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MAPPING THE LANDSCAPE OF BIOMATERIALS IN ORTHOPAEDICS: A BIBLIOMETRIC ANALYSIS OF GLOBAL RESEARCH TRENDS 2010-2025

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ABSTRACT

The aim of this bibliometric analysis is to investigate the global scientific crash report on orthopaedic biomaterials from 2010 to 2025, with emphasis on their significant contribution for Sustainable Development Goal 3 (Good Health and Well-being). The analysis is based on 3,322 documents identified in the Scopus database, and publication productivity, collaborative networks and emerging thematic clusters are mapped using VOSviewer. Results The number of publications and their contribution in this subspecialty are increasing enormously, mainly from China, the US and India, but also from European countries. Four research directions were most identified: medical applications of biomaterials, bone tissue engineering, cellular and animal studies, and antibacterial nanomaterials. General keywords such as biocompatibility, tissue engineering, and 3D printing emphasize the trend toward personalized implants, new regenerative strategies, and improved implant life span. The review also highlights underexplored fields including drug delivery systems, angiogenesis, and corrosion resistance, which shows valuable leads for upcoming studies. The multidisciplinary nature of the field that delves into not only materials science and engineering but also into biology and clinical medicine necessarily calls for global collaboration and ingenuity to create sustainable, effective and accessible orthopaedic solutions. This analysis presents as a strategic reference point that can inform subsequent science and policy related to the improvement of musculoskeletal health internationally.

Keywords : Bibliometric Analysis; Orthopaedic Biomaterials; Sustainable Development Goals; Biocompatibility; Tissue Engineering.

I. INTRODUCTION

Biomaterials are materials, either synthetic or natural, created to interact with biological systems for medical purposes, especially in implants. In orthopaedics, they help restore movement and improve the quality of life for patients with conditions like degenerative diseases, injuries, and age-related issues. As people live longer, the need for joint replacements is expected to double in the U.S. from 2014 to 2030 [1], [2], [3]. This growing demand highlights the need for effective biomaterials that integrate well with the body to aid recovery.

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Biomaterials play a crucial role in tissue healing and osseointegration, which is how implants attach to bones. Advances in materials science have led to stronger and biocompatible materials like titanium and cobalt-chromium alloys [4], [5], while ceramics and bioactive glasses help in bone growth and healing [6], [7]. Recent developments in nanotechnology have improved these materials by influencing cell behavior and reducing the risk of infections around implants [8], [9]. 3D printing technology allows for customized biomaterials that fit patients' specific needs, enhancing surgical results [10], [11]. The use of biomaterials in orthopaedics positively affects patients' lives by lowering complications, reducing the need for repeat surgeries, and helping patients regain mobility more quickly after surgery [12], [13], [14].

Research involving biomaterials in orthopaedics has been extensively progressing due to the development of multiple materials and technologies. Both materials have their own special properties that meet certain orthopaedic surgical needs, such as joint replacement, fracture fixation and tissue engineering [15], [16], [17]. Biocompatibility, mechanical strength, and bioactivity of these materials are the main objects of attention of a vast research effort. Integration of nanotechnology is of particular interest, owing to the fact that nanomaterials are capable of modulating cellular responses and mechanical properties, hence are suitable for implant candidates [18], [19], [20].

Moreover, the increasing use of 3D printing makes the manufacturing of customized implants (customizing implants to each patient's need) with complex shapes possible resulting in better surgical outcomes by incorporating patient-specific anatomical information [21], [22], [23]. Current studies are exploring the possibility of applying scaffold structures generated by 3D printing as templates for tissue regeneration [24], [25], [26]. As such, there are many studies regarding how such smart biomaterials can maximize repair of both osseous and soft tissue injuries [16], [18], [19].

Yet, in the area of biomaterials research there is a high degree of splintering across a wide range of journals, scientific disciplines and geographical regions. Future research should develop more comprehensive integrative platforms, pathways detailing the cooperation between the global researchers for innovation and better clinical application. Bringing the knowledge from various fields, such as materials science and biomedical engineering into a unique combined understanding of biomaterials and how they are used in clinics is needed to progress together [16], [22], [27].

The abundance in quantity and multidisciplinary of publications reflects a knowledge gap, namely the synthesis of worldwide research trends and international collaboration. Many works emphasize the need for bibliometric studies to map scientific landscapes, to reveal the prevalent themes in a certain field, and to reveal the collaboration networks as these are the research directions that would guide the research community to new research directions [28], [29], [30]. Bibliometric information can help to consolidate fragmented knowledge, and to demonstrate new topics that need further attention, thus it can assist to develop an harmonized research agenda [29], [31]. In addition, strategic funding opportunities for global collaborations have been recognized as a critical way to improve the research productivity and policy making [32], [33]. The general conclusions drawn from bibliometrics studies is that structured conceptual frameworks are needed to help navigate the multitude of twists and turns involved in modern scholarly publication and to cope with the changes needed to disseminate knowledge on a global scale in a networked world [31], [33], [34].

Bibliometric analysis is a quantitative methodology that uses information about documents published in scientific literature to find out the intellectual structure, subject area, and topic. In collaboration with other methods such as spatial analysis (GIS), visualization software like Gephi for example is able to process large-scale bibliometric data. This process allows researchers to analyse publication productivity, influential works and collaboration dynamics [35], [36], [37]. The Judgment of Citation data and publication volumes provides an insight into the most active research topics. Hence it is a guide for the strategic decisions of researchers, clinicians and policy-makers [38], [39], [40]. Again, bibliometric tools like Cite-Space and VOSviewer make what otherwise would be reams of data into a picture form, aiding understanding of the underlying structure and future development direction [41], [42]. In sum, bibliometric analysis is very meaningful for detecting research hotspots, knowing the output of academic products in any given field and laying a foundation to fix research directions across disciplines [43], [44].

