future policy.

For this reason, the present research is useful, as it is necessary to continue research on the formation of biofilm composed of different bacterial species involved in the development of periodontal diseases in the population.

Limitations

A thorough description of the research in this area is provided by the current bibliometrics on the study of biofilms of periodontal diseases, which was carried out using the PRISMA-2020 methodology and databases such as Scopus and Web of Science. However, it is essential to specify some limitations to which this type of bibliometric analysis is subject. First, the ability of databases to find relevant publications based on the search terms and strategies used depends to a large extent on the accuracy and completeness of the results. It is likely that they have overlooked research published in other sources or languages that would also improve our knowledge in the field, since the scope of this bibliometrics is limited to the selected databases.

The selection of keywords and the definition of thematic groups can be arbitrary and change according to the standards of the researcher, so two strong limitations need to be taken into account. Likewise, bibliometrics does not take into account subsequent

research that may have been carried out, since it is based on data available up to the cut-off date. Finally, although we used VOSviewer to visualize the keyword co-occurrence network, configuration, and filtering options may affect how the tool deciphers topic affinity and clustering. Such limitations highlight the need for future research in this area to have a broader focus and consider a variety of information sources to achieve a complete understanding of the development and trends in periodontal biofilm research.

Research gaps

To advance knowledge in this scientific area, future research must address the major research gaps identified in the study of periodontal biofilms, which are summarized in Table 2. The first of these is the need for more in-depth research into the dynamics of periodontal biofilms in *in vivo* environments, which would allow a more precise understanding of how these microorganisms interact in the context of periodontal disease and how they respond to different treatments.

Research on biofilm in periodontal disease has revealed several significant gaps that require attention to provide a more complete understanding of the problem. One of the most important gaps identified relates to thematic gaps. There is a need to further investigate the long-term effects of therapies on periodontal biofilms, and we still need to understand how microgravity conditions might interact with each other and affect disease development. The interaction of these is essential to address the problem in its entirety. In addition, despite the proposed preventive interventions, more robust evidence is needed on their long-term effectiveness in specific populations.

From a geographical perspective, significant geographical gaps have been identified. Specifically, research in developing countries and underserved communities has glaring disparities in care, highlighting the need for targeted strategies to improve access to dental care in such areas. This gap reinforces the need to continue studies on biofilm formation in periodontal disease in different regions.

At the interdisciplinary level, there is a perceived lack of interdisciplinary collaboration to address issues in spatial environments of integration between health and social data. Collaboration between health professionals and social scientists can provide valuable input and a deeper understanding of how socioeconomic and health factors interact and influence biofilm in periodontal disease. Finally, with regard to temporal gaps, the urgency of conducting more longitudinal studies that follow the population over time is highlighted.

Table 2. Research gaps.

Category	Investigative gap	Justification of the gap	Questions for future research
Thematic Gaps	Long-term effects of therapies on periodontal biofilms	There is a need to understand the durability of therapies.	How do current therapies affect the composition and virulence of periodontal biofilms over time?
	Multispecies biofilms in microgravity	Microgravity is an understudied environment.	What are the effects of microgravity on the formation and virulence of multispecies biofilms associated with periodontal disease?
Geographic Gaps	Research in developing countries	There is a lack of research representation in developing countries.	What are the key differences in the prevalence and severity of biofilm-associated periodontal disease between developed and developing countries, and how can these differences be addressed?
Interdisciplinary Gaps	Collaboration between Dentistry and Space Sciences	Interdisciplinary collaboration is needed to solve problems in the space environment.	How can dentists and space scientists work together to understand and address oral health challenges in space environments?
Temporal Gaps	Long-term monitoring of changes in biofilm composition	It is necessary to understand the temporal dynamics of the oral microbiota.	How does the composition of periodontal biofilms change over time, and how do these changes relate to the progression of periodontal disease?
	Long-term effects of therapies on periodontal biofilms	The long-term effects of these therapies are unclear.	What long-term interventions are necessary to maintain periodontal health after initial therapy in patients with biofilm-associated periodontal disease?

Author's compilation based on Scopus and Web of Science.

