

ORIGINAL

A bibliometric analysis of value creation and capture in biomedical engineering research

Análisis bibliométrico de la creación y captura de valor en la investigación en ingeniería biomédica

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ABSTRACT

The field of biomedical engineering has brought about a paradigm shift in healthcare, revolutionizing the creation and appropriation of value within the medical sector. This study delves into this transformative phenomenon by conducting a comprehensive bibliometric analysis of the biomedical engineering literature, aiming to elucidate the landscape of value creation and capture. Utilizing bibliometric tools and VOSviewer, we analyzed data from the Scopus database spanning from 2000 to 2024. Through citation analysis and keyword co-occurrence, we identified key authors, articles, journals, countries, and emerging trends in the realm of value creation and capture in biomedical engineering. Our findings not only shed light on the current state of research but also pinpoint areas for future investigation, thus contributing to the advancement of knowledge in this field. This paper serves as a roadmap for researchers, providing valuable insights into the dynamics of value creation and capture in biomedical engineering, and paving the way for future research endeavors.

Keywords: Bibliometric Analysis; Biomedical Engineering; Value Creation; Co-occurrence Analysis.

RESUMEN

El campo de la ingeniería biomédica ha supuesto un cambio de paradigma en la atención sanitaria, revolucionando la creación y apropiación de valor dentro del sector médico. Este estudio profundiza en este fenómeno transformador realizando un análisis bibliométrico exhaustivo de la literatura sobre ingeniería biomédica, con el objetivo de dilucidar el panorama de la creación y captura de valor. Utilizando herramientas bibliométricas y VOSviewer, analizamos datos de la base de datos Scopus desde 2000 hasta 2024. Mediante el análisis de citas y la co-ocurrencia de palabras clave, identificamos autores clave, artículos, revistas, países y tendencias emergentes en el ámbito de la creación y captura de valor en ingeniería biomédica. Nuestros hallazgos no sólo arrojan luz sobre el estado actual de la investigación, sino que también señalan áreas para futuras investigaciones, contribuyendo así al avance del conocimiento en este campo. Este artículo constituye una hoja de ruta para los investigadores, ya que aporta valiosas ideas sobre la dinámica de la creación y captura de valor en ingeniería biomédica y allana el camino para futuras investigaciones.

Palabras clave: Análisis Bibliométrico; Ingeniería Biomédica; Creación de Valor; Análisis de Co-ocurrencia.

INTRODUCTION

Biomedical engineering has recently emerged as a distinct and dynamic field, representing a significant evolution from its roots as an interdisciplinary specialization.⁽¹⁾ Unlike traditional engineering disciplines,

the scope of biomedical engineering encompasses a broad spectrum of research and development activities, spanning various subfields. These include the design and development of biocompatible prostheses, advanced diagnostic and therapeutic medical devices, such as clinical equipment and micro-implants, as well as cutting-edge imaging technologies like magnetic resonance imaging.⁽²⁾ Additionally, biomedical engineering plays a crucial role in the fields of tissue regeneration, pharmaceuticals, and therapeutic biological substances.^(3,4,5) It serves as the interface between engineering principles, design concepts, and their application in medicine and biology to address healthcare challenges, both diagnostic and therapeutic. Furthermore, biomedical engineers are tasked with managing and maintaining medical equipment in clinical settings, ensuring adherence to industry standards through procurement, regular testing, and preventive maintenance.⁽⁶⁾ This multifaceted role, also known as biomedical equipment technician or clinical engineer, underscores the importance of integrating engineering expertise with healthcare practices.

In the realm of biomedical engineering research, a pressing issue lies in comprehensively understanding the mechanisms driving value creation and capture.⁽⁷⁾ Despite the substantial volume of research in this field, there exists a gap in elucidating the intricate processes underlying these phenomena. This study aims to address this gap by delving into the nuanced aspects of value creation and capture within biomedical engineering. By doing so, we aspire to uncover novel insights that can drive innovation and inform future research endeavors in this critical domain.

Our contribution revolves around utilizing bibliometric analysis tools like Biblioshiny and VOSviewer to effectively visualize and interpret intricate bibliographic data within the biomedical engineering domain. Through the utilization of these sophisticated tools, our goal is to furnish researchers and stakeholders with user-friendly visualizations that unearth concealed patterns, trends, and associations within extensive scholarly literature datasets. Our unique methodology involves scrutinizing a vast array of scholarly works to pinpoint influential authors, articles, journals, and countries, thereby illuminating the dynamics of collaboration and knowledge dissemination. This innovative utilization of effective bibliometric tools empowers us to conduct thorough analyses of citation networks, co-authorship patterns, and keyword co-occurrences, thereby unearthing invaluable insights into the structure and dynamics of the biomedical engineering research landscape. By leveraging these powerful tools, we endeavor to streamline and enhance the efficiency of bibliometric research in biomedical engineering, ultimately making significant strides towards advancing knowledge and fostering innovation in the field.

The remainder of the paper is structured as follows: Section 2, Related Works, provides an overview of existing literature related to value creation and capture in biomedical engineering. Section 3, Research Methodology, outlines the methodology employed in this study, including data collection and analysis techniques. In Section 4, Results & Discussions, the findings of the bibliometric analysis are presented and discussed in detail, with a focus on identifying trends, patterns, and insights gleaned from the data. Finally, Section 5, Conclusion & Future Perspectives, offers a summary of the study's key findings, implications, and recommendations for future research directions.

Related Works

In recent years, numerous studies have investigated the application of bibliometric analysis in various fields, including biomedical engineering. Notably, Liu et al.⁽⁸⁾ conducted a comprehensive bibliometric study to analyze the trends and patterns in biomedical engineering research publications. Their work provided valuable insights into the growth of the field and identified key areas of focus. Similarly, Rostmani et al.⁽⁹⁾ explored the use of bibliometric techniques to assess the impact of research collaborations in biomedical engineering. Their study highlighted the importance of collaborative networks in advancing scientific knowledge and innovation.

