Journal of Multidisciplinary Healthcare

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ORIGINAL RESEARCH

Global Trends in Orthopedic Biofilm Research: A Bibliometric Analysis of 1994-2022

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Objective: Bibliometric analysis is commonly used to visualize the knowledge foundation, trends, and patterns in a specific scientific field by performing a quantitative evaluation of the relevant literature. The purpose of this study was to perform a bibliometric analysis of recent studies in the field of orthopedic biofilm research and identify its current trends and hotspots.

Methods: Research studies were retrieved from the Web of Science Core Collection and Scopus databases and analyzed in bibliometrix with R package (4.2.2).

Results: A total of 2426 literature were included in the study. Journal of orthopaedic research and Clinical orthopaedics and related research ranked first in terms of productivity and impact, with 57 published articles and 32 *h*-index, respectively. Trampuz A, Ohio State Univ and the United States ranked as the most productive authors, institutions, and countries. Biofilm formation, role of sonication, biomaterial mechanism and antibiotic loading have been investigated as the trend and hotspots in the field of orthopedic biofilm research.

Conclusion: This study provides a thorough overview of the state of the art of current orthopedic biofilm research and offers valuable insights into recent trends and hotspots in this field.

Keywords: biofilm, orthopedic infection, bibliometric analysis, hotspot, research trend

Introduction

The widespread usage of fixation implants is essential in orthopedic surgery to aid in stabilizing bone, joint and spine throughout the therapeutic phase. It has been estimated that over one million knee replacements and more than 400,000 spinal fusions are carried out annually in the United States.[1] Despite advances in orthopedic implant materials and techniques, there are still challenges and difficulties that need to be addressed. Infection and aseptic loosening are two of the most common reasons for orthopedic implant failure.[2] It is estimated that implant-associated infections occur after approximately 5% of orthopedic procedures.[3] Although the incidence of implant-associated infections may not be particularly high, they are a serious surgical complication that often require revision surgery, resulting in associated morbidity and economic costs. Once microorganisms colonize the implant surface, they form a biofilm that establishes a bacterial community that remains attached in situ. Biofilm-associated infections (BAIs) involving orthopedic implants remain a global challenge. The diagnosis and treatment of BAIs present significant challenges, causing patients to endure unnecessary suffering, increased morbidity, and placing huge burden on healthcare systems.

Biofilms refer to communities of surface-attached microbial cells that are surrounded by a matrix of extracellular polymeric substances (EPS).[4] Due to their enclosed and complex structure, bacteria within biofilms are highly resistant to both the immune system and antimicrobial agents. In fact, biofilms formed by sessile bacteria can be up to 1000 times less susceptible to antibiotics compared to planktonic bacteria.[5] This is due to the EPS matrix, which can easily block the

Received: 23 February 2024
Accepted: 15 June 2024
Published: 3 July 2024

penetration of antibacterial agents. Furthermore, bacteria in biofilms are in a stationary growth phase, with low metabolic activity, which makes them resilient not only to host defenses but also to most antimicrobial agents. Biofilms continuously release free bacteria and toxins, which can provide a persistent and resilient environment for dangerous bacteria in the body, leading to sepsis, toxemia, and bacteremia, especially in patients with implanted devices.[6,7] The current diagnostic techniques for orthopedic biofilm infections, along with their integration into related medical disciplines, have garnered significant interest. A recent review highlighted the contribution of clinical signs, imaging, culture techniques, microscopy, sonication, and DNA amplification methods in diagnosing biofilm infections related to orthopedic implants.[8] Nevertheless, these methods are constrained by their reliance on visual indicators, labor-intensive procedures, and the requirement for invasive techniques.

Bibliometric analysis involves using mathematical and statistical methods to analyze scientific publications. This analysis has gained popularity in recent years due to its ability for systematic depiction of the current progress, frontier topics, and popular trends within a specific research field. To aid researchers in this process, specialized bibliometric analysis tools such as bibliometrix have been developed, which allows researchers to construct knowledge network, evaluate hotspots, and even predict future trends through visualization techniques.[9]

However, there is currently a paucity of bibliometric research in the field of orthopedic biofilms, although some bibliometric studies have been conducted on biofilms related to wound healing,[10] biofilm eradication,[8] and microbial resistance.[11] Therefore, this study aimed to employ bibliometric visualization analysis based on bibliometrix to analyze current trend and hotspots in orthopedic biofilm research.

Materials and Methods

Data Source and Search Strategy

We collected relevant literature from the Web of Science Core Collection (WoSCC) and Scopus databases which are two largest and most used databases for performing bibliometric analysis. We use the following retrieval strategies in the databases: (orthopedic OR trauma OR arthroplasty OR joint OR spine) AND (biofilm OR biofilms). The search was conducted on 7 April 2023 for eliminating the potential errors caused by daily updates of WoSCC database. No language limitations were set. The database containing full records and cited references were retrieved and transformed as BibTex files format and then imported into R software (version 4.2.2). Only original articles were included in the bibliometric analysis, and those classified as other types of documents were excluded. A flowchart of literature screening was shown as Figure 1.