Research agenda for future research

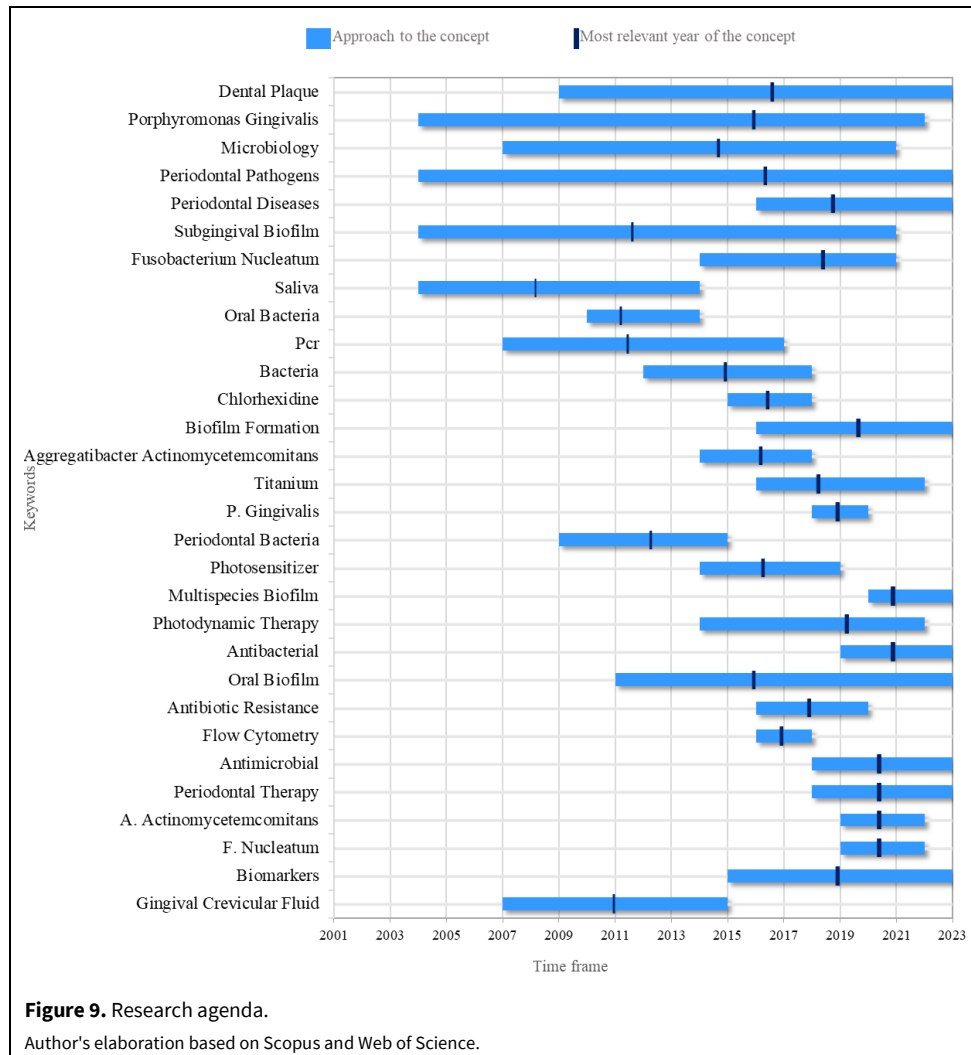
In periodontal diseases, the pathogenesis, formation, and development of biofilms play a fundamental role, as they are highly organized microbial communities adhering to biological surfaces characterized by their extracellular matrix and their ability to resist conventional treatments. In the field of periodontal diseases, it is known that dental biofilms are mainly composed of anaerobic bacteria and have been identified as key etiological factors in periodontal disease and periodontal tissue loss. Future research could focus on identifying and classifying these bacterial communities, studying their structure and composition, and determining which ones are most susceptible to disease development.

Survival analysis is a powerful statistical tool that has been used in biofilm studies to analyze the time to onset of events such as periodontal disease. Its importance lies in providing a more accurate understanding of the disease and how risk factors can affect its occurrence and how they interact with each other as the disease develops. Future studies could use survival analysis to identify specific risk factors that increase the likelihood of a population developing periodontal disease. In turn, the control of the microbial

population within the biofilm could be studied by selectively eliminating the microorganisms that make up the biofilm.

One of the most important factors in the prevention of early childhood caries is good oral hygiene habits. The importance of this idea lies in how children's dental health can be affected by brushing, flossing, and other oral hygiene practices. Future studies could examine the effectiveness of different methods to promote good oral hygiene in young children, as well as the usability and acceptability of oral hygiene tools and products designed for this population. It would also be beneficial to investigate how oral hygiene practices can be successfully integrated into the daily care routines of children and families.