Furthermore, Chiroma et al.⁽¹⁰⁾ proposed a novel approach combining bibliometric analysis with machine learning algorithms to predict emerging trends in biomedical engineering research. Their research demonstrated the potential of data-driven methods to anticipate future developments in the field. In contrast, Waris et al.⁽¹¹⁾ evaluated the limitations of traditional bibliometric indicators in capturing the multidimensional nature of scientific impact in biomedical engineering. They emphasized the need for more sophisticated metrics to assess the societal and economic impact of research.

While these studies have contributed significantly to our understanding of bibliometric analysis in biomedical engineering, they also exhibit certain limitations. For instance, Ahmar et al.⁽¹²⁾ focused primarily on descriptive statistics and did not delve deeply into the underlying mechanisms driving research trends. Similarly, Nti et al.⁽¹³⁾ relied heavily on historical data and may not accurately capture emerging trends. Addressing these limitations, our study aims to leverage advanced bibliometric tools to provide a more nuanced analysis of value creation and capture in biomedical engineering research. By integrating qualitative and quantitative approaches, we seek to offer a comprehensive perspective on the dynamics of the field and identify opportunities for future research and innovation.

In summary, the existing literature on bibliometric analysis in biomedical engineering provides a solid

foundation for our study. However, there remains a need for more in-depth investigations that address the complexities and challenges inherent in assessing research impact and trends in this rapidly evolving field.

Research Methodology

Proposed Framework: Flowchart for Biomedical Engineering Bibliometric Analysis

The research methodology employed in this study aims to establish a comprehensive framework for conducting bibliometric analysis on value creation and capture within biomedical engineering research. The methodology is meticulously structured to ensure specificity, reproducibility, and relevance in achieving the outlined research objectives. This methodological process is illustrated in Figure 1, depicting the flowchart detailing each step.

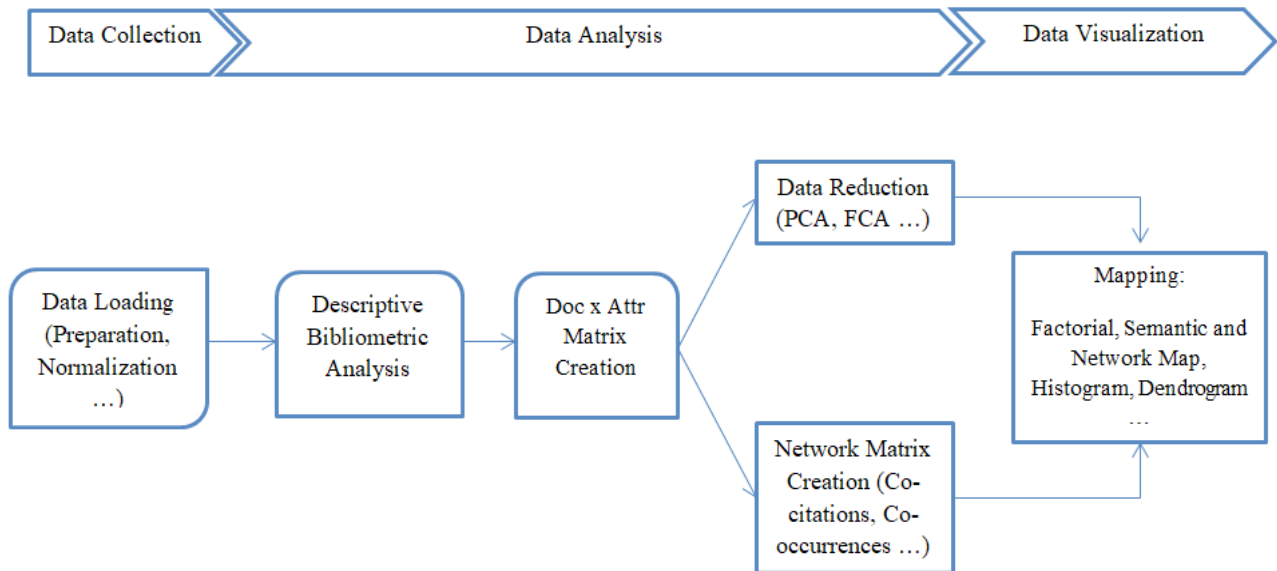


Figure 1. Proposed Methodological Framework for Bibliometric Analysis

The proposed methodology comprises a series of thoughtfully constructed layers, meticulously designed to guide readers through a seamless process of systematic data collection, exhaustive analysis, and insightful visualization. Each layer acts as a vital foundation in unraveling the complex landscape of biomedical engineering research, ensuring a systematic approach to uncovering valuable insights and trends. The following outlines the key components of this robust methodology:

- Firstly, the data collection layer involves specifying search criteria and retrieving bibliographic data from relevant databases such as Scopus or Web of Science. This step ensures that the dataset encompasses a comprehensive selection of scholarly literature pertaining to biomedical engineering.
- Next, the descriptive bibliometric analysis layer encompasses initial data exploration and citation analysis. Through exploratory analysis, key publication trends, authorship patterns, and citation metrics are examined to gain insights into the characteristics of the research landscape.
- Subsequently, the document attribute creation layer involves standardizing author names and affiliations, categorizing journals, and extracting keywords. These processes enable the classification and organization of bibliographic data, facilitating subsequent analysis.
- Following this, the data reduction layer entails removing duplicates and excluding non-relevant publications based on predefined inclusion criteria. This step ensures the integrity and relevance of the dataset for further analysis.
- In the subsequent layer, the network matrix creation stage involves constructing co-authorship and keyword co-occurrence matrices. These matrices serve as the basis for visualizing collaboration networks and identifying research themes and relationships.
- Finally, the data visualization layer utilizes network visualization techniques and cluster analysis to represent collaboration networks and research themes visually. This enables researchers to identify patterns, trends, and relationships within the data, facilitating meaningful interpretations and insights.

