

Scientometric Analysis of Artificial Intelligence Applications in Orthopedic Surgery: Global Research Trends and Emerging Hotspots

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Abstract

Background: The integration of Artificial Intelligence (AI) into orthopedic surgery has rapidly evolved, providing transformative opportunities to improve surgical precision, decision-making, and patient outcomes. In spite of the increase in related publications, a thorough scientometric analysis in this field has not yet been performed. Therefore, this study aims to systematically explore the global research trajectory, collaborative networks, influential journals and publications, as well as evolving hotspots in the application of AI to orthopedic surgery using a scientometric method.

Methods: A comprehensive literature search was conducted in the Web of Science Core Collection (WoSCC) on March 22, 2025 to include all relevant articles and reviews. VOSviewer and CiteSpace were used to visualize international collaborations, core institutions and journals, co-citation networks, keyword clusters, and citation bursts.

Results: A total of 991 publications were retrieved, showing an exponential growth since 2018. The United States emerged as the leading contributor, with Harvard University and the Journal of Arthroplasty being the most productive institution and journal, respectively. Influential authors like Schwab JH and Karhad AV have greatly influenced the field. Keyword and co-citation analyses revealed that the application of prediction models, machine and deep learning in orthopedic surgery such as total knee arthroplasty and spine surgery are the knowledge base, while emerging hotspots include intelligent surgical planning, precise prognosis prediction systems, AI-assisted perioperative management and decision support, specialized applications of large language models, algorithm optimization and verification standards.

Conclusion: AI applications in orthopedic surgery are rapidly growing interdisciplinary field led by leading U.S. institutions and journals. Future research is expected to concentrate on improving algorithm interpretability, clinical integration, and global accessibility, leading to precision and intelligent orthopedic treatment and management.

1. Introduction

In orthopedic surgery, there is an escalating requirement for greater precision in operations and the implementation of minimally invasive procedures, as conventional orthopedic techniques increasingly do not meet the elevated standards for superior surgical

performance [1, 2]. Orthopedic surgery is still dealing with several issues, including a lack of precision in surgeries, various complications after operations, and extended recovery times [3, 4].

In recent years, there have been notable progressions in Artificial Intelligence (AI) technologies, particularly in medical applications, demonstrating significant potential in orthopedic surgery [5]. AI technologies, including Machine Learning (ML) and deep learning, have been extensively incorporated into different stages of surgery, from preoperative planning and intraoperative navigation to postoperative rehabilitation assessment and outcome prediction, thereby substantially improving surgical precision, safety, and patient outcomes [6-8]. For instance, automated image segmentation using computer vision improves surgeons' precision in identifying bone structures, and predictive models help assess the risk of postoperative complications and optimize clinical decision-making [9, 10]. Additionally, combining AI algorithms with Robot-Assisted Surgery (RAS) has greatly advanced the precision and reproducibility of joint replacement procedures and spinal surgeries [11-13].

Scientometric analysis enables the identification of characteristics—including countries, institutions, journals, authors, and keywords—across published literature. This approach allows researchers to assess the current state and emerging trends within a specific research or disease field, thereby guiding future studies [14, 15]. As core tools for bibliometric analysis, CiteSpace and VOSviewer, with their powerful data parsing capabilities, can dynamically monitor the evolution trajectory of knowledge through multi-dimensional visualization forms such as co-occurrence networks and clustering graphs, helping researchers quickly obtain relevant information [16, 17]. Choi J et al. [18] provided the knowledge maps created by VOSviewer to help visualize the quantity and span of surgical literature, identify authors and institutions that can help provide expert advice, and illustrate new trends in surgical research. Ke L et al.[15] analyzed the research on drug-induced liver injury (DILI), reporting that the definition of DILI, the incidence rate or clinical characteristics, the etiology or pathogenesis, the differentiation of major drugs, and the evaluation of causal relationships are the knowledge basis of DILI-related research. Zhong S et al.[19] reported that the future research trend of AI in the field of fractures is the development of algorithms and fracture prevention.

Despite the rapid expansion of AI applications in orthopedic surgery research, there is no bibliometric study systematically to analyze the research hotspots, knowledge structure, and developmental trends within this field. Traditional reviews concentrate on technical details or clinical cases, offering limited landscape of research collaboration networks, knowledge base and future directions. Consequently, this study aims to comprehensively analyze both the global research trends and emerging hotspots concerning AI applications in orthopedic surgery through scientometric investigation.

2. Methods

2.1. Data Source and Search Strategy

On March 22, 2025, we performed a comprehensive literature search via the Web of Science Core Collection (WoSCC) at the University of Groningen to identify AI studies related to the field of orthopedic surgery, from inception to March 22, 2025. The database source was limited to Science Citation Index Expanded (SCIE) and publication types to "article" or "review". The search strategy was composed of two main components. In the first row (#1), the main search terms were "artificial intelligence", "AI", "deep learning", "machine learning", etc. In the second row (#2), the queried keywords were "orthopedic surgery", "musculoskeletal surgery", "joint replacement", "spine surgery", etc. The final dataset was #1 AND #2 and detailed search strategy is available in the Supplementary Material. For the accuracy of data, all relevant records were downloaded from the WoSCC on March 22, 2025, and analyzed by bibliometric software

Search strategy

(TS=("deep learning") OR TS=("machine learning") OR TS=("artificial intelligence") OR TS=("AI") OR TS=("neural network")) AND (TS=("orthopedic surgery") OR TS=("orthopaedic surgery") OR TS=("musculoskeletal surgery") OR TS=("joint replacement") OR TS=("spine surgery") OR TS=("fracture fixation") OR TS=("arthroscopy") OR TS=("bone graft") OR TS=("knee arthroplasty") OR TS=("hip replacement") OR TS=("spinal fusion"))