Epidemiology is essential to understanding early childhood caries because it provides information on prevalence, distribution, and associated risk factors. Although this idea is well established, further research into the epidemiology of dental caries in specific populations, such as vulnerable communities, may help to identify patterns and trends that can be used to develop more effective preventive measures. In addition, epidemiological research could investigate how new variables, such as parental influence



and oral hygiene habits, interact with social and economic determinants to influence early caries in different childhood populations.

Risk factors for early childhood caries continue to be significantly influenced by socioeconomic status. Despite its historical importance, current research can examine how economic disparities affect community access to preventive dental care and levels of childhood nutrition. Future studies could also investigate effective strategies to reduce socioeconomic disparities in the prevalence of early caries and improve access to oral health care for children from families with limited resources in rural areas without health care systems.

In order to continue to prevent tooth decay in early childhood, childhood nutrition is essential because this disease is sugar-dependent, meaning that its development is based on high sugar consumption. Future research can examine how feeding practices and nutritional counseling, such as bottle use and the introduction of solid foods, affect children's oral health,

although this is a growing idea. To develop healthy dietary strategies to prevent early caries in different contexts and communities, an interdisciplinary approach is required that combines pediatric dentistry and child nutrition, and that these go hand in hand in the support and counseling of the child patient and his or her environment (Fig. 9).

CONCLUSION

After the exhaustive bibliometric research carried out in this document, it can be interpreted that a constant and rapid increase in the study of biofilms of periodontal diseases has been demonstrated in recent years. It is crucial to note that the majority of articles on this topic were published in the years 2016, 2020, and 2023, indicating a growing interest in and remarkable research activity related to the study of biofilms of periodontal diseases. This demonstrates the awareness of the importance of addressing this oral health problem in the population and highlights the need to continue research in this area. Likewise, it shows that the field of research continues to expand,

proving the increased concern of the scientific community to understand and address the study of biofilms of periodontal diseases.

As for the main references in this field, there are authors such as Colombo APV, who stand out both in terms of his scientific production and his impact on citations. Kononen E, Sanz M, and Herrera D, despite having a lower level of scientific productivity, achieve a significant impact in their work, which indicates the importance of their research. These results demonstrate the diversity of the authors' contributions to the field and emphasize the value of producing scientific literature on biofilms and periodontal disease.

In addition, journals such as the Journal of Periodontology and the Journal of Dental Research stand out for both their scientific productivity and their impact in terms of citations. This trend highlights the importance of both quantity and quality in the production of scientific literature and points to specific areas of interest for future research.

On the other hand, research on biofilms in periodontal disease has advanced significantly, providing a deeper understanding of their pathogenesis. Although remarkable progress has been made, there are still gaps in knowledge that require more precise bibliometric analysis and therapeutic approaches. Innovative therapies have been explored, demonstrating the adaptability of emerging technologies in the treatment of periodontal biofilms, which promises to improve the understanding and treatment of these diseases in the future.

In turn, the keyword analysis reveals the appearance of emerging terms such as "subgingival biofilm" and "antimicrobial", reflecting the current attention in periodontal disease research. At the same time, consolidated terms such as "periodontal disease" maintain their relevance over time. This bibliometric approach provides an understanding of the dynamics of research in the field and highlights the importance of balancing the exploration of new areas with the consolidation of key knowledge.

Finally, the bibliometric analysis highlights the thematic evolution of research on biofilms in periodontal disease, with the transition from traditional socioeconomic approaches to more modern concepts such as biofilm formation. This has important practical implications for decision-making in oral health and public health policy. Emerging key terms such as "multispecies biofilm", "antimicrobial" and "periodontal therapy" reflect the growing attention to quality of life and dental care that may influence future policy. In addition, research gaps were identified, such as the need for longitudinal studies, interdisciplinary col-

laboration, and greater attention to underserved communities in developing countries.