Although there is insufficient evidence that critics are concerned about the issue, systematic bibliometric reviews are urgentlyneeded for research into biomaterials for orthopaedics. For serious researchers in the field, the aim of this article is to achieve an all-around view of the situation and discover what contemporary topics are being hotly pursued or are likely to figure prominently in future work beyond national borders; its results will serve our projects on both interdisciplinary and intercontinental levels [16], [45], [46]. The usefulness of this review stretches to guiding innovation in the creation of high-performance biomaterials necessitated by rising demands among patients for orthopedic interventions that no existing methods can meet [4].

By tying together examples from classical scientific literature and cutting edge research, systematic bibliometric strategies will shed light on changes in focus and contributions in biomaterials research. This information can be a guide for stakeholders in the future directions orthopaedic medicine needs, to create opportunities for cooperative ventures Identifying these shifts not only provides a springboard for building on existing knowledge but also opens up new fields (e.g. infrastructure-related research) which could transform patient outcomes in musculoskeletal health [18], [47], [48].

Based on the above description, this article aims is to offer a bibliometric analysis of the application of biomaterials in the field of orthopedics. The literature analyzed was collected from the Scopus database and limited to publication in the period 2010–2025, also included types of Articles, Reviews and Book Chapters, Conference Papers, Books, Conference Reviews. This study, which is money-oriented, invites the reader to give tit-for-tat aids in various aspects of scientific productivity and its contribution. Subjects covered in this comprehensive paper include data on top-ranked countries and institutions alike, major categories, core journals, comes up new areas to explore research questions that all editor must answer. The findings of this bibliometric analysis are expected to answer several research questions, which can be stated generally as follows:

1. What are the publication trends in scientific literature that Pertain to Biomaterial Applications for Orthopedic Surgery?
2. By what quantity-do countries and facilities contribute their resources to this field of research?
3. Whose works are the most numerous published or forthcoming research on materials relevant for orthopaedic surgery--if taken across such a wide range?
4. What is the relationship or non-relationship between publication type, scientific discipline and biomaterial applications in orthopedic surgery?
5. What can bibliometric mapping tell us with regard to the main current research directions of biomaterials for knee replacement surgery?

II. METHOD

This paper uses bibliometric methods based on publication databases to map the scientific field in a structured manner. The mapping process consists of five main stages: 1) Research design, 2) Bibliometric data collection, 3) Analysis, 4) Visualization, 5) Interpretation [49], [50]. The data set consists of articles indexed in scopus that have been collected in scopus. com. The database search was with title, abstract, and keyword filters from 2010 to 28 August 2025. The major search term used was: "application of biomaterials in orthopaedics”. The search results were filtered by document types including “Articles”, “Reviews”, “Book Chapters”, “Conference Papers”, “Books”, and "Conference Reviews". The data was downloaded in Comma Separated Values format (CSV) and Research Information Systems (RIS) format also and analyzed by VOSviewer version 1.6.20 [51].

A first search by the keyword “application of biomaterials in orthopaedics” found 3322 documents. CSV-formatted data were downloaded and imported to the VOSviewer software. The lowest keyword occurrence threshold was set at 75 so that a first bibliometric map for the orthopaedics research of the application of biomaterials could be set up by 233 items and 4 clusters. There was a considerable overlap of some items; for instance, like the similar or synonymous terms from item(s) that were combined into the same key words category..

In the second phase a thesaurus file organising similar terms under each class is developed as presented in **Table 1**. A total of 38 terms were expanded according to their semantic relationships. With the same CSV data as well as with the newly created thesaurus file the last bibliometric map was produced (and again applying a minimum occurrence scale of 75). This yielded 198 items falling within four dimensions. Non-relevant items to bibliometric research (e.g. article; defects; procedures; review) are also removed.

Table 1. Labels assigned to items with equivalent substitute vocabulary

No	Label	Replace By	No	Label	Replace By
1	additive manufacturing	additives	20	human	humans
2	alloy	alloys	21	hydrogel	hydrogels
3	implant	implants	22	polyester	polyesters
4	implants (surgical)	implants	23	polymer	polymers
5	magnesium alloys	magnesium	24	scaffolds (biology)	scafofolds

6	mechanical	mechanical properties	25	three dimensional printing	3d printing
7	mechanical stress	mechanical properties	26	tissues engineerings	tissue engineering
8	mechanics	mechanical properties	27	tissue scaffold	tissue scaffolds
9	orthopaedic application	orthopaedics	28	animal	animals
10	orthopaedic implant	orthopaedics	29	cells, cultured	cells
11	orthopaedic applications	orthopaedics	30	x ray diffraction	x-ray diffraction
12	orthopaedic implants	orthopaedic	31	printing, three-dimensional	3d printing
13	surface treatment	surface modification	32	three dimensional printing	3d printing
14	titanium alloys	titanium	33	in vitro study	in-vitro
15	zinc alloys	zinc	34	in vivo study	in-vivo
16	3d printers	3d printing	35	mesenchymal stem cell	mesenchymal stem cells
17	bone and bones	bone	36	osteoblast	osteoblasts
18	calcium phosphate	calcium phosphates	37	nanocomposite	nanocomposites
19	drug delivery	drug delivery systems	38	surface property	surface properties