By following this methodological flowchart, we ensure a structured and systematic approach to conducting the bibliometric analysis, facilitating the identification of key insights and trends in biomedical engineering research. The flowchart serves as a guide for researchers to navigate through the various stages of data

collection, analysis, and visualization, ultimately leading to meaningful interpretations and actionable conclusions. Thus, the proposal methodology is designed to adhere to best practices in bibliometric analysis, ensuring the reliability and validity of the study findings.

Experimental Setup

In this section, we provide a detailed overview of the experiment setup employed in our bibliometric analysis of value creation and capture in biomedical engineering research. The dataset used in our study was meticulously curated from the Scopus database, a widely acknowledged repository in the field. Beginning with the screening of fundamental articles related to "biomedical engineering," "value creation," "value capture," and "business model," a refined research query was formulated and iteratively optimized (as detailed in Table 1). From an initial pool of 15,700 articles, a total of 1436 relevant articles were thoughtfully selected and downloaded in BibTeX format on August 01, 2023.

Table 1. Selection Criteria and List of Articles	
Inclusion criteria	Description
Data source	Scopus
Search string	biomedical engineering
Category field	"Medicine" OR "Biochemistry"
Document type	"Conference" AND "Article"
Language	English

To conduct our comprehensive bibliometric analysis, we harnessed the power of Bibliometrix, a robust tool programmed on the R platform. Bibliometrix facilitated descriptive analysis and various network analyses, including collaboration and keyword co-occurrence analysis. Moreover, to enhance the interpretation of our results, we leveraged VOSviewer software, renowned for its capabilities in visualizing keyword co-occurrence patterns with clarity and precision. Our experimental environment was carefully configured to ensure optimal performance, with experiments conducted on a dedicated device equipped with high-performance hardware and software requirements. These specifications included an Intel(R) Core(TM) i7-10510U CPU @ 1,80GHz, Windows 10 operating system, 16GB RAM, 1TB HDD and 512GB SSD storage, Python programming language, and NVIDIA GeForce MX250 GPU. This meticulously designed experimental setup allowed us to execute our bibliometric analysis efficiently and accurately, thereby deriving valuable insights into the dynamics of value creation and capture in the field of biomedical engineering.

RESULTS AND DISCUSSIONS

In this section, we present the outcomes of the bibliometric analysis conducted on the selected articles, which are delineated into two primary segments. Subsection 4.1 encompasses a comprehensive descriptive analysis, unveiling various facets of the publication landscape. This includes an exploration of publication trends over time, an examination of the most prolific journals driving scholarly discourse, an assessment of the leading institutions and countries contributing to the field, and an elucidation of the most cited articles and frequently encountered keywords. Moving forward, Subsection 4.2 delves deeper into the analysis by exploring the intricate networks formed by keyword co-occurrences and collaborative efforts among authors. Through these analyses, we aim to unravel the underlying structures and dynamics of scholarly communication in the domain of biomedical engineering, thereby shedding light on emerging trends and influential contributors.

The descriptive analysis

In this subsection, we delve into a comprehensive descriptive analysis of the bibliometric data derived from the selected articles, unveiling multifaceted insights into the scholarly output within the realm of biomedical engineering. We encapsulate our key findings as follows:

- Providing a comprehensive overview of the general results obtained from our analysis.
- Examining the annual publication trends to discern patterns in the longitudinal dissemination of research in the field.
- Identifying the most frequently cited articles, spotlighting seminal contributions that have garnered significant scholarly attention.
- Acknowledging the most prolific authors, highlighting individuals whose scholarly contributions have been particularly noteworthy.
- Evaluating journals with the highest citation rates per article, elucidating influential publication platforms within the discipline.

- f. Assessing institutions with the highest citation rates per document, shedding light on centers of research excellence.
- g. Analyzing countries demonstrating the highest levels of publication productivity, unveiling geographical hubs of research activity and innovation in biomedical engineering.
- h. Analyzing the most frequent keywords unveils essential themes and concepts driving research in biomedical engineering, providing insights into the core areas of interest and focus within the field.

These conclusions provide a thorough understanding of the research landscape in biomedical engineering, offering insights that can guide future directions and strategic initiatives in the field.

a. Exploration of Biomedical Engineering Publications

Our study involved analyzing 1436 articles sourced from the Scopus database, authored by 6593 individuals affiliated with 2233 institutions across 61 countries. Table 2 presents a comprehensive overview of all articles considered in our investigation of the Biomedical Engineering domain, illustrating publication counts spanning from 2000 to 2024. This timeline underscores the dynamic evolution of the field within scholarly literature.

Table 2. Overview of Biomedical Engineering Publications	
Description	Results
Main information about data	
Timespan	2000-2024
Sources (Journals, Books, etc)	1436
Annual Growth Rate %	-21,64
Document Average Age	3,83
Average citations per doc	211,1
Document contents	
Keywords Plus (ID)	53035
Author's Keywords (DE)	25087
Authors	
Authors	6593
Authors of single-authored docs	444
Authors collaboration	
Single-authored docs	543
Co-Authors per Doc	4,57
International co-authorships %	17,74

b. Annual Scientific Production

The analysis of annual scientific production in the field of Biomedical Engineering unveils intriguing trends in research evolution over time. Particularly concentrated on the most recent six years (as depicted in figure 2) spanning from 2018 to 2024, there was a gradual increase in publication counts, with the 2018s witnessing a notable expansion, signaling a surge in research interest. Conversely, preceding years saw relatively low publication volumes, indicating slower development in Biomedical Engineering. Since the 2019s, there has been exponential growth in published articles, peaking at 2500 documents in 2020, indicating sustained growth intensified by rapid advancements in medical technologies and increased engineering applications in healthcare. However, it's crucial to note that publication quantity doesn't necessarily reflect research quality or impact. Further analysis is needed to evaluate these aspects. Overall, the analysis underscores substantial growth in Biomedical Engineering research since the 2020s, presenting significant potential for value creation and capture, albeit requiring continued scrutiny to gauge its broader impact on science and society.

c. Analysis of the Most Cited Articles in the Field of Biomedical Engineering

Upon reviewing both the table and graph of the most cited articles, we can discern those publications that have exerted a significant impact within the realm of Biomedical Engineering, as evidenced by their total number of citations received, citations per year, and Normalized Total Citations.