2.2. Data Analysis

All pertinent records were retrieved in various text formats, including abstracts, publication countries, author affiliations, journals, citation relationships, references, and other relevant metadata. A thorough analysis was carried out to generate ranking lists and perform statistical assessments for countries, institutions, authors, journals, keywords, and references using Microsoft Excel 2023. Data visualization, including the distribution patterns and relationships among the data, was performed with R software (v 4.4.3, <https://www.r-project.org/>). Bibliometric maps depicting the density and clustering of institutions, authors, and journals were created using VOSviewer software (v 1.6.20, Leiden University), providing a clear view of node relationships and their respective strengths [20]. Furthermore, CiteSpace (v 6.4.R1 (64-bit), developed by Chen C at Drexel University) was employed to examine emerging trends in keywords and references, with a focus on citation bursts and the interconnections between cited and co-cited journals [21]. To ensure the relevance of the trends, only data from the last decade were considered when analyzing bursts in references and keywords. The CiteSpace parameters were configured as follows: the link retention factor was set to 3 (LRF = 3), the top N value was set to 1 ($e = 2$), and the analysis covered the period from 1996 to March 22, 2025, with each time slice spanning one year. The look-back years were defined as -1 (LBY = -1), link strength was calculated using cosine similarity within slices, and the selection criteria were based on the g-index, with a threshold set to 25 ($k = 25$). The minimum burst duration was specified as 1 year (MD = 1).

3. Results

3.1. Trend of Annual Publication Growth

We systematically identified 991 studies published between 1996 and March 22, 2025 after removing duplication, comprising 826 publications and 165 reviews. The annual publication count serves as an indicator of overarching trends within this field. As 2025 is not over yet, the publication count for this year cannot accurately reflect the complete scholarly output, therefore our analysis was confined to publications from 1996 to 2024. (Figure 1) demonstrates that publication numbers remained relatively low from 1996 to 2017. However, there was a marked upward trend in annual research output related to AI applications in orthopedic surgery from 2018 to 2024, indicating increased academic interest in this domain during this period, with 2024 representing the peak year for publications. These findings clearly underscore the considerable potential of AI applications in orthopedic surgery, and the current research momentum is likely to continue in the foreseeable future.

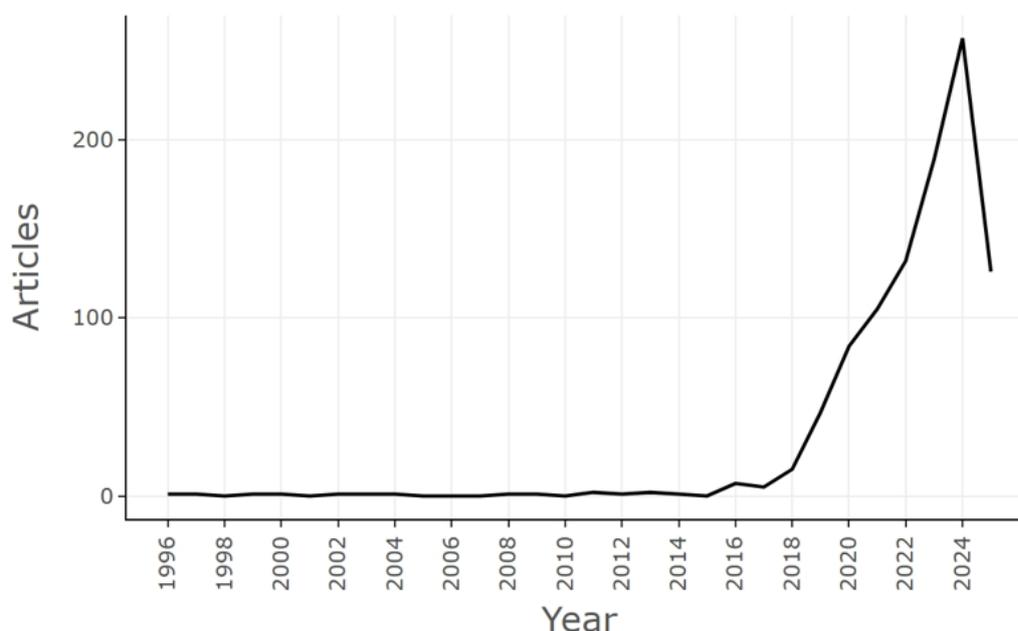


Figure 1: Annual Output Of AI Applications In Orthopedic Surgery Research

3.2. Countries/Regions and Institutions Analysis

We utilized VOSviewer to conduct the network of countries/regions and institutions. A total of 991 publications were published by 1,350 institutions across 66 countries/regions. The top 10 countries/regions and institutions by publication number are listed in (Table 1). The top 10 countries/regions are distributed across four continents, with half located in Europe (Figure 2A). Eight

countries/regions have fewer than 100 publications: United Kingdom (n=59), Germany (n=46), South Korea (n=43), Australia (n=43), Italy (n=40), Canada (n=38), Switzerland (n=35), and Netherlands (n=33). The United States contributed the most publications (n=437), followed by China (n=136) (Table 1). In (Figure 2B), countries/regions with more than 5 publications (T=5) were included to construct the network map. In this network visualization, node size corresponds to publication volume, while connecting lines represent international collaborations, with thicker lines indicating stronger collaborative relationships. The United States has the largest node, reflecting its leading publication output. Numerous active collaborations exist among countries/regions. For example, the U.S. maintains close partnerships with China, Germany, Netherlands, and the UK, while Germany collaborates with China, Switzerland, and Australia, etc. China has the second largest number of nodes, but it is still smaller than the United States, which ranks first. This indicates that China publishes fewer publications than the United States. Connections of China with other countries are also relatively small and thin, indicating that there is less cooperations between China and other countries. Among the top 10 institutions, nine are based in the U.S. and one in Switzerland. Two institutions have published over 50 publications: Harvard University (n=79) and Hospital for Special Surgery (n=59). Other institutions have fewer than 33 publications (Mayo Clinic: n=33) (Table 1). (Figure 3) presents the co-authorship network of institutions with ≥5 publications (T=5), displaying the largest connected subnetwork. In this visualization, each node represents one institution, with color indicating different clusters and size reflecting publication number. Harvard University, Hospital for Special Surgery, and Mayo Clinic appear as larger nodes due to their substantial research output. Active institutional collaborations are evident. For example, Massachusetts General Hospital has strong cooperations with Harvard University, Cleveland Clinic, and Rush University, etc.