III. RESULTS AND DISCUSSION

3.1. Author Performance Analysis

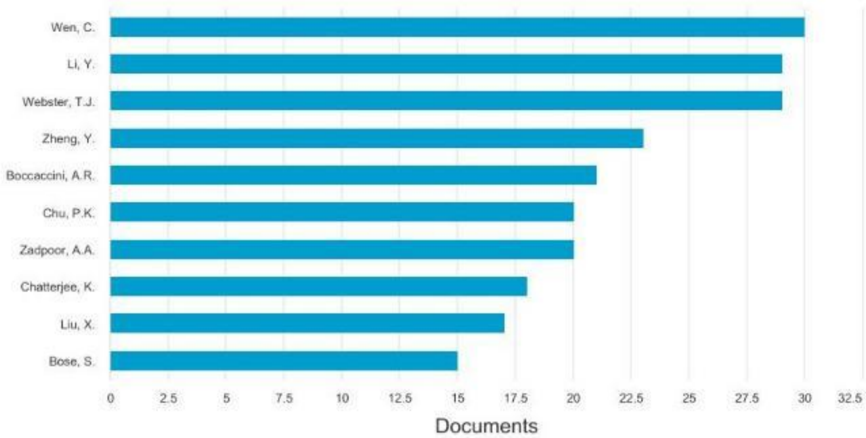

Fig 1. Total Publications by the Top 10 Authors

Figure 1 displays the total number of publications by the top 10 most prolific authors in the field of orthopaedic biomaterials from 2010 to 2025. Wen, C. is by far the outstanding novel author with this data set--about 30 publications. Li, Y. and Webster, T.J. around 29 publications. Zheng, Y. is at number four with well over 23 articles out- Boccaccini, A.R around 21 publications. Chu, P.K and Zadpoor, A.A both contributed almost 20 publications. All of the other authors- Chatterjee, K., Liu, X., Bose, S.-wrote around 15 to 20 papers.

The prominence of Wen, C., Li, Y., and Webster, T.J. indicates their major impact on shaping the structure of biomaterials research in orthopaedics. Their high article output shows not only that they are continuously active researchers but also the leading position taken by them as far ahead in promoting material innovation for orthopaedic applications, whether metallic biomaterials or ceramics, surface modifications is concerned. You may tell how solid Boccaccini, A.R. and Chu, P.K.'s work is in such areas as bioaetive glasses, nanomaterials, and biomaterial surface engineering. The diversity among the top authors, representing various regions and research groups, highlights the global and collaborative nature of this field. The inclusion of both established and emerging authors suggests a dynamic research environment conducive to innovation.

3.2. Country Performance Analysis

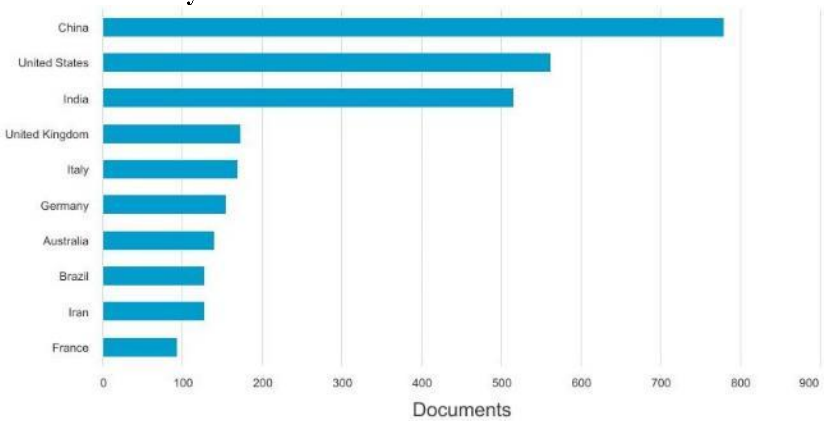

Fig 2. Number of documents produced by the top 10 countries/territories

Figure 2 illustrates the publication of the top 10 most prolific countries in the field of biomaterials for orthopaedics, 2010–2025. China is the top country by number of articles (about 780), followed by United States (about 560) and India (about 520). UK, Italy and Germany are the white area with 150-200 documents all in random order. Other countries like Australia, Brazil, Iran, and France provide between 80 and 150 papers each. The data also underlines the status of China, which has invested heavily in biomedical research as well as strategically in the area of orthopaedic biomaterials. The United States and India track closely, indicating that both developed economies as well as emerging ones are actively contributing in the progress of this front. The portrayal of the four European countries – UK, Italy, Germany, and France – underscores the region's well-established capabilities in medical device innovation and materials science. Submissions from Australia, Brazil, and Iran confirm the expanding international profile of biomaterials research, where the combined effect of global collaborative projects and the augmented global needs for health care are responsible of this trend. This geographical spread not only illustrates leadership in the region but also the global nature of research in managing orthopaedic problems.

3.3. Institutional Performance Analysis

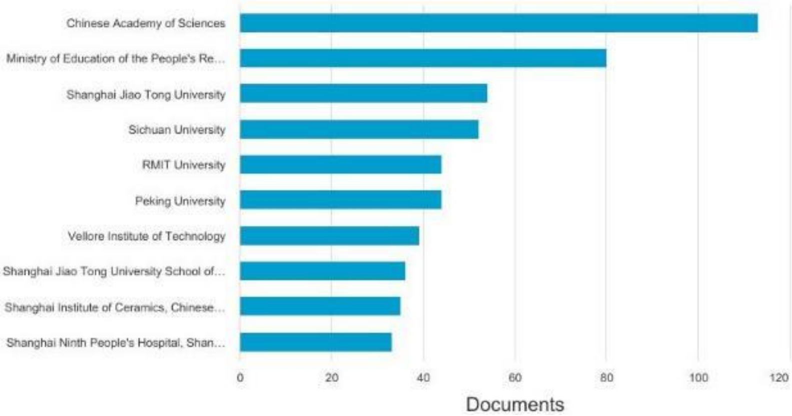

Fig 3. Number of documents produced by the top 10 institutions/organizations.