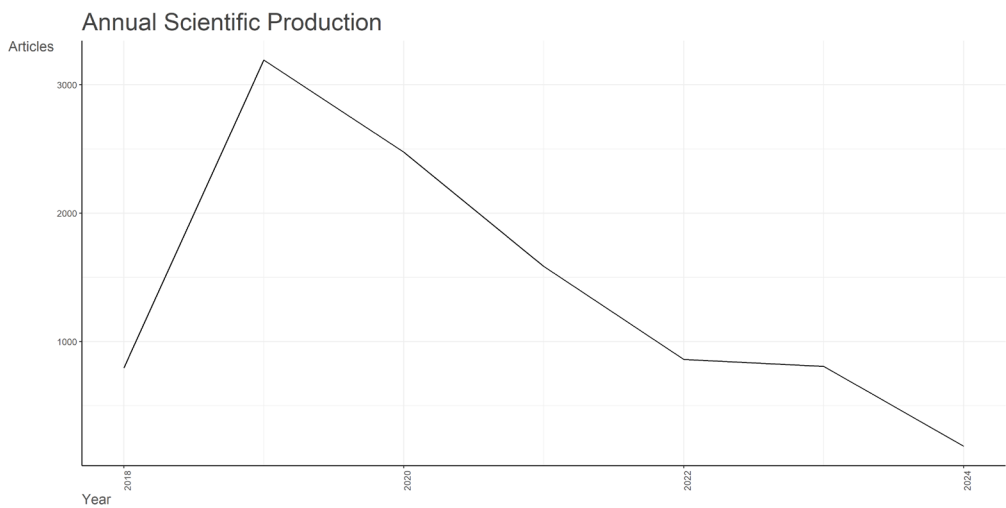


Figure 2. Annual Publication Trends in Biomedical Engineering

d. Most relevant authors

The examination of the figure 3 featuring the most productive authors in Biomedical Engineering underscores individuals who have made substantial contributions to the scientific literature. Two key metrics were considered: the total number of articles published by each author and the "Articles Fractionalized" measure, which indicates collaboration or the average number of co-authors per article. Among the most productive authors, WANG Y and ZHANG Y stand out with 119 articles each, followed closely by LIU Y and WANG X, each with 86 published articles. These authors have significantly contributed to research in Biomedical Engineering. Some authors have high values of "Articles Fractionalized" but a relatively low total number of articles. Conversely, authors like WANG J and WANG L have lower values of "Articles Fractionalized", suggesting fewer collaborations.