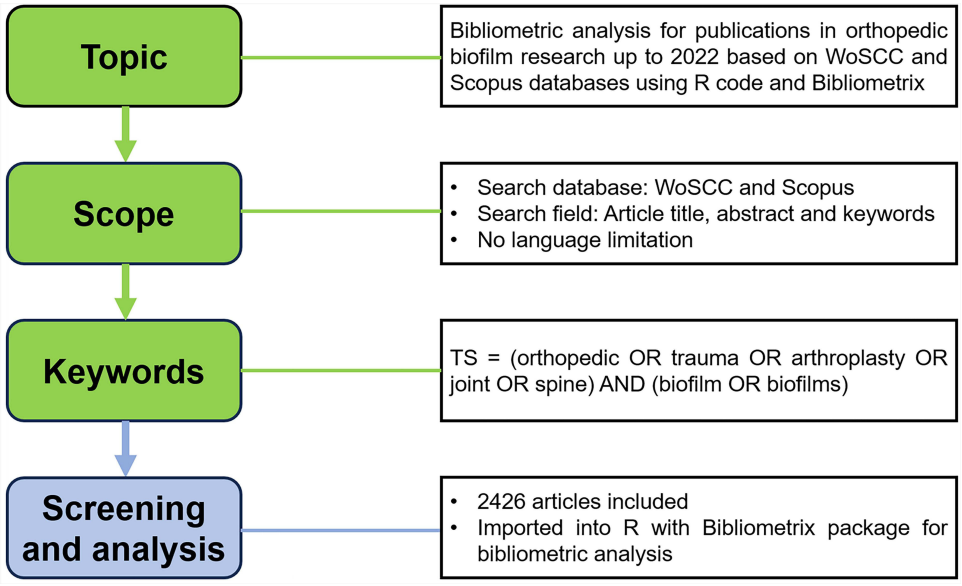

Figure 1 The flowchart of literature screening steps in orthopedic biofilm research.

Bibliometric Analysis

A bibliometric analysis was performed on the eligible records using bibliometrix R-package.[12] The Biblioshiny under the RStudio (RStudio, Inc, Boston, MA) environment was used for providing an interactive web interface (version 4.1). Annual publication productivity, the productivity and impact of journals and authors were evaluated using two different metrics: total number of publications and Hirsch index (*h*-index).

In addition, the analysis also examined the productivity and impact of countries. Production was measured by the total number of publications, while impact was determined by the average citation count per article. Maps of the main characteristics were also realized. The collaborative relationship among institutions and countries were presented as a collaboration network map, where lines illustrate the frequency of collaboration between each entity. The top 10 most cited articles were summarized and analyzed. Keyword co-occurrence network, thematic map as well as trend topic analysis were performed. The analysis was conducted collaboratively by two authors. Any discrepancies had arisen during the analysis were resolved through discussion and consensus between the two authors (ZYH and XBY).

Results

General Information

The search identified a total of 2426 documents. Orthopedic biofilm research has seen growing interest since the publication of the first article in 1994. This interest is reflected in the increasing number of published articles on the topic, with the largest number, 274, being published in 2022 (As shown in Table 1). The most representative document type was the article (82.2%, n = 1995), while there were only 431 reviews and other types of documents, accounting for 17.8% of the total.

Journals

The top 10 most productive and influential journals in the orthopedic biofilm research were listed in Table 2. The top 10 most productive journals published a total of 426 articles, contributing 17.6% of the total publications. The Journal of orthopedic research ranked first in terms of total publications (57 articles, accounting for 2.3%), followed by

Table 1 The Main Information of Analyzed Publications on Orthopedic Biofilm Research

MAIN INFORMATION ABOUT DATA	
Timespan	1994:2022
Sources (Journals, Books, etc.)	759
Documents	2426
Annual Growth Rate %	15.66
Document Average Age	7.3
Average citations per doc	31.44
References	77,021
DOCUMENT CONTENTS	
Keywords Plus (ID)	5037
Author's Keywords (DE)	4792
AUTHORS	
Authors	9682
Authors of single-authored docs	68
AUTHORS COLLABORATION	
Single-authored docs	75
Co-Authors per Doc	5.99
International co-authorships %	22.3
DOCUMENT TYPES	
Article	1995
Review and other types	431

Table 2 Top 10 Productive and Influential Journals on the Field of Orthopedic Biofilm Research

Production Ranking	Journal	Articles	Influence Ranking	Journal	TC*	*h*-index
1	Journal of orthopaedic research	57	1	Clinical orthopaedics and related research	4077	32
2	Antimicrobial agents and chemotherapy	52	2	Biomaterials	4057	28
3	Clinical orthopaedics and related research	52	3	Antimicrobial agents and chemotherapy	3696	26
4	Frontiers in microbiology	44	4	Journal of bone and joint surgery	3019	25
5	PLOS one	43	5	Journal of arthroplasty	2602	23
6	Antibiotics-Basel	41	6	Clinical infectious diseases	2353	22
7	Journal of arthroplasty	39	7	Journal of clinical microbiology	2280	19
8	Acta biomaterialia	34	8	Journal of antimicrobial chemotherapy	1839	19
9	Journal of biomedical materials research part a	34	9	PLOS one	1746	19
10	International journal of artificial organs	30	10	Infection and immunity	1745	17

Abbreviations: *TC, total citation.

Antimicrobial agents and chemotherapy and Clinical orthopaedics and related research, both of which tied for the second place with publishing a total of 52 articles (accounting for 2.1%).

Clinical orthopaedics and related research ranks first in terms of journal influence, with a total of 4077 total citation (TC), and a *h*-index of 32. Biomaterials and Antimicrobial agents and chemotherapy ranked second and third respectively, with TCs of 4057 and 3696 and *h*-indexes of 28 and 26, respectively.