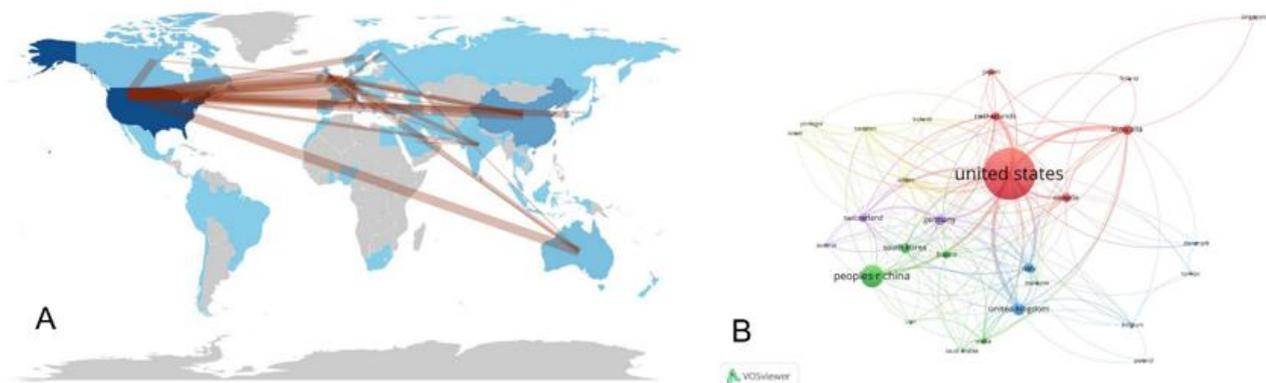


Figure 2: The regional distribution (A) and the network map of countries/regions (B, T = 5) related to AI applications in orthopedic surgery research

Table 1: The top 10 countries/regions and institutions involved to AI applications in orthopedic surgery research

Rank	Country/Region	Count	Institution	Count
1	United states (North America)	437	Harvard University	79
2	Peoples r china (Asia)	136	Hospital for Special Surgery	59
3	United kingdom (Europe)	59	Mayo Clinic	33
4	Germany (Europe)	46	Rush University	21
5	South korea (Asia)	43	Cleveland Clinic	18
6	Australia (Oceania)	43	Stanford University	18
7	Italy (Europe)	40	Massachusetts General Hospital	17
8	Canada (North America)	38	Icahn School of Medicine at Mount Sinai	16
9	Switzerland(Europe)	35	The Johns Hopkins University	16
10	Netherlands(Europe)	33	University of Zurich	16

4	Spine Journal (United States)	25	4.7	Q1
5	World Neurosurgery (United States)	22	2.1	Q2
6	Journal of Clinical Medicine (Switzerland)	17	2.9	Q1
7	Global Spine Journal (United States)	15	3	Q1
8	Archives of Orthopaedic and Trauma Surgery (Germany)	13	2.1	Q1
9	Neurosurgery (United States)	12	3.9	Q1
10	Journal of Bone and Joint Surgery-American Volume (United States)	12	4.3	Q1
11	BMC Musculoskeletal Disorders (United kingdom)	12	2.4	Q2
12	European Spine Journal (Germany)	12	2.7	Q1

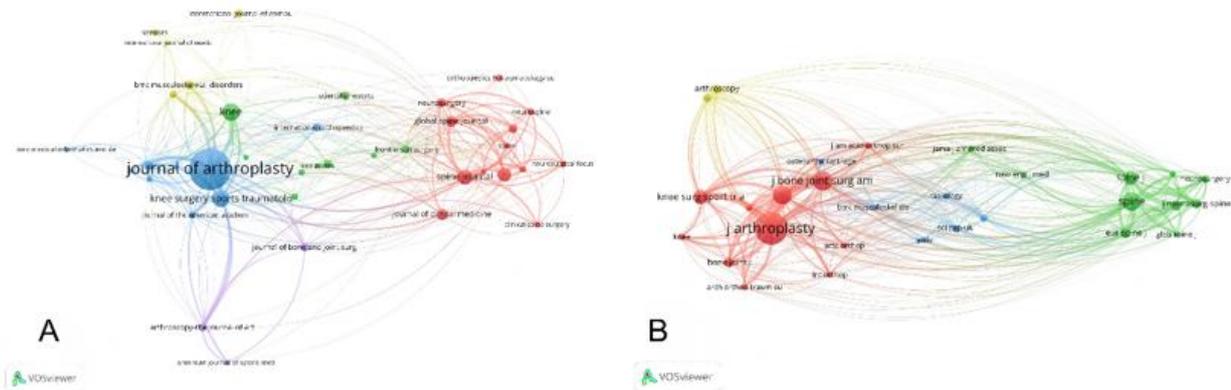


Figure 4: The network map of academic journals (A, T = 5) and co-cited academic journals (B, T=200) for AI applications in orthopedic surgery research