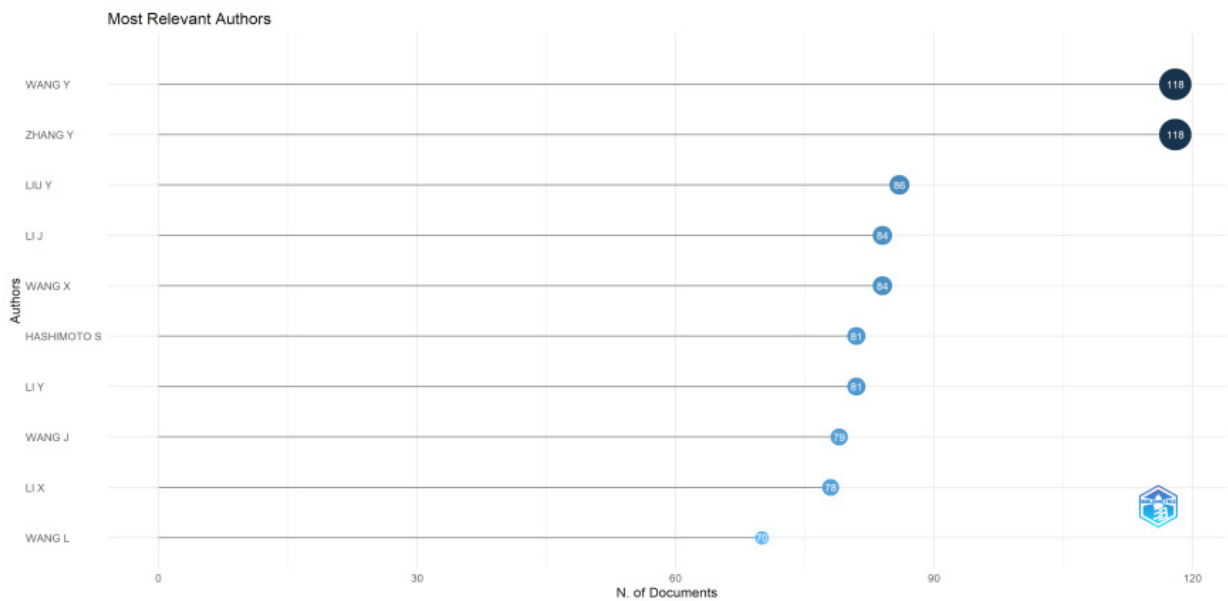


Figure 3. Top Authors in Biomedical Engineering Research

e. Most Frequent and Relevant Sources

A comprehensive analysis of the bibliographic data revealed a distribution of 1184 publications across 410 journals (as depicted in figure 4). The top ten publishers, determined by the highest number of research publications and total citation counts, are illustrated in the following histograms. Notably, " IFMBE PROCEEDINGS" emerged as the most prolific journal, followed closely by the " PROCEEDINGS - 2019 12TH INTERNATIONAL CONGRESS ON IMAGE AND SIGNAL PROCESSING, BIOMEDICAL ENGINEERING AND INFORMATICS, CISP-BMEI 2019" with 286 articles. Conversely, " IEEE EMBS CONFERENCE ON BIOMEDICAL ENGINEERING AND SCIENCES, IECBES - PROCEEDINGS " had the lowest publication count, with only 126 articles. These findings offer valuable insights into the distribution of publications across various journals, facilitating the identification of key sources for biomedical research endeavors.

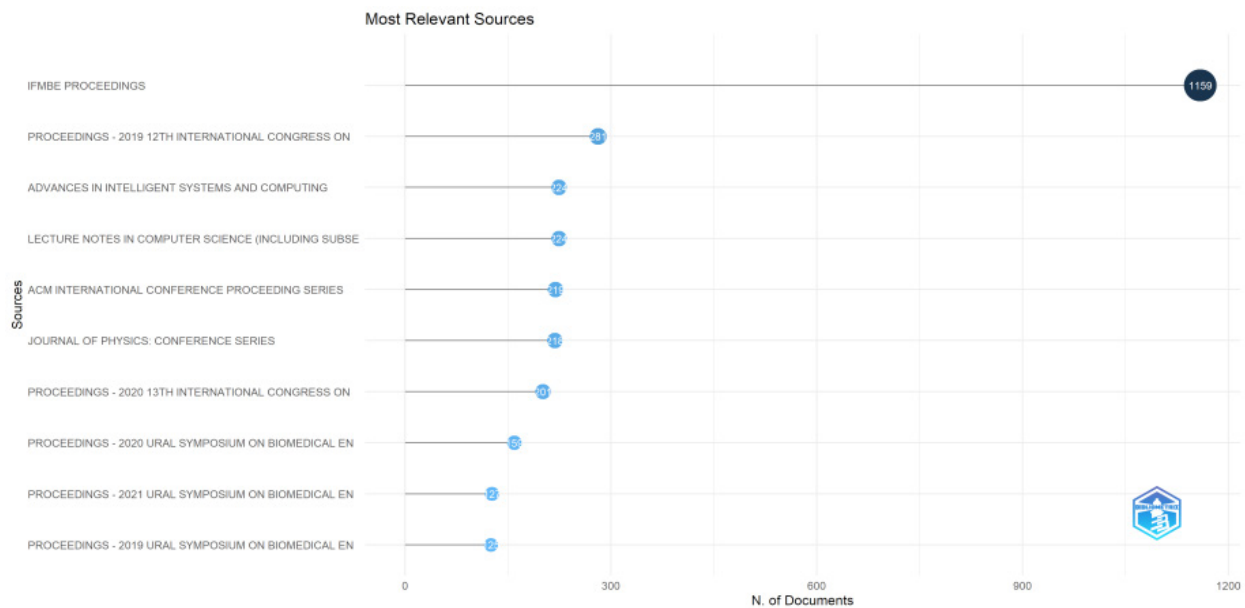


Figure 4. Top Sources in Biomedical Engineering Research

f. Analysis of the Leading Affiliations in the Field of Biomedical Engineering

The presented data reveals the prominent affiliations (as illustrated in Figure 5) shaping advancements in biomedical engineering research. Institutions like “TSINGHUA UNIVERSITY, SILESIAN UNIVERSITY OF TECHNOLOGY and SICHUAN UNIVERSITY” demonstrate significant contributions with their substantial article counts. However, it's imperative to acknowledge that publication numbers represent only one aspect of scientific productivity. Collaborations, funding sources, and specialized research areas all contribute to the broader impact of these institutions' work, highlighting the multifaceted nature of scientific contribution.