Figure 3 illustrates the institutional dissemination of biomaterials research in orthopaedics between 2010 and 2025. They are most significantly led by the Chinese Academy of Sciences, of over 110, followed by the Ministry of Education of the People's Republic of China, of around 80. Shanghai Jiao Tong University and Sichuan University also submit significant papers with the number of papers reaching to more than 50 for each one. The other main institutions are RMIT University, Peking University and Vellore Institute of Technology, which contribute around 40–45 per document. Some more contributors including Shanghai Jiao Tong University School of Medicine, Shanghai Institute of Ceramics and Shanghai Ninth People's Hospital, reveal cooperation of research activities within China, as well as the rising contribution of international institutes.

The dominance of Chinese institutions reflects strong leadership of the country in the field of biomaterial and orthopaedics research, supported by large national funding programs and a network of cooperation between universities, hospitals and research institutions. Organizations like the Chinese Academy of Sciences and Shanghai

Jiao Tong University are hubs of innovation, and this demonstrates the integration between basic science, materials engineering, and clinic. The presence of RMIT University (Australia) and Vellore Institute of Technology (India) confirms that significant work is also being done outside China, indicating worldwide dissemination of the expertise in orthopaedic biomaterials. This diversity of Chinese and international institutionsfurther suggests that, although China is the clear leader, the author set is highly collaborative and internationalized, with significant regional contributions to the advancement of science.

3.4. Document Type Distribution Analysis

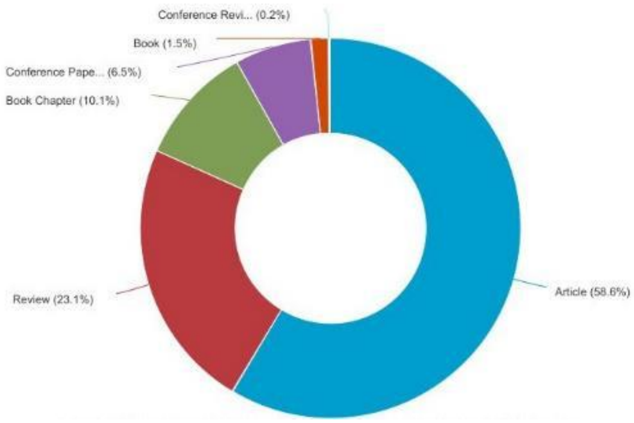

Fig 4. Distribution of Document Types

Distribution of document type published on biomaterials research in orthopaedics has been depicted in **Figure 4** between the year 2010 to 2025. The majority of records are articles (58.6%) followed by reviews (23.1%). We can observe book chapters are 10.1% and conference papers are 6.5%. A smaller number is made up of other types such as books (1.5%) and conference reviews (0.2%).

As a consequence of the emphasis in the field of orthopaedics on empirical studies, experimental progress, and new biomaterial applications, research articles are predominant in this domain. The significant percentage of literature review papers demonstrates a simultaneous attempt to collate, review, and evaluate existing evidences, as the latter are needed to pro-pel future endeavors and to consolidate the knowledge base within this rapidly changing area of research. And the inclusion of book chapters and conference papers reflects knowledges transmission in both academic and industry collaboration, which indicates an active contributions of scholarly communication and the interdisciplinary exchanges. This relatively low proportion of books and conference reviews is perhaps not surprising given the faster publishing schedule of that field, where journal articles and reviews are the dominant way in which research visibility and impact is achieved.

3.5. Evaluation of Subject Area Publication Patterns

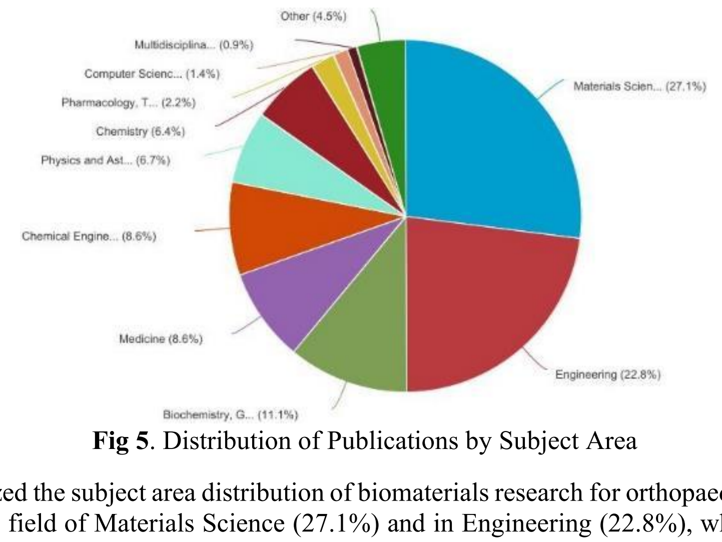

Fig 5. Distribution of Publications by Subject Area

Figure 5 summarized the subject area distribution of biomaterials research for orthopaedics from 2010 to 2025. Most papers are in the field of Materials Science (27.1%) and in Engineering (22.8%), which makes sense since the technology is the basis of the field. Biochemistry, Genetics and Molecular Biology (11.1%) and Medicine

(8.6%) also participate considerably in contrast to Chemical Engineering (8.6%). Physics and Astronomy (6.7%)Chemistry (6.4%)Pharmacology/ Toxicology (2.2%) Computer Science (1.4%) Multidisciplinary (0.9%) The remaining 4.5 percent fall into the other subject areas.