Authors and Collaborations

A total of 9764 authors were analyzed, with Trampuz A, Patel R, and Stoodley P being the most productive authors who published 63, 48, and 41 articles, respectively. Figure 2 shows the production and citation trend of the top 10 authors with the highest publication volume over time. It indicates that since 2003, two authors, Trampuz A and Patel R have had a consistent number of publications and citations. The top 10 organizations with the most published literature can be observed in the Table 3. The top 10 organizations published a total of 998 papers, accounting for 42.3%. Ohio University topped the list with 157 papers published, followed by Shanghai Jiaotong University with 153 papers. The third-ranked

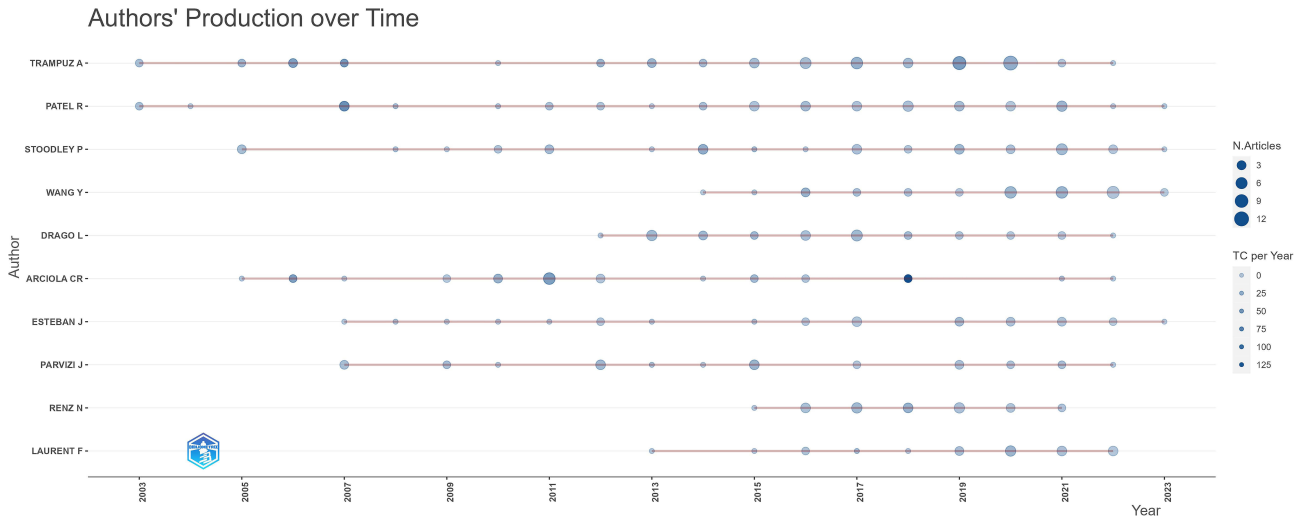

Figure 2 Authors' production in the field of orthopedic biofilm research over time.

Table 3 The Top 10 Most Productive Institutions and Countries

Rank	Affiliation	Articles	Country	Articles	SCP*	MCP#
1	Ohio State Univ	157	USA	652	527	125
2	Shanghai Jiao Tong Univ	153	China	298	254	44
3	Univ Pittsburgh	99	Germany	202	161	41
4	Univ Southampton	98	Italy	156	113	43
5	Univ Groningen	96	Spain	116	96	20
6	Charite Univ Med Berlin	95	United Kingdom	106	73	33
7	Johns Hopkins Univ	94	France	97	83	14
8	Mayo Clin	87	Switzerland	70	36	34
9	Univ Milan	76	Netherlands	65	46	19
10	Univ Maryland	74	India	55	45	10

Abbreviations: *SCP, single-country publication; #MCP, multi-country publication.

institution is far behind the top two, with 99 papers published by the University of Pittsburgh. Regarding the top ten countries by corresponding author with the highest number of publications, the United States has published 652 articles, with a single-country publication rate (SCPr) of 80.8%. China follows with 298 articles, and a SCPr of 85.2%, while Germany has 202 articles, with an SCPr of 79.7%. The detailed results were shown in Table 3 and Figure 3.

A collaboration network map was described which displayed the institutions and countries involved in orthopedic biofilm research (Figure 4). The countries having collaborations were represented by a red line whose width is proportional to the number of collaborations. Three major clusters leading by Mayo clinic from the USA, Charité – Universitätsmedizin Berlin from Germany, and Ohio State University from the USA can be observed within the intertwined and extensive network of cooperation (see Figure 4a). As shown in Figures 4b and 5, Europe and the United States had the closest connection. Germany and Switzerland had the most intimate collaboration among all the European countries. The United Kingdom and Germany shared a closer relationship with the United States. Meanwhile, it is worth noting that China, Italy, and the United States also had a vital cooperative relationship.