Table 3: The top 10 co-cited journals of AI applications in orthopedic surgery research

Rank	Co-cited Journal	Co-citation	IF2024	JCR
1	Journal of Arthroplasty (United States)	2155	3.8	Q1
2	Journal of Bone and Joint Surgery-American Volume (United States)	1042	4.3	Q1
3	Clinical Orthopaedics and Related Research (United States)	1005	4.4	Q1
4	Spine (United States)	1000	3.5	Q1
5	Knee Surgery Sports Traumatology Arthroscopy (Germany)	695	5	Q1
6	Spine Journal (United States)	637	4.7	Q1
7	European Spine Journal (Germany)	443	2.7	Q1
8	World Neurosurgery (United States)	410	2.1	Q2
9	Journal of Neurosurgery: Spine (United States)	399	3.1	Q1
10	The Bone & Joint Journal (United kingdom)	393	4.6	Q1

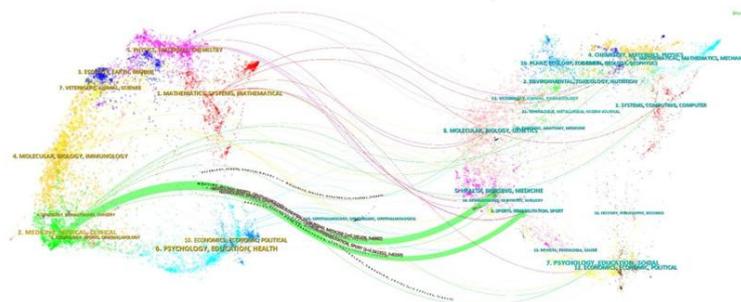


Figure 5: The dual-map overlay of journals related to AI applications in orthopedic surgery research

3.4. Authors and Co-Cited Authors

A total of 5,762 authors contributed to research on AI applications in orthopedic surgery. Among them, two authors published more than 20 publications: Schwab JH ranked first with the highest number of publications (n=28), followed by Kwon YM (n=23) (Table 4). The co-authorship network was constructed using authors with more than 5 publications (T=5), with the largest subnetwork shown in (Figure 6A). In this visualization, each node symbolizes an author, with the node color indicating the author's active period and node size corresponding to publication count (a larger size indicates a greater number of publications). Connecting lines represent collaborative relationships, where a higher number of connections correlates with increased research recognition. Schwab JH and Kwon YM appear as larger nodes due to their substantial publication output. Notably, Schwab JH shows the most connections with other authors, indicating particularly high recognition of his research. The more intense node color for Schwab JH, Ramkumar PN, Haerberle HS, and Bono CM represents their early-stage research involvement in AI applications within orthopedic surgery. In contrast, the lighter node coloration associated with Klemt C, Buddhiraju A, and Kwon YM indicates their more recent entry into this research area. Regarding co-cited authors (authors cited together in publications), among 21,277 co-cited authors, five were co-cited over 100 times. Karhade AV (n=255 co-citations), Ramkumar PN (n=182), Kunze KN (n=168), Collins GS (n=104), Klemt C (n=101) (Table 4). Other top authors had co-citation counts ranging from 42 to 87. The co-citation network (T=30) identifies Karhade AV as the most prominent node, representing the highest number of co-citations. Active co-citation relationships were observed among Karhade AV and Shah AA, Kunze KN, Ogink PT, etc. There were also strong co-citation connections among Kunze KN and Nwachukwu BU, Ramkumar PN, Lu YN, etc (Figure 6B).

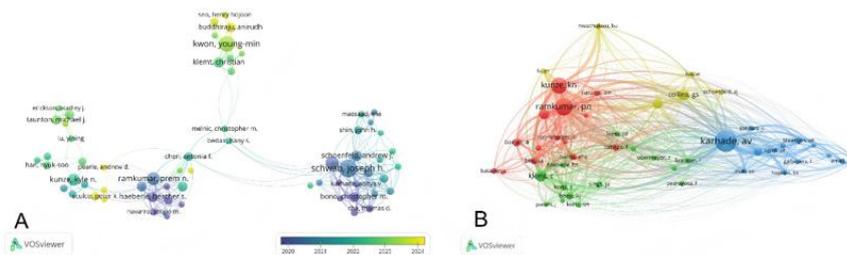


Figure 6: The network map of authors (A, T = 5) and co-cited authors (B, T = 30) related to AI applications in orthopedic surgery research

Table 4: The top 12 authors and co-cited authors of AI applications in orthopedic surgery research

Rank	Author	Count	Co-cited author	Co-citation
1	Schwab JH	28	Karhade AV	255
2	Kwon YM	23	Ramkumar PN	182
3	Karhade AV	17	Kunze KN	168
4	Ramkumar PN	17	Collins GS	104
5	Kunze KN	15	Klemt C	101
6	Schoenfeld AJ	12	Karnuta JM	87
7	Haerberle HS	12	Steyerberg EW	85
8	Klemt C	12	Kim JS	63
9	Bono CM	11	Borjali A	62
10	Karnuta JM	11	Harris AHS	54
11	Mont MA	11	Staatjes VE	54
12	Buddhiraju A	11	Bozic KJ	54