The dominance of Materials Science and Engineering demonstrates the significance of material design, mechanical properties and structural innovations in the development of orthopaedic biomaterials. The high percentage of representation of Biology and Molecular Biology reflects the interest in biological interfaces, as cellular response and tissue incorporation, important for clinical translation. Honours in Medicine and Chemical Engineering are also indicative of how the discipline is of an interdisciplinary nature, and relates the integration of clinical requirements with process engineering, and the large scale production of biomaterials. Contributions from Physics, Chemistry, and Pharmacology suggest the development of fundamental knowledge, material synthesis, and safety tests. The relatively low proportion of Computer Science is an indication that that the digital and computational strategies (modeling, AI, simulations) are still at emergent phase but may have a potential to expand.

3.6. Overview of the Leading 10 Journals

Table 2 Lists the Top Ten Productive Journals in Orthopedic Biomaterials

No	Name Journal	Publications	% of total publications (3322)
1	Acta Biomaterialia	133	4,00
2	Materials Science and Engineering C	118	3,55
3	Journal of the Mechanical Behavior of Biomedical Materials	78	2,35
4	Journal of Biomedical Materials Research Part A	57	1,72
5	Materials	55	1,66
6	International Journal of Molecular Sciences	49	1,48
7	Ceramics International	45	1,35
8	Journal of Materials Science Materials in Medicine	44	1,32
9	Journal of Biomedical Materials Research Part B Applied Biomaterials	41	1,23
10	ACS Applied Materials and Interfaces	39	1,17

The top 10 journals according to productivity in the field of orthopaedic biomaterials research during the period of 2010-2025 are shown in **Table 2**. Acta Biomaterialia is the first one in this list with 133 publications (4.00%), with Materials Science and Engineering C (118 publications; 3.55%) and the Journal of the Mechani- cal Behavior of Biomedical Materials (78 publications; 2.35%) the next two important entries. Also among the major publications are the Journal of Biomedical Materials Research Part A (57, 1.72%), Materials (55, 1.66%), and the International Journal of Molecular Sciences (49, 1.48%). Further contributions can also be found in Ceramics International (45, 1.35%), Journal of Materials Science: Materials in Medicine (44, 1.32%), Journal of Biomedical Materials Research Part B: Applied Biomaterials (41, 1.23%) and ACS Applied Materials & Interfaces (39, 1.17%).

The predominance of Acta Biomaterialia and Materials Science and Engineering C as core publication venues for biomaterials (and particularly for orthopaedic) research is emphasized. These journals are now well-established as leading vehicles for the communication of the most exciting research in material design, biomechanics, and clinical translation. Specialized journals including the Journal of the Mechanical Behavior of Biomedical Materials and the Journal of Biomedical Materials Research (A and B) clearly indicate the emphasis on both mechanical characterization and clinical relevance of biomaterials. On the other hand, such major interdisciplinary journals as Materials and International Journal of Molecular Sciences indicate a strong convergence of the field of materials science with molecular biology. The introduction of Ceramics International and ACS Applied Materials and Interfaces reflects the significant role that ceramics, composites and advanced material interfaces are playing in the innovation of orthopaedic biomaterials. Taken together, these journals form a well-balanced ecosystem of specialized and multidisciplinary publication venues.

3.7. Analysis of Research Trends

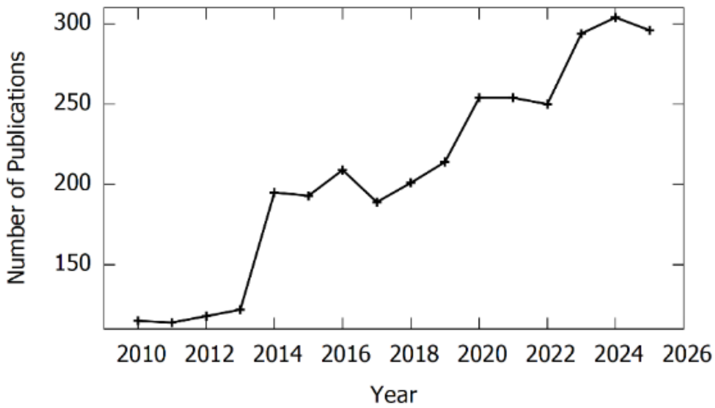

Fig 6. Annual Number of Publications

Figure 6 shows the annual output of the studies on biomaterials research in the field of orthopaedics during 2010-2025. The number of publications continued to rise slowly till 2013 and increased sharply in 2014 with nearly 190 articles. There had been fluctuations during 2015-2019 period, but since 2020 the field started to grow, and publications surpassed 250. The maximum was reached in 2024, with a little more than 300 papers, and a slight decrease in 2025.

The increasing number of publications over the past decade reflects the growing global interest and investment in biomaterials for orthopaedic use. The rapid increase after 2014, may be attributed to the fast development of advanced materials, such as bioactive ceramics, metallic alloys, and nanocomposites, as well as improved opportunity of finding and crosscutting projects. The acceleration starting in 2020 indicates that research about this topic is spreading and that some sources of momentum are being introduced, including in new areas of technological development such as additive manufacturing, tissue engineering and surface treatments. The little dip in 2025 is not a decrease, but likely a fluctuation due to data completeness or continued publishing later years.