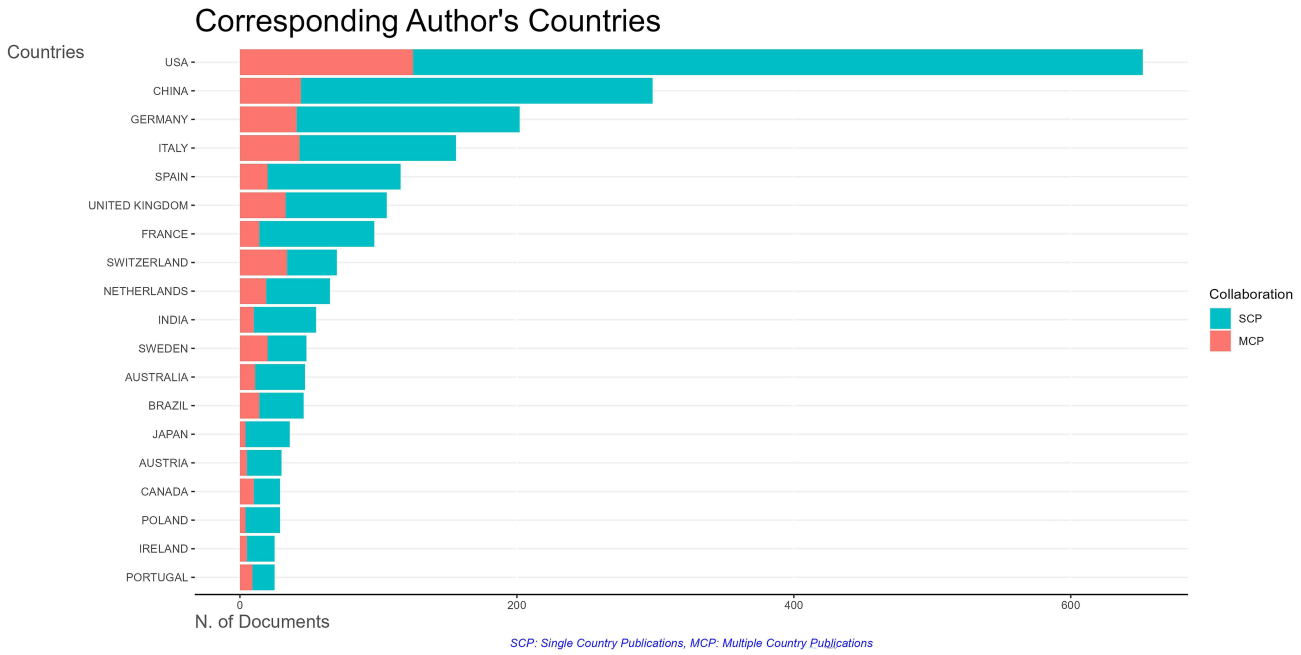

Figure 3 Most productive countries divided by single country publications and multiple country publications according to corresponding author in orthopedic biofilm research.

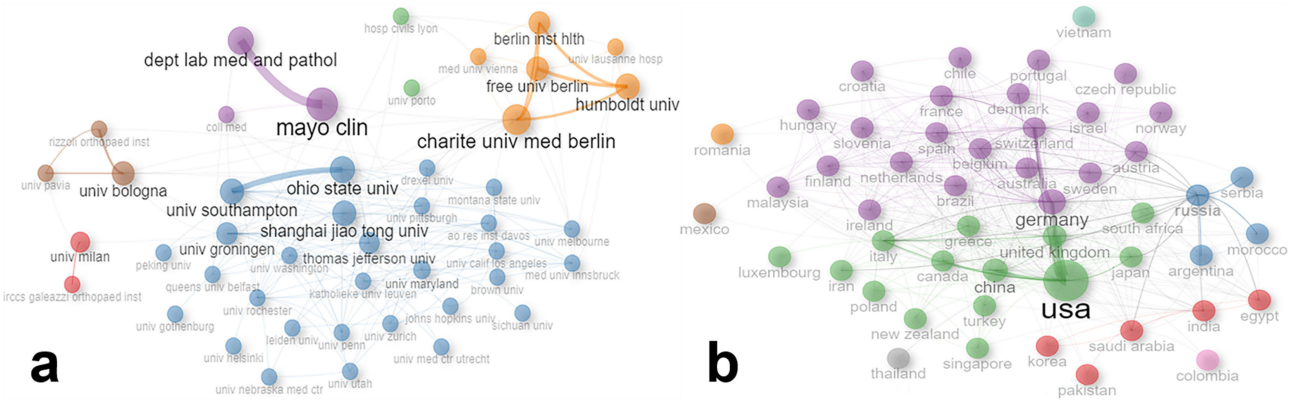

Figure 4 The clustered collaboration network map of the most productive institutions and countries of orthopedic biofilm research. (**a**) the most productive institutions and (**b**) the most productive countries.

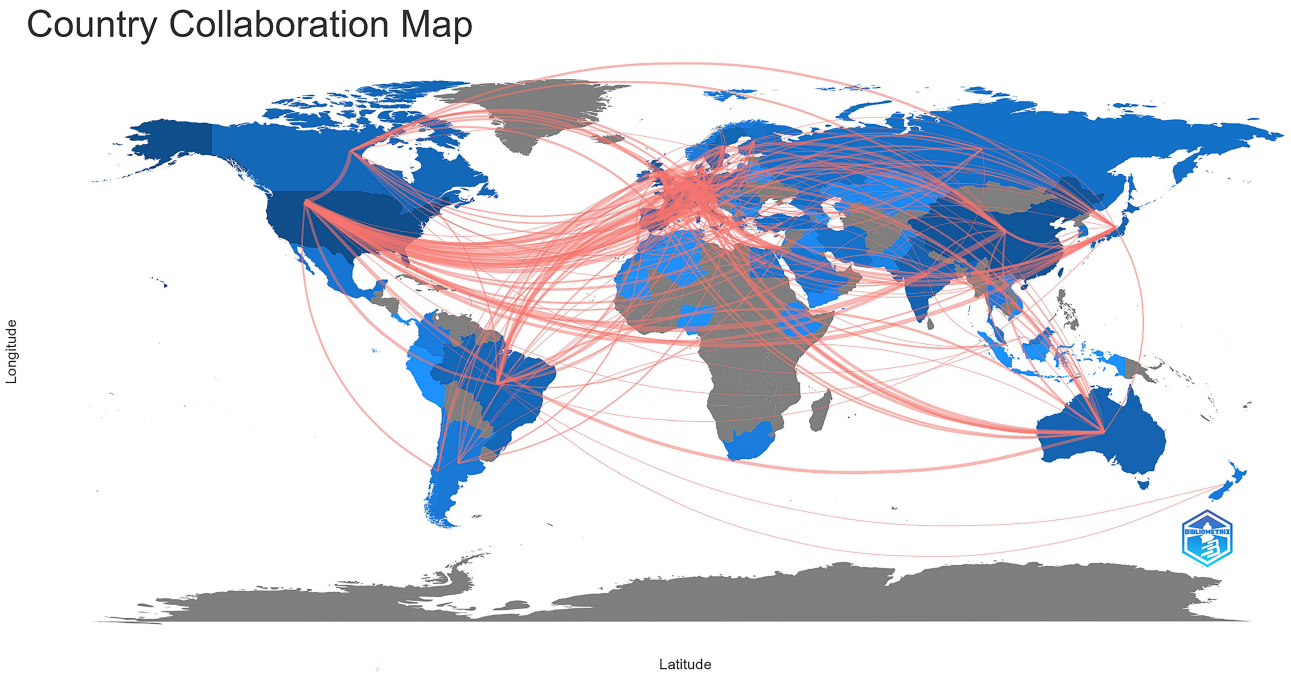

Figure 5 Country collaboration map on orthopedic biofilm research around the world.