3.5. Co-Cited References

Co-cited references refer to those cited together with other publications [15]. Among 991 publications related to the application of AI in orthopedic surgeries, there were 33,000 co-cited references. We have listed the top 10 co-cited references in (Table 5). Each www.annalsofglobalpublishinggroup.com

reference was co-cited at least 34 times. Collins GS et al. [22] published a study entitled "Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): the TRIPOD statement". This publication has the most co-citations (n = 72) and ranks first, followed by Kurtz S et al.[23] in Journal of Bone and Joint Surgery-American Volume (2007,n = 45), and Fontana MA et al.[24] in Clinical Orthopaedics and Related Research (2019, n = 42), Ronneberger O et al.[25] in Lecture Notes in Computer Science (2015, n = 42), Kim JS et al.[26] in Spine (2018, n = 41). The remaining 5 literatures were co-cited 34 to 38 times. The co-citation network was constructed using references with co-citation numbers greater than or equal to 20. "Collins GS et al., 2015, Annals of Internal Medicine [22]" with the largest size shows active co-cited relationships with "Luo W et al., 2016, Journal of Medical Internet Research[27]", "Stekhoven DJ et al., 2012, Bioinformatics [28] ", etc. Several references, such as "Kurtz S et al., 2007, Journal of Bone and Joint Surgery-American Volume [23]", "Fontana MA et al., 2019, Clinical Orthopaedics and Related Research [24]", "Ronneberger O et al., 2015, Lecture Notes in Computer Science [25]", "Bini SA et al., 2018, Journal of Arthroplasty [29]", were also simultaneously co-cited actively in other publications.

Table 5: The top 10 co-cited references related to AI applications in orthopedic surgery research

Rank	Co-cited references	Citations
1	Collins GS, 2015, Ann Intern Med, V162, P55	72
2	Kurtz S, 2007, J Bone Joint Surg Am, V89A, P780	45
3	Fontana MA, 2019, Clin Orthop Relat Res, V477, P1267	42
4	Ronneberger O, 2015, Lect Notes Comput Sci, V9351, P234	42
5	Kim JS, 2018, Spine, V43, P853	41
6	Cabitz F, 2018,Front Bioeng Biotechnol, V6	38
7	Navarro SM, 2018, J Arthroplasty, V33, P3617	37
8	Bini SA, 2018, J Arthroplasty, V33, P2358	36
9	Pedregosa F, 2011, J Mach Learn Res, V12, P2825	35
10	Luo W, 2016, J Med Internet Res, V18	34

3.6. References with Citation Burstness

Citation burst refers to the instances where certain references receive concentrated attentions from scholars within a specific research field during a defined time period [30]. In (Figure 7), "Year" indicates the publication year of the reference, "Begin" and "End" represent the start and end years when the reference became a research hotspot, while "Strength" denotes the burst intensity. The red line segments signify citation burst periods, and light blue indicates that the reference had not yet attracted attentions, while dark blue marks its emergence into the research landscape. Among the top 25 references with the strongest burstness, the highest burst intensity (n=7.95) was observed for the publication titled "Towards better clinical prediction models: seven steps for development and an ABCD for validation" by Steyerberg EW et al.[31], which exhibited a citation burst from 2019 to 2022. The references with the longest-lasting citation bursts were: "Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD): the TRIPOD statement" by Collins GS et al.[22] (2015, Annals of Internal Medicine) (n = 5.2) and "Machine Learning in Medicine" by Deo RC et al. [32](2015, Circulation) (n = 4.53). Notably, six references have shown citation bursts starting from 2023 and are still on-going, including "Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030" by Kurtz S et al.[23] (2007, Journal of Bone and Joint Surgery); "A Unified Approach to Interpreting Model Predictions" by Lundberg SM et al.[33] (2017); "Machine Learning Model Developed to Aid in Patient Selection for Outpatient Total Joint Arthroplasty" by Lopez CD et al. [34](2021, Arthroplasty Today); "Machine learning algorithms predict extended postoperative opioid use in primary total knee arthroplasty" by Klemm C et al. [35] (2022, Knee Surgery Sports Traumatology Arthroscopy); "Performance of ChatGPT on USMLE: Potential for AI-assisted medical education using large language models" by Kung TH et al. [36](2023, PLOS Digital Health); and "What Is the Accuracy of Three Different Machine Learning Techniques to Predict Clinical Outcomes After Shoulder Arthroplasty?" by Kumar V et al.[37] (2020, Clinical Orthopaedics and Related Research).

Top 25 References with the Strongest Citation Bursts



Figure 7: Top 25 References With Strong Citation Burstiness.

3.7. Keywords Network, and Temporal Evolution Analysis

High-frequency keywords in academic publications can effectively assist researchers in identifying and determining research directions within specific fields. They can reflect the existing knowledge base and inform the developmental trajectory of scholarly domains [38]. The Keyword co-occurrence network was constructed by using VOSviewer. (Figure 8A). In this network, each node represents a keyword, with node colors indicating distinct clusters (each corresponding to a specific research theme) and node sizes reflecting keyword frequency where larger nodes denote higher frequency. The connecting lines between nodes represent the strength of relationships between keywords. The most frequent keywords were machine learning, followed by total knee arthroplasty, outcomes, deep learning, spine surgery, surgery, classification, arthroplasty, and osteoarthritis. In (Figure 8B), colors denote the average publication year of keywords: early-appearing keywords (e.g., machine learning, deep learning) are marked in blue, while recently emerged keywords (e.g., revision, alignment) are highlighted in yellow. Keyword clustering reveals the structural framework of interconnected research fields. (Figure 9A) displays 11 distinct clusters generated: #0 patient question, #1 predictive model, #2 spine surgery, #3 near-infrared spectroscopy, #4 total knee arthroplasty, #5 ethical consideration, #6 artificial intelligence, #7 knee rehabilitation, #8 hip osteoarthritis, #11 failed rotator cuff repair, #12 spinal fusion, Each color represents a keyword cluster, with nodes denoting keywords and lines indicating co-occurrence relationships. Overlapping color zones reflect shared keywords across clusters. The timeline view (Figure 9B), generated using CiteSpace, visualizes temporal trends in research hotspots. The purple bar at the top marks the timeline (1996–2025). Nodes represent keyword clusters, where larger size indicates higher co-occurrence frequency, and colors (mapped to the scale) show citation bursts in specific years. This visualization clarifies the historical trajectory of the field and temporal relationships among research themes.