3.8. Analysis of Network Visualization

The network visualization generated with VOSviewer provides an effective means of analyzing the relationships among concepts, keywords, and research collaborations [52], [53], [54], [55], [56]. **Figure 7** illustrates this visualization within the context of biomaterials applications in orthopaedics.

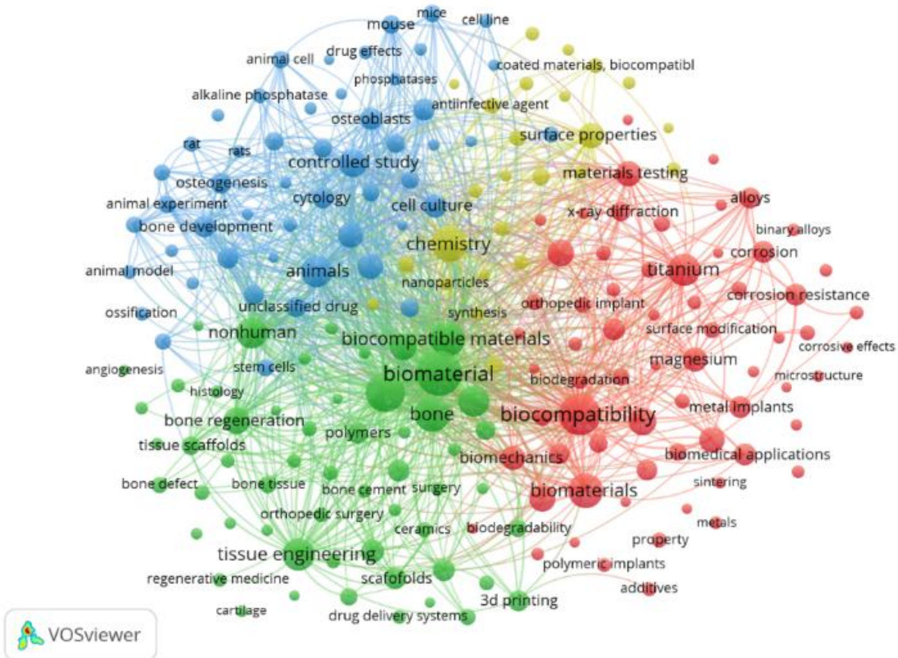

Fig 7. Network Visualization

The keyword co-occurrence network map in orthopaedic biomaterials research from 2010 to 2025 is shown in **Figure 7** created by VOSviewer. **Cluster 1** (red) is the study of biomaterials for orthopaedic and medical application. This cluster of 66 keyword terms includes, for instance: additives, alloys, aluminum alloys, apatite, binary alloys, bioactivity, biocompatibility, biodegradable implant, biodegradation, biological implants, biological materials, biological properties, biomaterials, biomechanics, biomedical applications, body fluids, calcium, chemical composition, chemical structure, clinical application.

Cluster 2 (green) is centered on bone-related biomaterials and tissue engineering approaches. This cluster of 56 keyword terms includes, for instance: 3D printing, angiogenesis, bioactive glass, bioceramics, biocompatible materials, biodegradability, biological activity, biomaterial, biomimetics, bone, bone cement, bone defect, bone graft, bone prosthesis, bone regeneration, bone remodeling, bone substitutes, bone tissue, bone tissue engineering, and calcium phosphates. **Cluster 3** (blue) focuses on cellular and animal-based studies in biomaterials research. This cluster of 51 keyword terms includes, for instance: alkaline phosphatase, animal cell, animal experiment, animal model, animal tissue, animals, bone development, cell adhesion, cell culture, cell differentiation, cell line, cell proliferation, cell survival, cell viability, cells, comparative study, contact angle, controlled study, cytology, and cytotoxicity. **Cluster 4** (yellow) emphasizes antibacterial agents, surface coatings, and nanomaterials in biomaterials research. This cluster of 25 keyword terms includes, for instance: anti-bacterial agents, antibacterial activity, antibacterial properties, antiinfective agent, bacteria, biocompatible coated materials, chemistry, coated materials, durapatite, Escherichia coli, Fourier transform infrared, infrared spectroscopy, microscopy, nanocomposites, nanomaterial, nanoparticles, nanostructures, particle size, prostheses and implants, and prostheses and orthoses. The frequency of keywords reflects the popularity of certain words in the research literature. **Table 3** shows the top five most common and least common keywords found in this study.

Table 3. Frequency distribution of five keywords: Highest and lowest occurrences

No	Keyword	Occurrences	No	Keyword	Occurrences
1	Biomaterial	1284	1	Biological Properties	76
2	Biocompatibility	1140	2	Dental Alloys	76
3	Humans	1021	3	Polycaprofactons	76
4	Chemistry	824	4	Ultrastructure	76
5	Bone	823	5	Simulated Body Fluids	77

As shown in **Table 3**, the keywords Biomaterial, Biocompatibility, Humans, Chemistry, and Bone demonstrate the highest occurrence values, indicating that these themes remain the central focus in orthopaedic biomaterials research. Conversely, the keywords Biological Properties, Dental Alloys, Polycaproactons, Ultrastructure, and Simulated Body Fluids show the lowest occurrence values, suggesting that these represent more specific or emerging areas of interest within the field. **Table 4** summarizes the extent to which these keywords are associated with other research themes, in this case both strong and weak associations.