Citation

The 10 most global and local cited documents were analyzed and displayed in Table 4. Trampuz A et al's article published in N Engl J Med (2007) is the most cited worldwide, with 900 citations and 52.9 TC per year. The most frequently cited local document was published by Tunney MM et al in J Clin Microbiol (1999), with 89 local and 344 global citations. After merging both global and local articles while eliminating duplicates, we arrived at 16 articles. Among these, 87.5% (n = 14) were published after 2006. Biomaterials had the highest number of contributions (3 out of 16 papers, accounting for 18.8%).

Topics and Trends Analysis

The co-occurrence network analysis based on author's keywords of publications were analyzed to assess the topic trend underlying the orthopedic biofilm research. The Louvain clustering algorithm and 0.1 repulsion force were applied. After setting

Table 4 List of the Top 10 Most Global and 10 Local Cited Articles

Items	Document	DOI*	TC#	TC per year
TOP 10 most GLOBAL cited	TRAMPUZ A, 2007, N ENGL J MED	10.1056/NEJMoa061588	900	52.9
	PUCKETT SD, 2010, BIOMATERIALS	10.1016/j.biomaterials.2009.09.081	477	34.1
	TUNNEY MM, 1999, J CLIN MICROBIOL	10.1128/JCM.37.10.3281–3290.1999	344	13.8
	SCHAEFER P, 2008, CLIN INFECT DIS	10.1086/592,973	330	20.6
	ROHDE H, 2007, BIOMATERIALS	10.1016/j.biomaterials.2006.11.046	328	19.3
	COLON G, 2006, J BIOMED MATER RES PART A	10.1002/jbm.a.30789	320	17.8
	TAN L, 2018, ADV MATER	10.1002/adma.201801808	305	50.8
	GORDON O, 2010, ANTIMICROB AGENTS CHEMOTHER	10.1128/AAC.01830–09	298	21.3
	CAMPOCCIA D, 2010, BIOMATERIALS	10.1016/j.biomaterials.2010.05.005	283	20.2
	TUNNEY MM, 1998, J BONE JOINT SURG-BR VOL	10.1302/0301-620X.80B4.8473	257	9.9
TOP 10 most LOCAL cited	TUNNEY MM, 1999, J CLIN MICROBIOL	10.1128/JCM.37.10.3281–3290.1999	89	13.8
	ZIMMERLI W, 2014, J INTERN MED	10.1111/joim.12233	63	26.6
	BERNTHAL NM, 2010, PLOS ONE	10.1371/journal.pone.0012580	61	11.0
	ROHDE H, 2007, BIOMATERIALS	10.1016/j.biomaterials.2006.11.046	56	19.3
	HOLINKA J, 2011, J ORTHOP RES	10.1002/jor.21286	47	8.3
	ESTEBAN J, 2008, J CLIN MICROBIOL	10.1128/JCM.01762–07	43	6.8
	BJERKAN G, 2009, ACTA ORTHOP	10.3109/17,453,670,902,947,457	42	9.2
	DASTGHEYB S, 2015, J INFECT DIS	10.1093/infdis/jiu514	42	11.7
	CAMPOCCIA D, 2010, BIOMATERIALS	10.1016/j.biomaterials.2010.05.005	40	20.2
	PUCKETT SD, 2010, BIOMATERIALS	10.1016/j.biomaterials.2009.09.081	40	34.1

Abbreviations: *TC, total citation; #DOI, digital object identifier.

minimum number of edges at 2 and removing isolated nodes, a visual network map has been identified (Figure 6). Nodes of different colors represent different types of clustering, the size of the node represents the frequency of keywords, and the thickness of the connecting line represents the close relationship between two nodes. Based on the findings of the cluster analysis, we have identified four distinct clusters of co-occurring keywords: (1) Biofilm formation (2) Sonication function for arthroplasty infection diagnosis; (3) Biomaterials for orthopedic implant infection; (4) Antibiotic-loaded bone cement.

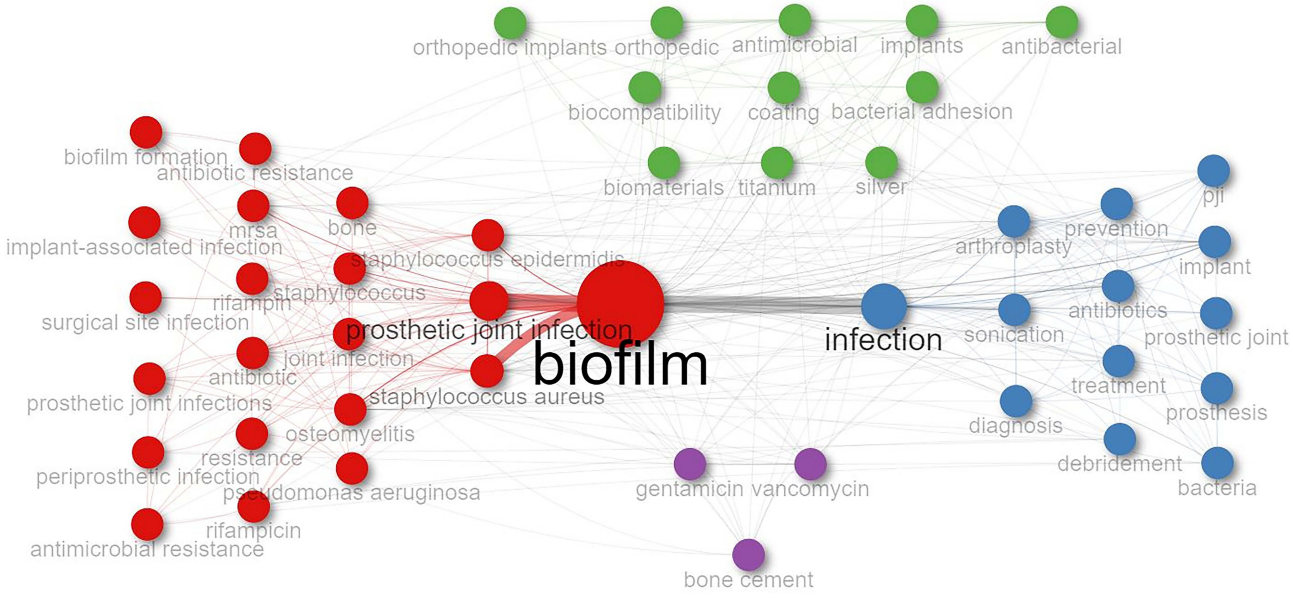

Figure 6 The clustered co-occurrence network analysis based on authors' keywords of orthopedic biofilm research.