Table 6: Most Frequent Words

Rank	Keywords	Occurrences	Total link strength
1	Machine Learning	330	2,027
2	Artificial Intelligence	256	1,542
3	Total Knee Arthroplasty	168	915
4	Deep Learning	115	655
5	Outcomes	102	657
6	Spine Surgery	101	664
7	Surgery	81	534

8	Complications	67	485
9	Replacement	67	412
10	Classification	65	436

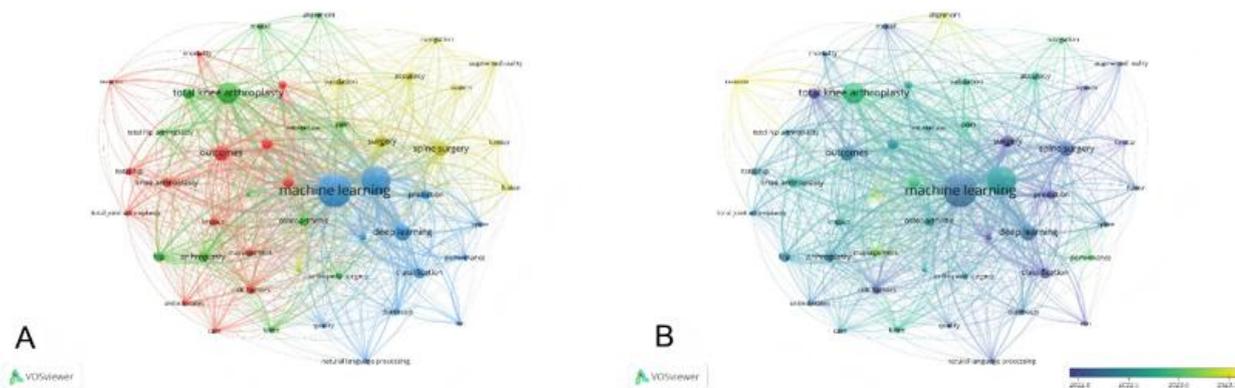


Figure 8: Keyword Co-Occurrence Network Graph Of AI Applications In Orthopedic Surgery Research

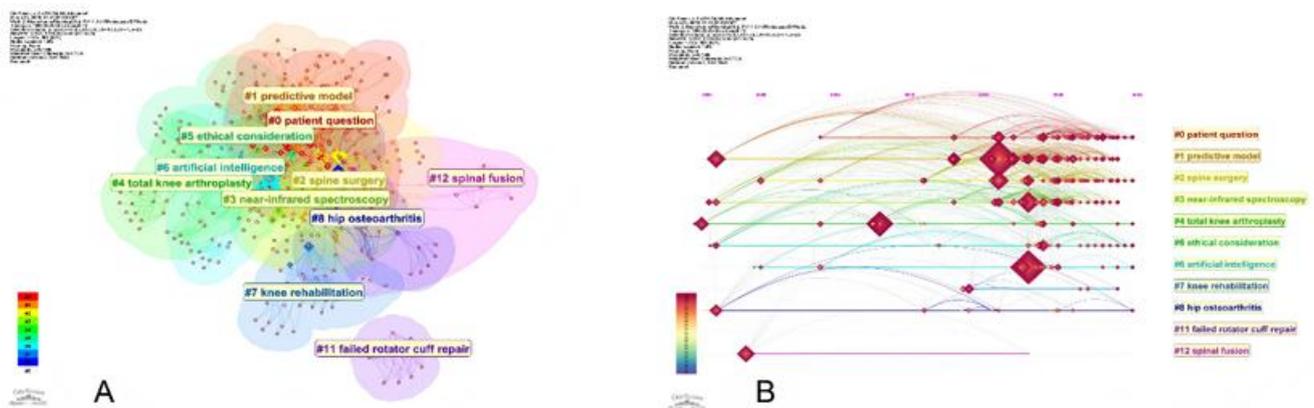


Figure 9: Keyword clustering map (A) and the timeline view of keyword clustering (B) related to AI applications in orthopedic surgery research

4. Discussion

4.1. General Information

Based on SCIE data from the WoSCC spanning 1996 to March 22, 2025, this scientometric analysis investigated the current research landscape, developmental trends, and emerging hotspots in the application of AI in orthopedic surgery. The study encompasses 991 publications authored by researchers from 1,350 institutions across 66 countries/regions, with 33,000 co-cited references. From 1996 to 2017, publication output in this field remained relatively low, likely due to the limited recognition of AI's potential benefits among researchers. Additionally, the initial state of computer science technology at the time may impede broader adoption of AI in orthopedic surgery research. However, from 2018 to 2024, there has been a consistent increase in annual publications concerning AI applications in orthopedic surgery. This growth likely reflects concurrent advancements in computer science and the demonstrated efficacy of AI in resolving complex clinical challenges. This trend suggests a heightened research focus on AI in orthopedic surgery in recent years. Notably, the majority of the top 10 most prolific countries in this field are developed economies, suggesting a strong correlation between research output and economic development. The United States led with 437 publications, significantly outpacing other countries (China: 136 publications; UK: 59 publications). Prominent American institutions, including Harvard University (79 publications) and the Hospital for Special Surgery (59 publications), occupied nine of the top ten positions in global institutional rankings, highlighting the United States' substantial academic influence and concentration of resources in this domain. Although several European countries including UK, Germany, Italy, etc., were represented on the list, none of them