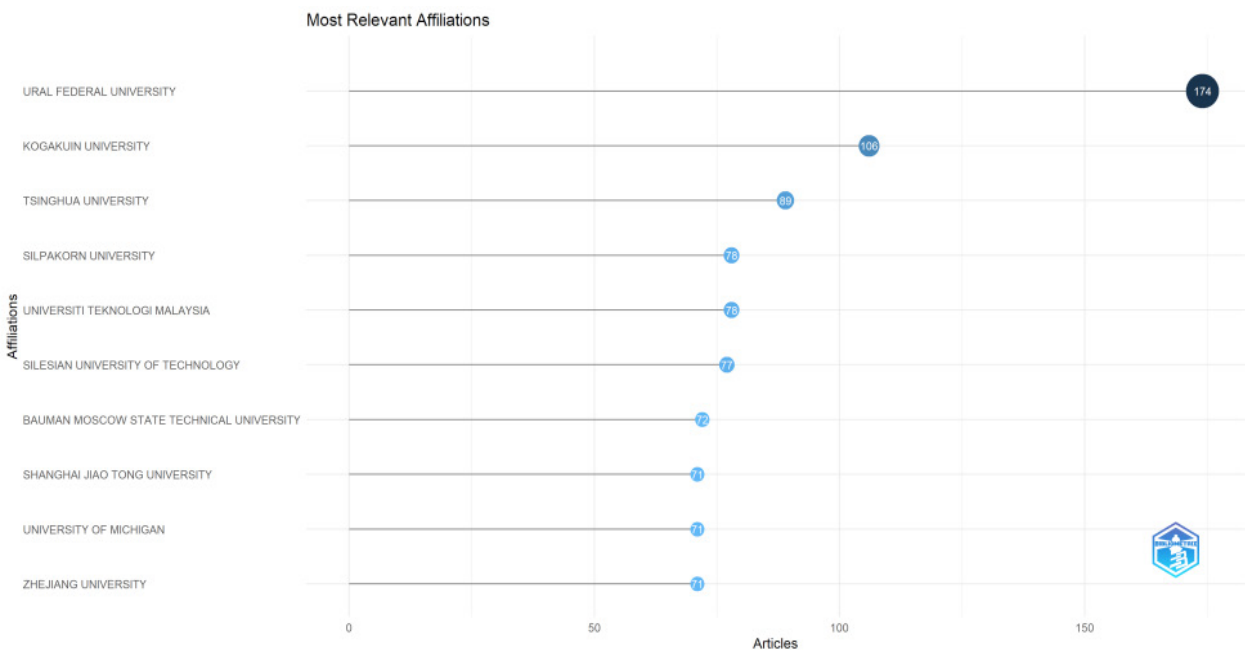


Figure 5. Top Affiliations in Biomedical Engineering Research

g. Most Productive Countries

Examining the forefront of productivity in biomedical engineering unveils the top ten countries driving innovation in this pivotal domain (as depicted in figure 6). Leading the charge is the China, boasting a formidable 1246 publications, closely trailed by USA with 535 publications, Brazil with 348 publications, India with 350 publications, Japan with 230 publications and Germany with 206 publications. These findings

underscore the profound global impact and collaborative ethos driving biomedical engineering research, with these leading nations spearheading transformative strides in healthcare technology and innovation. Moreover, these insights underscore the pivotal role of developed nations in advancing biomedical engineering research, characterized by robust publication outputs from countries such as the China, USA, and Brazil. These nations exhibit commanding leadership in medical research, leveraging extensive datasets to propel technological breakthroughs in biomedical engineering. While some developing nations like BELGIUM, GEORGIA, and Iraq display comparatively fewer publications, they nonetheless contribute significantly to biomedical research. It is imperative for all countries, irrespective of their developmental status, to persist in fostering research in this critical field to propel advancements in healthcare and medical technology.

Country Scientific Production

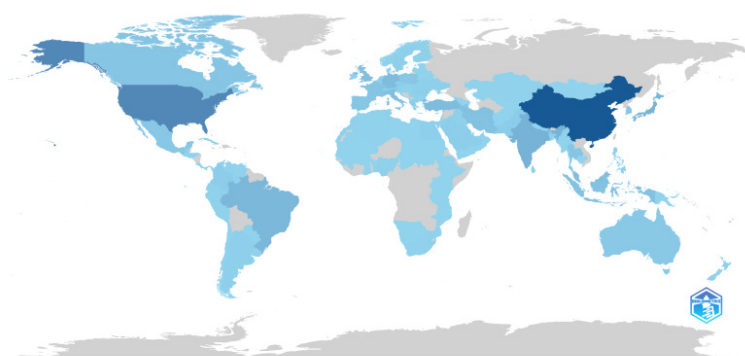


Figure 6. Countries' Scientific Production

h. Most Frequent Terms

The analysis unveils the recurring terms prevalent in biomedical engineering publications, shedding light on key thematic areas (as depicted in figure 7). "Biomedical engineering" emerges as the most prevalent term, followed closely by "clinical engineering" and "additive manufacturing". These terms highlight the central focus on biomedical engineering as a discipline, the role of articles as primary scientific outputs, and the human-centric nature of medical research. Furthermore, keywords related to research methodology and experimentation underscore the emphasis on rigorous scientific inquiry. The prevalence of terms indicates a growing reliance on modeling and simulation techniques to explore biomechanical and physiological phenomena. Additionally, specialized terms like "magnetic resonance imaging", "tissue engineering", and "radiotherapy" underscore the critical role of medical imaging, tissue engineering, and therapeutic technologies in biomedical applications.

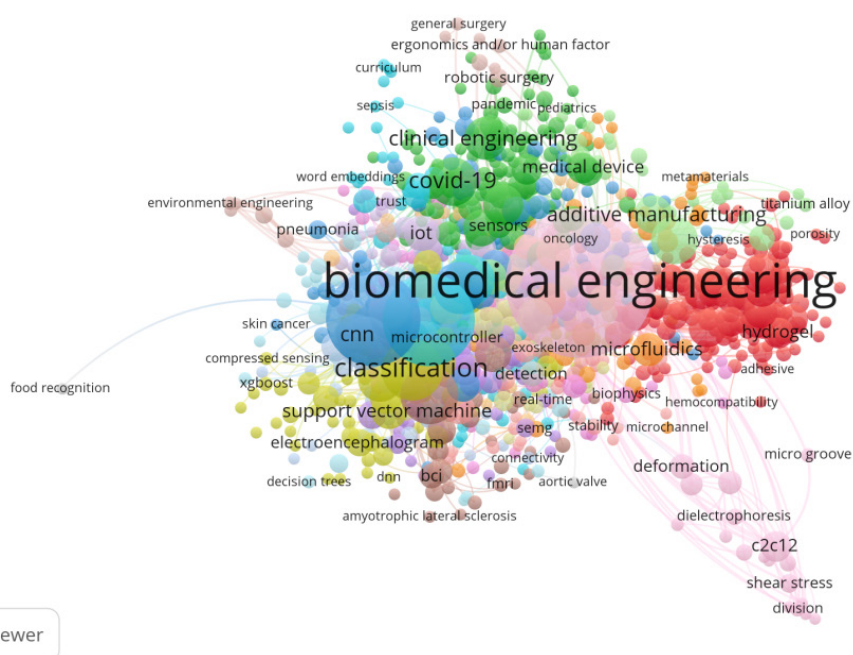


Figure 7. Most Frequent Terms in Biomedical Engineering Research

Network Analysis

In this subsection, we delve into the intricate web of bibliometric data to explore the collaborative landscape within biomedical engineering research. Our study delves into the collaborative landscape of biomedical engineering research through a comprehensive analysis of (a) author, (b) country, and (c) institutional collaborations –to illuminate the interconnectedness of scholarly endeavors in this dynamic field. Through the dissection of collaborative networks, we unveil profound insights into the collective efforts and emerging trends that shape the landscape of biomedical engineering research. The results of our collaborative analysis serve as illuminating guides, revealing light on the dynamic networks that drive innovation in this field.