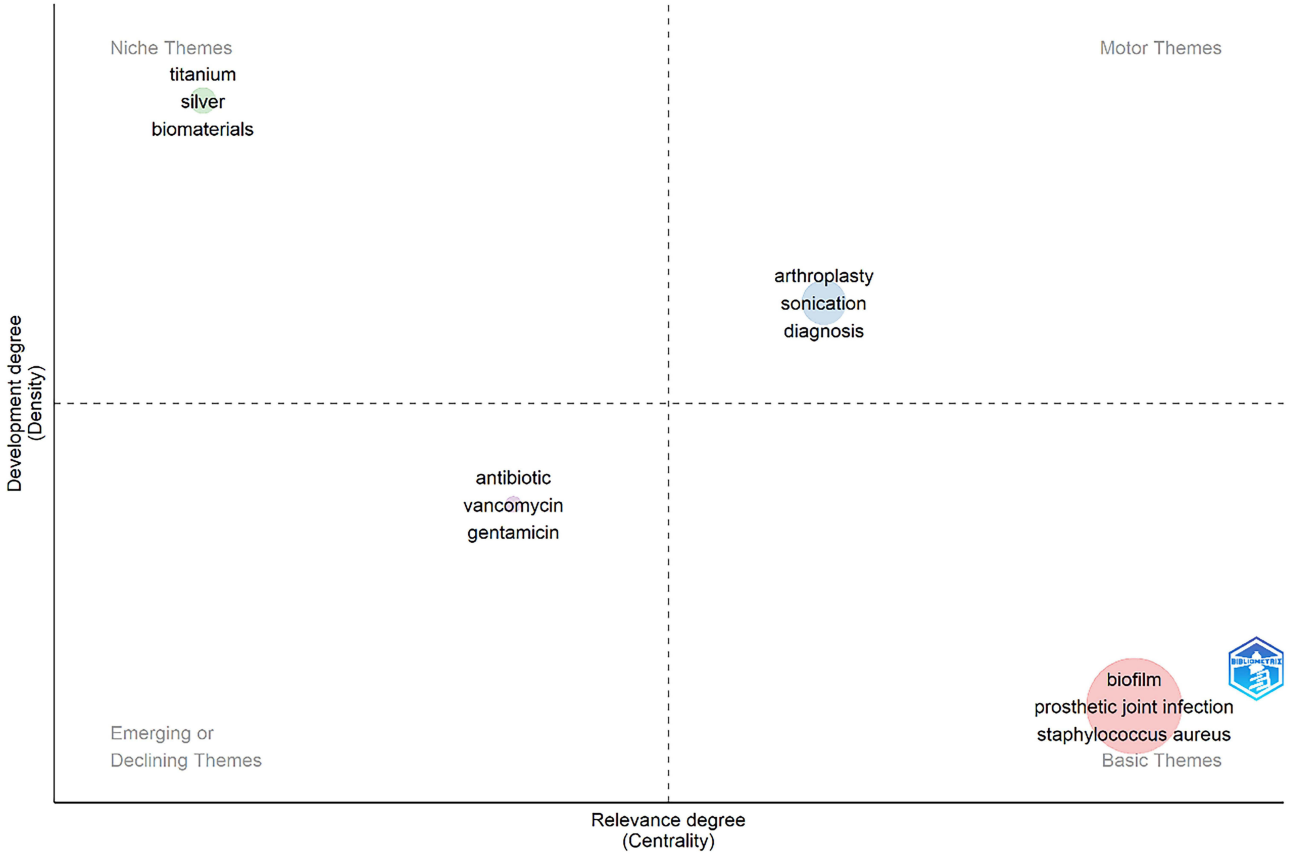

Figure 7 Thematic map analysis of the four identified clusters based on author's keywords of orthopedic biofilm research.

Thematic map analysis based on author's keywords has been conducted using the above four clusters to showcase their level of development (density) and relevance (centrality). The four quadrants depicted in Figure 7 represent different thematic categories: motor themes, niche themes, emerging or declining themes, and basic themes. The upper-right quadrant, known as motor themes, features topics with both high centrality and high density, indicating their critical and well-developed nature within the research field. In the lower-right quadrant, basic themes are found; these topics possess high centrality but low density, indicating their broad relevance across various research areas. The lower-left quadrant encompasses themes that are either emerging or in decline, characterized by both low centrality and low density, suggesting they are less developed and more peripheral. Finally, the upper-left quadrant houses niche themes, which have high density due to substantial internal development but low centrality, signifying they are important in specific contexts but have less overall influence.[13] The thematic analysis helps scientific readers identify which areas of biofilm research are most influential, which are broadly applicable yet underdeveloped, which are emerging or declining, and which are specialized but intensively studied. This can guide them in selecting research topics, understanding the landscape of current research, and finding potential areas for collaboration or innovation.