exceeded 100 publications, thereby necessitating cross-border collaborations (e.g., among Germany, Switzerland, Netherlands) to amplify their impacts. China, while ranking second in publication output (136 publications), did not have any institution in the top 10 list, which may indicate underdeveloped domestic collaboration or international networks. Notably, only 2 out of 66 countries produced more than 100 publications, and just 2 out of 1,350 institutions exceeded 50 publications, illustrating a pronounced concentration of research output among a limited number of developed nations and elite institutions. This underscores potential barriers to participation faced by developing countries (e.g., funding, technology gaps) and suggests that predominant productive nations could enhance their influence by strengthening collaborations with other countries while simultaneously developing their domestic core institutions. Developing countries can integrate into global AI research by enhancing their capabilities, accessing open resources, and collaborating internationally. Disparities can also be minimized through funding support, shared datasets, and inclusive policies. Among 284 journals, five journals (1.8%) published 211 publications (21.3% of 991), with Journal of Arthroplasty alone contributing 104 publications (10.5% of 991), indicating a significant concentration of research in this field. Four American journals exceeded 1,000 co-citations (e.g., The Journal of Arthroplasty, co-cited 2,155 times). This confirms their dual functions as favored platforms for publishing and also centers of knowledge, likely attributed to high impact factors and JCR Q1 status, which attracts high-quality research. The dominance of the U.S. about AI application in orthopedic surgery research was evident in the alignment between top-productive and highly co-cited journals and its leading position in the country and institution analyses. Researchers can prioritize frequently co-cited journals for literature search and target productive journals for submitting their manuscripts. The journal network map also offers essential guidance for new researchers in the field. Among the authors, Schwab JH published the majority of the studies, while Karhade AV was the most frequently co-cited author. Furthermore, we identified five authors—Karhade AV, Ramkumar PN, Kunze KN, Klemm C, and Karnuta JM—who not only ranked among the top 10 most prolific authors but also appeared in the top 10 most co-cited authors, indicating their significant contributions to the field. Tracking their latest developments may provide cutting-edge insights in this area.

4.2. Knowledge Base

Co-cited references refer to the phenomenon where two or more references are cited by other references simultaneously. This relationship reveals the thematic relevance among the references and is often used to identify the knowledge base of the research field [21]. The most co-cited references was authored by Collins GS et al. in *Annals of Internal Medicine* in 2015, which established a standardized framework for the development, validation, and reporting of clinical prediction models [22]. The second most frequently co-cited paper was published by Kurtz S et al. in *Journal of Bone and Joint Surgery-American Volume*. By using poisson regression modeling, it predicted the growth trend of hip and knee replacement surgeries in the United States from 2005 to 2030 and remains one of the most influential works in the field of joint replacement surgery [23]. This study highlights the combination between AI and traditional clinical research, especially in key topics in orthopedic surgery such as joint replacement surgery and complications related to prostheses. In 2019, Fontana MA et al. published the third most co-cited reference in *Clinical Orthopaedics and Related Research*, exploring the potential of ML algorithms to predict the likelihood of Total Joint Arthroplasty (TJA) patients achieving the Minimal Clinically Important Difference (MCID). The results demonstrated that ML can enhance clinical decision-making and patient care by optimizing the allocation of postoperative monitoring resources and informing preoperative discussions about potential TJA outcomes. This represents an innovative application of AI in the evaluation of orthopedic surgery outcomes [23]. The fourth most co-cited reference, published by Ronneberger O et al. in *Lecture Notes in Computer Science (2015)*, introduced a novel deep learning model (U-Net), that significantly advanced the capabilities of deep learning in image processing. This milestone in medical image segmentation underscores the critical role of AI-based image analysis (e.g., fracture detection, 3D bone reconstruction) in orthopedic surgical navigation [25]. The fifth most co-cited publication, by Kim JS et al. in *Frontiers in Bioengineering and Biotechnology (2018)*, evaluated the accuracy of an Artificial Neural Network (ANN) ML model in predicting postoperative complications following Posterior Lumbar Fusion (PLF) and compared its performance with traditional statistical methods. The finding showed that ANNs exhibit robust performance in predicting complications associated with lumbar fusion, outperforming traditional methodologies in specific areas [26]. The publication ranked sixth in the number of co-citations is a review

by Cabitza F et al. in 2018, which systematically analyzed the current applications and predictive performance of ML in the field of orthopedic surgery. Although significant progress of ML has been made, this method has not yet reached full maturity [39]. The seventh co-cited reference, by Navarro SM et al. in 2018, applied ML algorithms to predict the Length Of Stay (LOS) and hospitalization costs after primary Total Knee Arthroplasty (TKA). This study concluded that ML algorithms exhibit excellent efficacy in predicting LOS and costs preoperatively, with extensive value-based applications [40]. The eighth most co-cited reference, authored by Bini SA et al. in 2018, provided a systematic explanation of AI and its core technologies (such as ML, deep learning, cognitive computing) in healthcare, along with their impacts [29]. The ninth, by Pedregosa F et al. (2011), comprehensively introduced Scikit-learn, a Python ML toolkit, detailing its design philosophy, core functionalities, and applications in scientific computing [41]. The tenth, authored by Luo W et al. in 2016, presented guidelines developed by multidisciplinary experts for standardizing the development and reporting of ML predictive models in biomedicine.

In the keyword co-occurrence network, high-frequency keywords are also related to machine learning, predictive model, total knee arthroplasty, deep learning, spine surgery, etc. It reflects that the deep integration of AI technology with orthopedic surgery (especially in joint replacement and spinal surgery) represents a central focus of current research. Notably, some clusters (such as AI and TKA, spinal surgery) exhibit overlapping keywords, indicating that there is technological transfer and coordinated development across different research domains. From the perspective of the trend of time evolution, algorithms such as ML and deep learning emerged early (indicated in blue) and have maintained their influence up to now. Recent keywords (indicated in yellow), such as revision and alignment, indicate that research is increasingly focusing on clinical refinement issues, including postoperative revision and precise surgical planning. Furthermore, clusters such as #0 patient question, #1 predictive model, and #2 spine surgery demonstrate significant continuity over time. Conversely, the emergence of clusters such as #5 ethical consideration also indicates the ethical issues of AI in medical applications are receiving increasing attentions.