a. Author Collaboration Patterns

In this part, we delve into the complex network of collaborative relationships among authors within the domain of biomedical engineering. Our study employs sophisticated bibliometric techniques to meticulously analyze author collaborations, aiming to map out the intricate web of scholarly interactions. By doing so, we illuminate the interconnectedness and collaborative dynamics that underpin innovation in this dynamic field. Through our analysis, we uncover patterns of collaboration among authors, highlighting key partnerships and research clusters that drive advancements in biomedical engineering knowledge. For instance, authors Wang Y and Zhang Y emerge as among the most collaborative researchers, illustrating the depth of collaborative engagement within the field. This exploration of collaborative networks provides valuable insights into the collaborative landscape of biomedical engineering research, offering a deeper understanding of the collective efforts and emerging trends shaping the field. Figure 8 reveals the intricate web of co-authorship relationships, with nodes representing authors and links indicating collaborations. Notably, the size of the text reflects the frequency of publications, providing insight into prolific contributors.

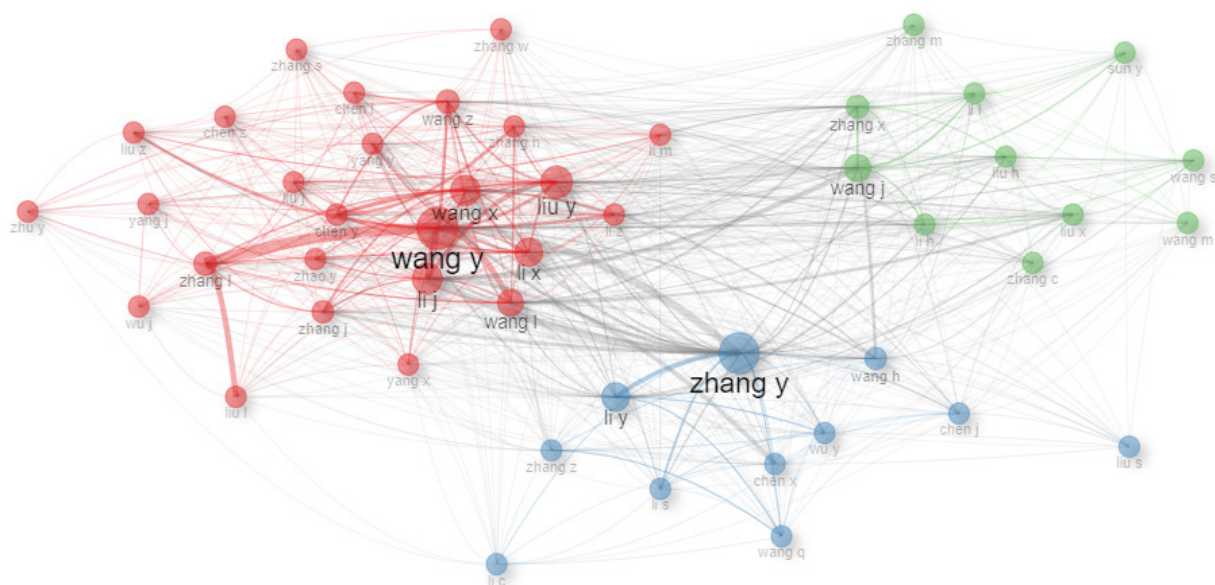


Figure 8. Author's Collaboration Network

b. Countries Collaboration Patterns

In this part, we explore the collaborative landscape of biomedical engineering research on a global scale, focusing on the patterns of collaboration among countries. Our analysis reveals the most collaborative nations in this field, highlighting the extensive partnerships that drive innovation and knowledge dissemination. Notably, countries such as the United States, China, Japan, the Russian Federation, India, and Brazil emerge as the most collaborative, fostering extensive research networks and collaborations. These countries play a pivotal role in advancing biomedical engineering through their collaborative efforts, contributing significantly to the field's growth and development. Figure 9 provides a visual representation of the collaborative landscape among countries, depicting the interconnectedness and shared research endeavors that characterize the global biomedical engineering community.