Discussion

This study investigated the field of orthopedic biofilm research from 1994 to 2022, utilizing the bibliometrix with R package to conduct a comprehensive bibliometric analysis, presenting a comprehensive perspective on this field. Current status, development trends and future research hotspots of orthopedic biofilm research were systematically described aiming to help scientists and doctors in this field stay up-to-date with emerging trends and optimize article performance.

The first paper on the development of an in vitro model of orthopedic prosthesis-associated infection was published in 1994 by Darouiche RO et al[14] but the number of research articles began to increase significantly from 2008 and has been

steadily rising ever since. The overall average annual growth rate is 22.2%, and a total of 807 articles were published in the past three years, accounting for 34.2% of the total. The Journal of orthopaedic research published the largest number of articles on this field, while Clinical orthopaedics and related research was the most influential journal that also ranked third in terms of publication volume. Two authors, Trampuz A and Patel R, have maintained a stable number of publications and citations since 2003, focusing on the diagnosis of prosthetic infection and biofilm eradication. Their research institutions with close cooperation were also the largest clusters in the field of orthopedic biofilm research. Ohio State university had the largest number of publications among all institutions but does not connect closely with other institutions. The United States is the leading country in terms of both number of publications and institutions. Germany and Switzerland share close cooperation within Europe, whereas the United Kingdom and Germany have strong ties with the United States. China, Italy, and the United States also have significant collaborative relationships. All countries exhibit high SCPr scores, indicating great potential for future cooperation among them. The most cited papers were analyzed for determine their impacts in orthopedic biofilm research. The top three globally most cited articles were milestones in the field. The first article by Trampuz A et al[15] published in the New England Journal of Medicine in 2007 and introduced the novel method of sonication for microbiological diagnosis of periprosthetic infection. This groundbreaking technique has led to increased sensitivity in diagnosing hip and knee prosthetic infections with a diagnostic sensitivity increase of 17.7%. This article has an average of over 50 citations per year globally, making it one of the most influential papers in the field. The second paper was written by Puckett SD and his team[16] from Brown University in the United States. It investigated the potential of nanotechnology to reduce the adhesion of bacteria and biofilms on titanium (Ti) surfaces used in orthopedic implants. The study observed that electron beam evaporation produced nanorough Ti could reduce the adhesion of Staphylococcus aureus, Staphylococcus epidermidis, and Pseudomonas aeruginosa bacteria the most. This discovery highlights the potential for designing implant materials with improved biocompatibility and reduced infection risk using nanotechnology. The third most cited article was authored by Tunney MM et al[17] and published in the Journal of Clinical Microbiology in 1999. The researchers utilized immunofluorescence microscopy to examine bacterial cells aggregations growing on removed hip implant surfaces. Propionibacterium acnes and Staphylococcus spp. grew within adherent biofilms on these surfaces were observed, which made it difficult to diagnose prosthetic joint infection (PJI). This study is the first to compare immunological and PCR detection methods for diagnosing infections in explanted prosthetic hip joints. The investigation covered 72% of explanted instruments and found the expression of bacterial 16s rRNA genes. As a comprehensive guide to orthopedic BAIs, the article highlights the expected pathogens that grow within biofilms and their susceptibility to antimicrobials.

Through co-occurrence network analysis, four highly connected clusters were identified. The first, also the main cluster involves the term "biofilm" tightly bound to "prosthetic joint infection", containing various keywords regarding microbial species (staphylococcus aureus, staphylococcus epidermidis, pseudomonas aeruginosa) and their impacts on implant-associated infection (antibiotic resistance, osteomyelitis, rapamycin). The onset of symptoms of PJI can vary widely depending on the type of microorganism that attaches the implant after surgery.[18] High virulent microorganisms such as Staphylococcus aureus, pseudomonas aeruginosa typically cause acute infection (<4 weeks after surgery),[19,20] while low virulent species such as Staphylococcus epidermidis and Propionibacterium acnes (now called Cutibacterium acnes) contribute mostly chronic infection.[21,22] It might be difficult to determine the exact contribution of biofilm to infections such as PJI or osteomyelitis caused by MRSA. However, taking proactive measures against bacterial resistance caused by orthopedic biofilms could lead to better patient outcomes and a decreased risk of morbidity and mortality.[23] Recent research suggests that rifampicin effectively penetrates biofilms with higher efficacy than vancomycin and daptomycin for reducing the bacterial load of MRSA biofilm.[24,25] The concurrent use of rifampicin in combination with other antibiotics is recommended; however, the optimal systemic use of antibiotics such as the best combination, duration, and dosage for treating orthopedic BAIs remains a topic of debate.[26] The second cluster mainly contains terms "infection", "arthroplasty", "sonication", 'diagnosis' and "treatment", showing the role of sonication in the management of arthroplasty infection in the current literature. Sonication has been used as a means of dislodging adherent bacteria from the surface of the implant based on the application of long-wave ultrasounds. Pioneers Trampuz A et al[15] prospectively compared 331 patients (252 with sterility failure and 79 PJI) with cultured samples obtained from sonicated treatment of explanted hip and knee prostheses and conventional cultures of periprosthetic tissue. The sensitivity of

periprosthetic tissue culture and sonicated liquid culture to infection was found to be 61% and 79%, respectively. Another pioneer Tunny MM et al[17] further improved the sensitivity of diagnosing infection by combining the PCR technology. Inspired by the application of sonication in PJI, the advancement of sonication in detecting spinal implant associated infection[27,28] and orthopedic trauma implant infection[29,30] has been achieved. It has been investigated that sonication has a diagnostic sensitivity of over 90% in detecting microorganisms, which suggests that regardless of the type of fixation used - such as plates on long bones, screws in vertebral bones, or joint prostheses, sonication exhibits excellent performance beyond what conventional methods can achieve, and therefore some scholars propose that sonication be used as a tool for routine clinical diagnosis of orthopedic biofilm infections.[31]