In this regard, in terms of research trends, interdisciplinary collaboration has become a crucial aspect in the study of biofilms related to periodontal diseases. Collaboration among various disciplines, such as microbiology, dentistry, biomedical engineering, and immunology, has increased, indicating a more comprehensive and holistic approach to addressing this complex oral health issue. This trend demonstrates the increasing recognition that periodontal diseases and their associated biofilms are complex phenomena that necessitate interdisciplinary approaches for prevention, diagnosis, and treatment. Collaborating across various research areas can result in greater innovation and progress in comprehending and managing periodontal diseases, as well as in creating more efficient and individualized therapies to combat biofilms.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

- AlRyalat SAS, Malkawi LW, Momani SM (2019) Comparing bibliometric analysis using PubMed, Scopus, and Web of Science databases. *J Vis Exp* (152): e58494. <https://dx.doi.org/10.3791/58494>
- Carli E, Pasini M, Lardani L, Giuca G, Miceli M (2021) Impact of self-ligating orthodontic brackets on dental biofilm and periodontal pathogens in adolescents. *J Biol Regul Homeost Agents* 35(3 Suppl. 1): 107-115. <https://doi.org/10.23812/21-3suppl1-13>
- Colombo APV, Tanner ACR (2019) The role of bacterial biofilms in dental caries and periodontal and peri-implant diseases: a historical perspective. *J Dent Res* 98(4): 373-385. <https://doi.org/10.1177/0022034519830686>
- Cunha E, Rebelo S, Carneiro C, Tavares L, Carreira L, Oliveira M (2020) A polymicrobial biofilm model for testing the antimicrobial potential of a nisin-biogel for canine periodontal disease control. *BMC Vet Res* 16: 469. <https://doi.org/10.1186/s12917-020-02646-3>
- Durieux V, Gevenois P (2010) Bibliometric indicators: quality measurements of scientific publication. *Radiology* 255(2): 342-351. <https://doi.org/10.1148/radiol.09090626>
- Esfahanizadeh N, Nourani M, Bahador A, Akhondi N, Montazeri M (2018) The anti-biofilm activity of nanometric zinc doped bioactive glass against putative periodontal pathogens: An *in vitro* study. *Biomed Glasses* 4(1): 95-107. <https://doi.org/10.1515/bglass-2018-0009>
- Herrera D, Bermejo P, Sánchez MDC, Figuero E, Sanz M (2020) Biofilms around dental implants. In: *Bone Augmentation by Anatomical Region: Techniques and Decision-Making*- Artzi Z