4.3. Emerging Hotspots

Highly cited burst publications refer to academic papers that have a sudden surge in citations within a short period, significantly exceeding the average citation levels of comparable studies. These high-burst publications typically represent critical breakthroughs in their respective fields, such as novel theories, emerging technologies, or groundbreaking clinical discoveries [16], so they can be viewed as emerging hotspots. CiteSpace was used to identify the top 25 references with strong citation bursts. Among them, the reference with the strongest citation burstness ($n=7.95$) is "Towards better clinical prediction models: seven steps for development and an ABCD for validation" published by Steyerberg EW et al. in 2014 [31]. This literature proposes a framework for the development and validation of clinical prediction models. This work reflects the methodological requirements of AI in orthopedic prediction models (such as postoperative complications and therapeutic effects evaluation). The literatures with the longest duration of sudden incidents are (Collins GS et al., 2015) [22], (Deo RC et al., 2015) [32]. Collins GS et al. [22] provided the international standard for research reports on predictive models. Its long-term high citation rate indicates the emphasis on transparency and repeatability in AI research for orthopedic surgeries. Additionally, Deo RC et al. [32] provides a comprehensive review of the application framework of ML in the medical field. Compared with traditional methods, ML demonstrates superior efficiency in uncovering hidden patterns within complex medical data, particularly excelling in areas such as image analysis and risk stratification. This literature lays the foundational theory of AI in medicine and facilitates the advancement of orthopedic AI from theoretical concept to clinical application. Six publications [23, 34-37, 42] exhibited citation bursts beginning in 2023, which remain ongoing. These references represent the most recent emerging themes in the application of AI in orthopedic surgery and were selected for further discussion. Kurtz et al. [23] used a predictive model to predict the number and revision rates of hip/knee replacement surgeries in the United States from 2005 to 2030, providing national surgical volume prediction data to support AI model development, resource optimization and surgical planning. Lundberg SM et al. (2017) [42] proposed the SHAP (SHapley Additive exPlanations) method, which addresses the "black box" problem (Algorithm interpretability) of AI, enabling doctors to understand the prediction logic of the model and enhancing clinical trust. Kumar et al. [37] compared the accuracy of three ML algorithms (such as XGBoost, SVM) in predicting the effects after shoulder joint replacement surgery, highlighting the necessity

for algorithm optimization and personalized medical care. Lopez et al. [34] developed the ML model to identify patients suitable for joint replacement, optimize surgical indications, and reduce the hospitalization rate. The study by Klemm et al. on postoperative opioid use prediction [35] integrates AI with pain management strategies to mitigate the risk of overmedication. The evaluation of the ChatGPT performance in the US medical licensing examination from Kung et al. [36] explored the potential of large language models in medical education and orthopedic decision support, suggesting a novel trajectory for AI-assisted communication between doctors and patients. In summary, current and future research hotspots are identified as intelligent surgical planning and precise prognosis prediction systems, AI-enabled perioperative management, AI-assisted clinical decision-making, specialized applications of large language models, algorithm optimization and verification standards. For example, by employing machine learning algorithms, AI aids in determining the most suitable implant types, forecasting surgical outcomes, and stratifying patient risk profile. AI-driven image analysis and robotics can also improve surgical precision, thereby minimizing variability and complications. The research trajectory of AI in orthopedic surgery is shifting towards precision, real-time responsiveness, and humanization. Future efforts should focus on overcoming the three primary challenges of data fusion, algorithm interpretability, and clinical application, with the aim of establishing an intelligent assistance system covering the entire diagnostic and therapeutic process.

4.4. Strengths and Limitations

This study has several distinctive strengths. Firstly, we systematically analyzed the literature on AI applications in orthopedic surgery using scientometric methods for the first time, which provides comprehensive guidance for clinicians and researchers concentrating on AI in this field. Secondly, in contrast to traditional narrative reviews, scientometric analysis offers more insightful perspectives on developmental trends and emerging research fronts. However, like other scientometric studies [15], our study also has certain limitations. Primarily, as the visualization of CiteSpace is constrained by existing database coverage, our analysis was limited to publications in the WoSCC and only English literature was included, which may cause language bias. Consequently, if pertinent studies are absent from this database in this database, CiteSpace may not accurately depict the citation networks in this field. Additionally, we included only limited literature from 2025 due to the inadequate data. Furthermore, as CiteSpace primarily functions as a bibliometric visualization tool, it does not provide access to the full content of the analyzed publications, necessitating supplementary manual review and in-depth analysis to derive comprehensive insights.

5. Conclusion

The United States has made a substantial contribution to the research concerning the application of AI in orthopedic surgeries, with Harvard University emerging as the leading institution in terms of the publications number. Journal of Arthroplasty serves as a pivotal journal related to the research of AI application in orthopedic surgery. Schwab JH and Karhade AV have potentially exerted a significant influence in this field, evidenced by their publication number and frequent co-citations. Current and prospective research hotspots include intelligent surgical planning and precise prognosis prediction systems, AI-enabled perioperative management, AI-associated clinical decision-making, specialized applications of large language models, and algorithm optimization and verification standards. As more researchers investigate more information on the application of AI in orthopedic surgery, as well as the development of large models, robot-assisted systems and remote surgery technologies, we expect AI will completely improve the traditional surgery strategy and management to benefit more orthopedic patients.

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