After analyzing the third cluster, it can be determined that the research interest pertains to 'Biomaterials for orthopedic implants'. Orthopedic implant biomaterials are used to replace or repair bones, cartilage, ligaments, tendons, and other tissues, as well as guide bone repair.[32] The initial stage of infection occurs when bacteria form a biofilm and attach to the surface of the implant. However, this process can be influenced by various factors such as material chemical composition, hydrophobicity, topography, wettability, etc.[3,33–36] Titanium and its alloys have emerged as the most commonly used implant materials in orthopedic surgery,[37] which possess excellent biocompatibility and corrosion resistance at the same time. Nevertheless, studies have shown that the surface structure of commonly used titanium implant materials is relatively rough, which promotes the formation of biofilm.[38–40] As a result, research has been conducted on modifying the properties of implant materials by optimizing wettability, topography, and pattern size to prevent biofilm formation.[41] Several studies have utilized nanoimprint lithography as a patterning technique to create hierarchically patterned samples.[42–44] These studies have demonstrated an 82% and 86% reduction in bacterial attachment for Escherichia coli and Staphylococcus aureus, respectively. Furthermore, researches have been conducted on developing antibacterial implant coatings. These coatings, which typically use inorganic bioactive layers containing agents such as silver, copper, zinc, or cerium to produce antimicrobial effects through contact killing or release killing mechanisms, have potential clinical applications in combating orthopedic biofilms.[45,46] The fourth cluster, which involves bone cement antibiotic coating, especially via using vancomycin and gentamicin.[26] Antibiotic-impregnated bone cement serves as a local antibiotic delivery system that can provide high concentrations of selected antibiotics, and has been used successfully in the prevention and treatment of orthopedic BAIs, especially in revision and septic failure of the arthroplasty as well as chronic osteomyelitis.[47,48] Orthopedists and clinical scientists should prioritize the combined application of vancomycin and gentamicin in bone cement. Research indicates that this combination exhibits superior efficacy in inhibiting biofilm colonization by Staphylococcus aureus, Staphylococcus epidermidis, Escherichia coli, and Pseudomonas aeruginosa compared to individual usage.[49] However, its shortcomings have also been widely discussed, such as the association between antibiotics and the weakened structure and mechanical properties of the cement.[26,50,51] In addition, the systemic and local toxicity of bone cement that carries antibiotics cannot be ignored.[52]

Current diagnostic methods of orthopedic biofilm infections and interdisciplinary integration with related medical fields have attracted attention. A recent review discussed that clinical signs, imaging, culture techniques, microscopy, sonication and DNA amplification methods all contributed in diagnosing orthopedic implant biofilm infections. However, these methods have limitations such as reliance on visual cues, lab-intensive processes, and the need for invasive procedures.[8] This study also highlighted emerging non-invasive techniques (eg, disclosing agents and biomarkers α-defensin) and the need for standardization to improve diagnostic accuracy and clinical translation. A recent review[53] discussed the interdisciplinary efforts required to combat biofilm infections in orthopedic medicine, combining insights from microbiology, immunology, biochemistry, and materials science to develop innovative diagnostic and therapeutic approaches. This study delved into the intricate processes behind biofilm formation, such as bacterial dormancy and infiltration into host cells and bone structures, which contribute to the chronicity of infections and their resistance to conventional antibiotics.[54] It also underscored the influence of host-derived factors in enriching the biofilm matrix, thereby supporting bacterial survival. Biofilms impact the host's immune response and trigger a chronic inflammatory state, which inhibits cell recruitment and the production of anti-inflammatory cytokines.[55] This environment compromises the immune system's capacity to clear the infection effectively. Notably, the promising potential of nano-therapeutic diagnostics merits attention.[56] By integrating diagnostic and therapeutic agents within a single nanoparticle, it enhances the precision and effectiveness of treating biofilm infections linked to orthopedic implants.[57]

This study has several limitations warrant mentioning. Firstly, it is important to note that the number of citations for articles can change over time. Our analysis was based on articles and their citations up to 2022, but the number of citations may change in the coming months or years. Second, this paper combines literature from the WoSCC and Scopus databases, which are extensive but limited to their indexed publications. While these databases are authoritative, they may still possibly exclude valuable literature not present in their collections. Third, problems with researchers self-citing and citing their colleagues are difficult to detect in this bibliometric analysis, hence the resulting inflated citation counts can lead to inaccurate estimations of documents as well as journal impact.

Conclusions

The present study offered a comprehensive overview of the status of orthopedic biofilm research. Our findings identified prominent countries, institutions, journals, original articles, and authors to indicate the most influential research channels. The cooperation analyses of institutions, and countries indicated that research on orthopedic biofilm research needed to be strengthened. Microbial biofilm formation, role of sonication, biomaterial mechanism and antibiotic loading strategies have been investigated as the trend and hotspots in orthopedic biofilm studies.

Ethical Approval and Informed Consent

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Huazhong University of Science and Technology Union Shenzhen Hospital.

Consent for Publication

All authors state here that the details of any images, videos, recordings, etc. in the work can be published. All authors have actively contributed to its content, have thoroughly read it, agree with its contents, and confirm that the work presented in the manuscript is honest.

Funding

This work is funded by the Nursing Critical Care Key Technology Training Base Project (Grant No. SHDC22022223); the Nanshan District Health Science and Technology Project (Grant No. NS2023002; NS2023044); the Nanshan District Health Science and Technology Major Project (Grant No. NSZD2023023; NSZD2023026); the National Natural Science Foundation of China (Grant No. 82102640), and the National Key Research and Development Program of China (Grant No. 2022YFC3602203), the Medical Scientific Research Foundation of Guangdong Province of China (Grant No. A2023195) and the Science, Technology, and Innovation Commission of Shenzhen Municipality (Grant No. JCYJ20230807115918039). The sponsors played no part in the study design, data collection, data analysis, data interpretation, manuscript writing, or the decision to submit the article for publication.

Disclosure

The authors declare no relevant competing interests for this work.

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