Table 4. Total link strength of the five most and least frequent keywords

No	Keyword	Total link strength	No	Keyword	Total link strength
1	Biomaterial	25091	1	Bilogical Implants	1047
2	Humans	20254	2	Metallic Biomaterials	1055
3	Chemistry	19394	3	Wear Resistance	1131
4	Biocompatibility	19209	4	Microstructure	1147
5	Biocompatible Materials	17164	5	Dental Alloys	1149

Table 4 shows that the keywords Biomaterial, Humans, Chemistry, Biocompatibility, and Biocompatible Materials have the top five total link strength values over all keywords. This reflects their frequent association with other terms and their importance in orthopaedic biomaterials investigations. On the other hand, the top five values of total link strength stem from: Dental Alloys, Microstructure, Wear Resistance, Metallic Biomaterials, Biological Implants, indicating they are more specific, less connected and possess weaker conecctivity in the extant literature. These results are consistent with previous work on the importance of high versus low link strength values in research networks [57], [58].

3.9. Analysis of Overlay Visualization

The overlay visualization function in VOSviewer is a useful instrument to investigate the trend of research and the switching over of theme in a certain knowledge area. This visualization allows researchers to: "Trace the first appearance as well as rate of growth of keywords and research topics Detect the emergence of new trends and promising areas for future research, and Chart the historical development of research domains by marking the point when certain keywords appear to be gaining popularity [59]. Overlay visualization results of the analysis applied to our application biomaterials in orthopaedic research is shown in **Fig. 8**.

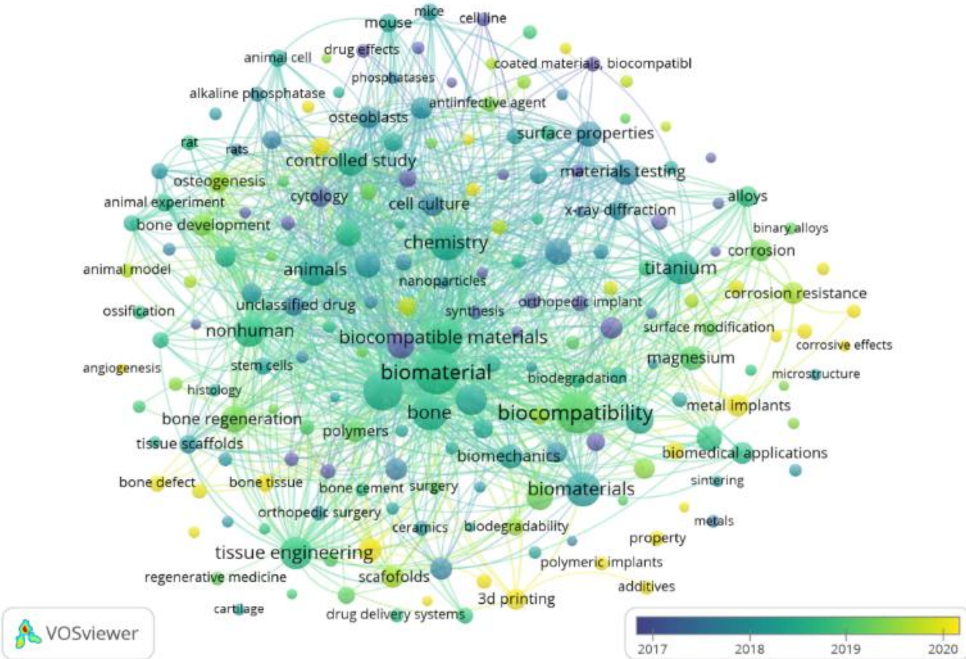

Fig 8. Overlay Visualization

Temporal pattern **Figure 8** shows the temporal pattern of research topics using color coding, with dark blue indicating the older research themes and bright yellow indicating the recent trends. We also observed from the visualization that the studies in the early time period (2017–2018) were dominated by foundational themes such as tissue scaffolds, orthopedic surgery, tissue. Calcium phosphates, bone subtitutes, bone pcosthesis, priority journal, unclassified drug, cytology, biological materials, orthopedic applications, orthopedic implant, synthesis, cells, cell adhesion, physiology, drug effects, cell survival, cell line, coated material, biocompatible, coatings, cell culture, hardness , which reflects reflect the direction of biomaterials research toward orthopedic applications, emphasizing the development of tissue scaffolds, bone substitutes, prostheses, and biocompatible coatings, while also addressing cellular interactions, drug effects, and the synthesis of biological materials for improved implant performance. Towards the mid-term period (2019), These keywords indicate that research in biomaterials is directed toward advancements in tissue engineering and regenerative medicine, with a strong focus on bone tissue engineering, bioceramics, and orthopedics, while also addressing critical aspects such as biodegradability, biocompatibility, osteogenesis, antibacterial and anti-infective agents, surface modification, corrosion resistance, and cell viability for improved clinical applications. The more recent publication trends (from 2020) are in yellow colour and focus on 3D printing, bone defect, bone tissue, tissue regeneration, hydrogels, wound healing, controlled drug delivery, scaffolds, polymeric implants, additives, property, biological implants, metal implants, osseointegration, orthopaedic, angiogenesis, alumunium alloys, morphology, antibacterial activity, drug effect, biocompatible coated material, corrosive effects, ternary alloys, zinc, corrosion rate, and corrosion resistant alloys . These indications are constituents of the new frontiers of orthopaedic biomaterials and represent a strong move towards the highperformance, biocompatible and clinically applicable biomaterials.