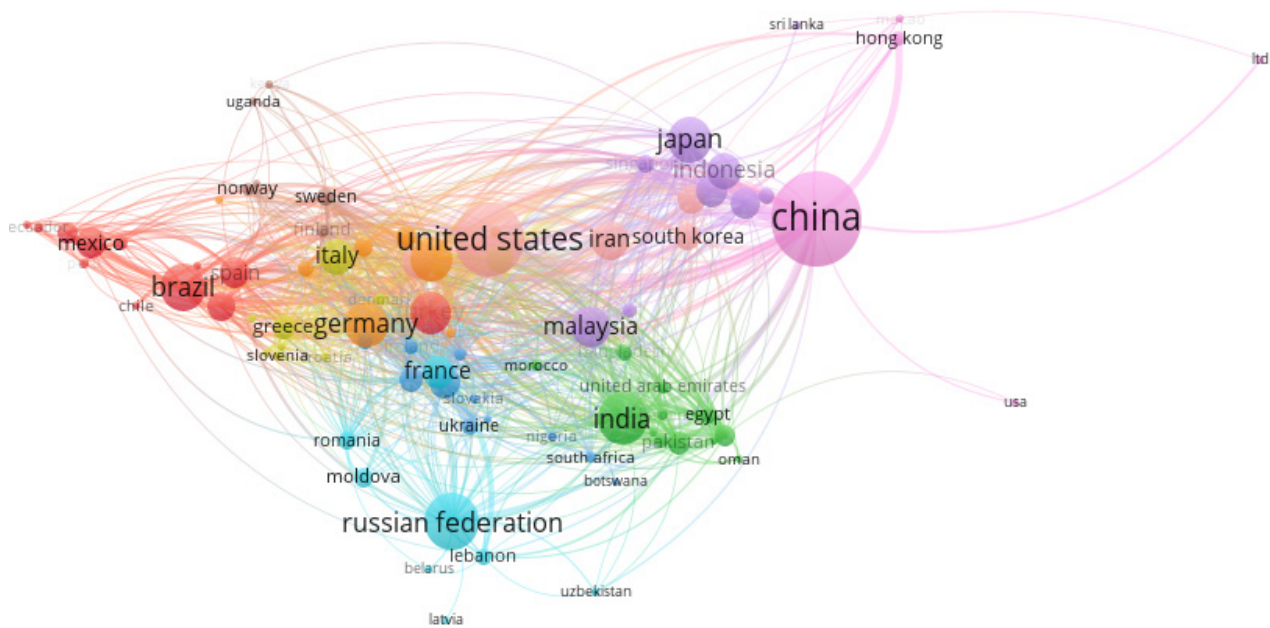


Figure 9. Countries' Collaboration World Map

c. Affiliations Collaboration Patterns

In this section, we delve into the collaborative patterns among affiliations within the realm of biomedical engineering research. Our analysis unveils the collaborative dynamics between various affiliations, shedding light on the interconnectedness and shared research endeavors within the field. As exemplified by collaborations between departments such as Biomedical Engineering Systems, Biomedical Engineering Mechanics, Health Medical Research, and Kogakuin University, affiliations play a crucial role in fostering interdisciplinary research and knowledge exchange. These collaborations contribute to the advancement of biomedical engineering by leveraging diverse expertise and resources. Figure 10 provides a visual representation of the collaboration patterns among affiliations, illustrating the intricate networks that facilitate collaborative research efforts within the biomedical engineering community.

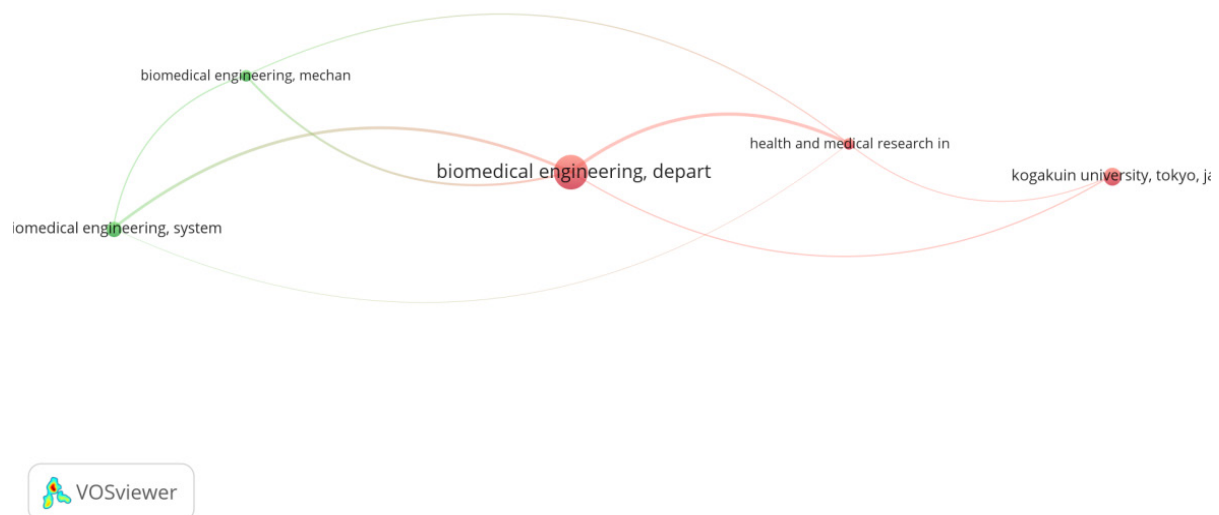


Figure 10. Affiliation's Collaboration Network

Overall, our analysis highlights the robust collaborative networks that underpin biomedical engineering research, emphasizing the essential role of global partnerships in driving innovation and advancing healthcare technology. Further, the relationships between prominent universities and countries, showcasing the breadth and depth of collaborative endeavors in this field. These findings offer valuable insights for researchers, policymakers, and industry stakeholders, guiding future collaborations and strategic initiatives in biomedical engineering research.

CONCLUSION

The bibliometric analysis and network analysis conducted in this report provide a comprehensive insight into Biomedical Engineering research. The trends revealed in the descriptive analysis highlight a significant growth in scientific production in this field since the 2000s, with an exponential increase in the number of published articles. This evolution reflects the growing importance of engineering applications in the fields of healthcare and advanced medical technologies.

The collaboration analysis has shed light on authors, countries, and institutions playing pivotal roles in Biomedical Engineering research. Collaboration clusters have been identified, revealing authors and institutions frequently collaborating to conduct studies and research projects. This interinstitutional and international collaboration is a major asset for advancing research and developing innovative solutions in the medical field. Factorial analysis has detected semantic clusters of keywords, indicating links between certain concepts and themes in this domain. However, a more thorough and contextual interpretation is necessary to draw accurate and informative conclusions from this data. This underscores the importance of combining bibliometric analysis with qualitative approaches for a comprehensive understanding of the relationships between the studied concepts.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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