- (ed.), John Wiley & Sons Ltd. pp. 487-504. <https://doi.org/10.1002/9781119427926.ch24>
- Herrero E, Fernandes S, Verspecht T, Ugarte-Berzal E, Boon N, Proost P, Bernaerts K, Quirynen M, Teughels W (2018) Dysbiotic biofilms deregulate the periodontal inflammatory response. *J Dent Res* 97(5): 547-555. <https://doi.org/10.1177/0022034517752675>
- Jungbauer G, Favaro L, Müller S, Sculean A, Eick S (2022) The *in vitro* activity of a cold atmospheric plasma device utilizing ambient air against bacteria and biofilms associated with periodontal or peri-implant Diseases. *Antibiotics* 11(6): 752. <https://doi.org/10.3390/antibiotics11060752>
- Muras A, Mayer C, Otero-Casal P, Exterkate R, Brandt B, Crielgaard W, Otero A, Krom B (2020) Short-chain N-acylhomoserine lactone quorum-sensing molecules promote periodontal pathogens in *in vitro* oral biofilms. *Appl Environ Microbiol* 86(3): e01941-19. <https://doi.org/10.1128/AEM.01941-19>
- Page M, McKenzie J, Bossuyt P, Boutron I, Hoffmann T, Mulrow C, Shamseer L, Tetzlaff J, Akl E, Brennan S, Chou R, Glanville J, Grimshaw J, Hrobjartsson A, Lalu M, Li T, Loder E, Mayo-Wilson E, McDonald S, McGuinness L, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int J Surg* 88: 105906. <https://doi.org/10.1016/j.ijsu.2021.105906>
- Parga A, Muras A, Otero-Casal P, Arredondo A, Soler-Ollé A, Álvarez G, Alcaraz L, Mira A, Blanc V, Otero A (2023) The quorum quenching enzyme Aii20J modifies *in vitro* periodontal biofilm formation. *Front Cell Infect Microbiol* 13: 1118630. <https://doi.org/10.3389/fcimb.2023.1118630>
- Qi M, Ren X, Li W, Sun Y, Sun X, Li C, Yu S, Xu L, Zhou Y, Song S, Dong B, Wang L (2022) NIR responsive nitric oxide nanogenerator for enhanced biofilm eradication and inflammation immunotherapy against periodontal diseases. *Nano Today* 43: 101447. <https://doi.org/10.1016/j.nantod.2022.101447>
- Sanz M, Beighton D, Curtis MA, Cury JA, Dige I, Dommisch H, Ellwood R, Giacaman RA, Herrera D, Herzberg MC, Könönen E, Marsh PD, Meyle J, Mira A, Molina A, Mombelli A, Quirynen M, Reynolds EC, Shapira L, Zaura E (2017) Role of microbial biofilms in the maintenance of oral health and in the development of dental caries and periodontal diseases. Consensus report of group 1 of the Joint EFP/ORCA workshop on the boundaries between caries and periodontal disease. *J Clin Periodontol* 44 (Suppl 18): S5-S11. <https://doi.org/10.1111/jcpe.12682>
- Soares GM, Mendes JA, Silva MP, Faveri M, Teles R, Socransky SS, Wang X, Figueiredo LC, Feres M (2014) Metronidazole alone or with amoxicillin as adjuncts to non-surgical treatment of chronic periodontitis: A secondary analysis of microbiological results from a randomized clinical trial. *J Clin Periodontol* 41(4): 366-376. <https://doi.org/10.1111/jcpe.12217>
- Souza JGS, Bertolini M, Costa RC, Cordeiro JM, Nagay BE, de Almeida AB, Retamal-Valdes B, Nociti FH, Feres M, Rangel EC, Barão VAR (2020) Targeting pathogenic biofilms: Newly developed superhydrophobic coating favors a host-compatible microbial profile on the titanium surface. *ACS Appl Mater Interfaces* 12(9): 10118-10129. <https://doi.org/10.1021/acsami.9b22741>
- Tonon C, Ashraf S, de Souza Rastelli A, Ghosh G, Hasan T, Xu Q, Greer A, Lyons A (2022) Evaluation of photosensitizer-containing superhydrophobic surfaces for the antibacterial treatment of periodontal biofilms. *J Photochem Photobiol B Biol* 233: 112458. <https://doi.org/10.1016/j.jphotobiol.2022.112458>
- Uribe-García A, Paniagua-Contreras G, Monroy-Pérez E, Bustos-Martínez J, Hamdan-Partida A, Garzón J, Alanís J, Quezada R, Vaca-Paniagua F, Vaca S (2021) Frequency and expression of genes involved in adhesion and biofilm formation in *Staphylococcus aureus* strains isolated from periodontal lesions. *J Microbiol Immunol Infect* 54(2): 267-275. <https://doi.org/10.1016/j.jmii.2019.05.010>
- Van Eck N, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 84(2): 523-538. <https://doi.org/10.1007/s11192-009-0146-3>
- Vieira Colombo AP, Magalhães CB, Hartenbach FA, Martins do Souto R, Maciel da Silva-Boghossian C (2016) Periodontal-disease-associated biofilm: A reservoir for pathogens of medical importance. *Microb Pathog* 94: 27-34. <https://doi.org/10.1016/j.micpath.2015.09.009>
- Wecke J, Kersten T, Madela K, Moter A, Göbel UB, Friedmann A, Bernimoulin J (2000) A novel technique for monitoring the development of bacterial biofilms in human periodontal pockets. *FEMS Microbiol Lett* 191(1): 95-101. <https://doi.org/10.1111/j.1574-6968.2000.tb09324.x>
- Widyarman AS, Theodorea CF (2022) Novel indigenous probiotic *Lactobacillus reuteri* strain produces anti-biofilm reuterin against pathogenic periodontal bacteria. *Eur J Dent* 16(1): 96-101. <https://doi.org/10.1055/s-0041-1731591>
- Zhang T, Ying D, Qi M, Li X, Fu L, Sun X, Wang L, Zhou Y (2019) Anti-biofilm property of bioactive upconversion nanocomposites containing chlorin e6 against periodontal pathogens. *Molecules* 24(15): 2692. <https://doi.org/10.3390/molecules24152692>

AUTHOR CONTRIBUTION:

Contribution	Romero Gamboa JC	Pinella-Vega M	Millones-Gómez PA	Gallego-Ramírez JE	Valencia-Arias A
Concepts or ideas	x		x		
Design	x			x	
Definition of intellectual content		x	x		x
Literature search	x		x		x
Experimental studies	x	x	x	x	x
Data acquisition		x			
Data analysis			x	x	x
Statistical analysis	x		x	x	
Manuscript preparation					x
Manuscript editing			x		x
Manuscript review	x	x	x	x	x

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