3.10. Analysis of Density Visualization

Density visualization is one of the graphical methods to show the concentration of item or keywords in a field or network [60]. This analytical procedure is a useful tool to: Detect topic clusters and their relationships, Analyse the trends and holes in the state of the art, Explore the conceptual density of the knowledge. Here in **Figure 9** is the density visualization of application biomaterials in orthopeadic keywords.

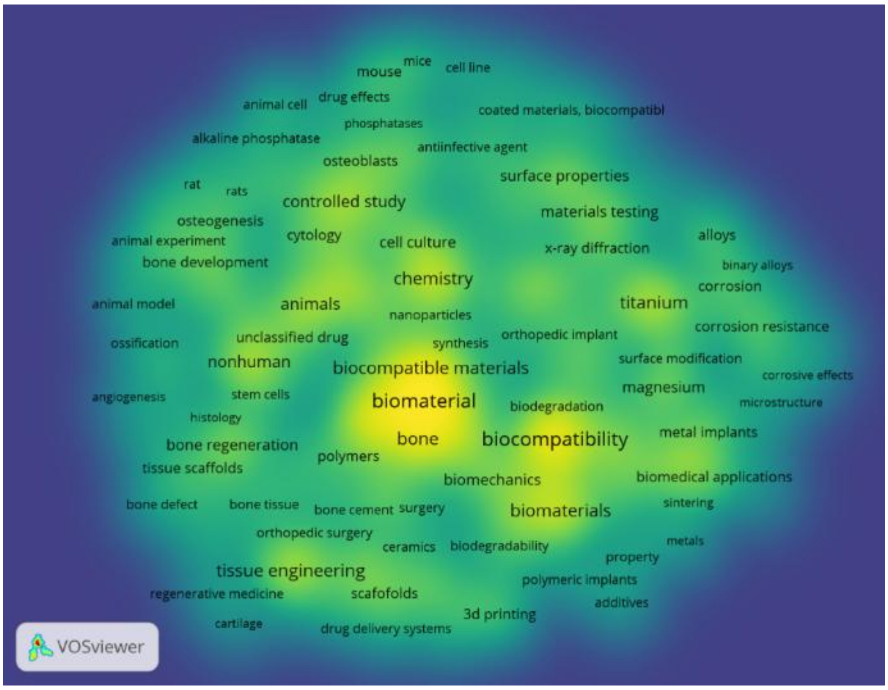

Fig 9. Density Visualization

The density visualization reveals distinct research concentrations, with high-density (bright-colored) clusters centered around keywords such as bimaterial, biocompatibility, bone, bicompatible materials, chemistry, biomaterials, titanium, tissue engineering, controlled study, and nonhuman, , indicating these domains represent the core focus of current biomaterials application in orthopaedic research. Conversely, low-density (dark-colored) areas correspond to terms including drug effects, phosphatases, coated materials biocompatibilities, antinfective agent, animal model, ossification, angiogenesis, bone deffect, cartilage, drug delivery systems, 3d printing, additives, polymeric implants, property, sintering, microstructure, corrosive effects, aloyys, corrosion, rats, alkaline phosphates, animal cell, mouse, mice, and cell line—suggesting these understudied areas may present novel research opportunities, knowledge gaps, and technical challenges for future investigations in biomaterials and orthopedic applications.

3.11. Synthesis of Findings

The interrelationship between the various analyses is evident. The high productivity of authors like Wen, C. and Webster, T.J. is supported by leading institutions, primarily in China and the US, which also dominate the country-level output. The predominant document types (articles and reviews) and subject areas (Materials Science, Engineering) reflect the field's applied and interdisciplinary nature. The journal analysis confirms that the primary outlets for this work are high-impact, specialized publications. The keyword and visualization analyses (Figures 7-9) directly map onto these productivity metrics, revealing that the core research themes—biocompatibility, tissue engineering, and 3D printing—are driven by the most active authors, countries, and institutions. The identified trends and gaps, such as the growing focus on antibacterial nanomaterials and the underexplored potential of drug delivery systems, provide a clear agenda for the global research community highlighted in the performance analyses.

IV. CONCLUSION

This bibliometric analysis provides a comprehensive overview of global research trends in orthopaedic biomaterials from 2010 to 2025. The study reveals a significant and growing body of literature, driven largely by contributions from China, the United States, and India, with strong participation from European nations. The field is characterized by its multidisciplinary nature, integrating materials science, engineering, biology, and medicine.

The analysis identified four prominent research clusters: 1) medical applications and biocompatibility, 2) bone tissue engineering and regenerative strategies, 3) cellular and animal studies, and 4) antibacterial nanomaterials and coatings. The evolution of research themes, tracked through overlay visualization, shows a clear progression from foundational studies on biomaterials and implants toward advanced areas like 3D printing, personalized implants, and multifunctional systems incorporating drug delivery and enhanced corrosion resistance.

Despite the considerable progress, several knowledge gaps remain. Topics such as controlled drug delivery systems, angiogenesis, and detailed corrosion mechanisms appear underexplored, presenting valuable opportunities for future investigation. The density visualization further highlights areas with lower research concentration, suggesting potential for innovation in computational modeling, advanced composite materials, and long-term clinical performance studies.

This study has limitations inherent to bibliometric methods, including reliance on a single database (Scopus) and the focus on specific document types and keywords, which may exclude some relevant publications. Nevertheless, the findings offer a strategic reference for researchers, clinicians, and policymakers. By outlining the current landscape and emerging frontiers, this analysis can help guide resource allocation, foster international collaboration, and accelerate the development of sustainable, effective, and accessible orthopaedic solutions to improve global musculoskeletal health.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

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