TJVS Turkish Journal of Vascular Surgery

Turk J Vasc Surg 2024;33(2):103-11
DOI: 10.9739/tjvs.2024.07.027

Available online at www.turkishjournalofvascularsurgery.org

Original Article

The rise of artificial intelligence in vascular surgery: A bibliometric analysis (2020-2024)

Ufuk Demirkilic[1], Burcu Tosun[2]

[1]Acıbadem Hospital, Department of Cardiovascular Surgery, Ankara, Türkiye
[2]Atılım University, Faculty of Business, Department of Business, Ankara, Türkiye

Received: June 14, 2024 Accepted: July 17, 2024 Published online: July 24, 2024

Abstract

Aim: This study aims to perform a comprehensive bibliometric analysis of academic publications on AI applications in vascular surgery, identifying key authors, influential journals, prevalent research themes, and international collaborations, focusing on infrastructure, conceptual structure, and social networks within the field.
Material and Methods: The analysis covers 815 documents published from 2020 to 2024, retrieved from the Web of Science Core Collection database. Metrics analyzed include publication growth, citation rates, key contributors, leading journals, prevalent themes, and international collaborations.
Results: The research output showed a 15% annual growth rate, peaking in 2023. Despite increasing publications, the average citation rate per article declined. The study identified 5039 contributors with significant international co-authorship. Leading authors included Lareyre F and Raffort J, and the "Journal of Vascular Surgery" was the most influential journal. The USA and China led in contributions, reflecting robust research infrastructure. Key themes include risk assessment, diagnostic methods, and patient management, highlighting AI's role in enhancing diagnostic accuracy, treatment planning, and patient outcomes in vascular surgery.
Conclusion: The analysis highlights the rapid growth and collaborative nature of AI research in vascular surgery. Key contributors, influential journals, and emerging themes were identified, emphasizing AI's role in improving diagnostics and patient outcomes. Limitations include the focus on one database and a five-year period, suggesting future research should include more databases and a longer timeframe. Exploring high-impact studies and practical applications will further advance the field.

Keywords: Artificial intelligence, vascular surgery, bibliometric analysis

INTRODUCTION

Technology is a fundamental part of our daily lives, and its advancements are poised to revolutionize healthcare delivery in the future. Despite the presence of artificial intelligence (AI) for over fifty years, only recently have we begun to fully grasp its potential applications, especially through machine learning (ML) and deep learning (DL) in the field of vascular surgery. AI involves using specific mathematical algorithms that enable machines to perform problem-solving tasks, recognize words or objects, and make controlled decisions. This rapidly evolving technique addresses complex problems by analyzing data with neural networks to emulate intelligent human behavior [1].

In vascular surgery, AI tools have been utilized to study new genotypes and phenotypes in existing diseases, enhance patient care, increase cost-effectiveness, and reduce readmission and mortality rates. The objective of AI in vascular surgery is to

CITATION
Demirkilic U, Tosun B. The rise of artificial intelligence in vascular surgery: A bibliometric analysis (2020-2024). Turk J Vasc Surg. 2024;33(2):103-11.

OPEN ACCESS

Corresponding Author: Burcu Tosun, Atılım University, Faculty of Business, Department of Business, Ankara, Türkiye
Email: burcu.tosun@atilim.edu.tr

predict the most accurate diagnosis or outcome and choose the most effective treatment. Each year, the number of vascular imaging investigations rises, significantly increasing overall healthcare costs. Furthermore, imaging studies generate rich data that, when combined with clinical information from electronic health records and mobile health devices, offer vast opportunities for data-driven discovery and research. Traditional statistical methods often struggle to process and model imaging data due to the large number and complexity of inputs. AI, however, can manage high-dimensional data effectively, transforming vascular imaging by improving efficiency and reducing costs [2].

ML is essential for processing data that surpasses human brain capacity and comprehension. Computational technologies such as AI, computational simulations (CS), and extended reality (ER) are transforming medical practice. These technologies can guide procedures and potentially improve outcomes in vascular interventions. AI algorithms, including ML and DL, facilitate data collection, randomization, and mining, as well as personalized risk predictions and clinical decision-making. CS of vascular interventions generates patient-specific data related to the diagnosis and treatment of vascular diseases. ER technologies improve understanding of complex vascular anatomy and interventional procedures, providing safe and reproducible environments for training healthcare providers and medical technology developers [3].

Previous bibliometric analyses in related areas have often focused on broader topics such as general surgery, cardiology, or the overall medical applications of AI. Some examples include bibliometric and visual analyses of AI in cardiovascular diseases, like the study of Zhang et al. (2024) [4]. However, few studies have specifically addressed the niche yet impactful intersection of AI and vascular surgery, investigating major topics, main AI techniques, contributors, journals, and research context. While some studies, like Javidan et al. (2022) and Lareyre et al. (2022), have explored this area [5,6], our study offers distinct contributions. Notably, it is more contemporary and focuses exclusively on the Web of Science (WOS) database, ensuring a comprehensive and high-quality dataset. Additionally, our research delves deeper into citation networks, author collaborations, and the impact of influential publications, providing a more detailed analysis of the research landscape.

The primary objective of this study is to perform a comprehensive bibliometric analysis of academic publications on AI applications in vascular surgery. This analysis will identify key authors, journals, citation networks, prevalent themes, historiographic network of intellectual structure, and international collaborations. By doing so, the study aims to map the intellectual landscape of this emerging field and provide insights into its conceptual structure and social network. The ultimate goal is to fill a significant gap in the literature and offer a valuable guide for those interested in AI's role in vascular surgery, by offering a targeted analysis that highlights the unique contributions and trends within this domain. The findings are expected to serve as a valuable resource for researchers, clinicians, and policymakers interested in the advancements and future potential of AI in vascular surgery.

Applications of AI in Vascular Surgery

AI, which debuted in 1956, has become integral to various fields, including healthcare. AI functions can be categorized as ML, which predicts outcomes from new data, and DL, a subset of ML that uses multiple processing layers to enhance data detection and classification. The most common DL algorithms are Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN), modeled after human neural connections. Computer Vision (CV) represents the pinnacle of imaging detection and processing [7].

Since the 1970s, advancements in AI have sparked growing interest in its medical applications. Vuong et al. (2019) categorize AI in medicine into two branches [8]: the physical branch, involving assistive robots for care and surgery, and the virtual branch, involving informatics and expert systems. AI's applications span various specialties, with significant research in oncology, radiology, cardiology, and neurology, but less in vascular disease management [9].

In vascular surgery, AI is used for healthcare information management, disease detection, automatic image analysis, natural language processing (NLP), personalized medical decision-making, risk stratification, and research in Evidence-Based Medicine (EBM). AI is particularly important in diagnostics, treatment, and patient surveillance [1]. AI-supported healthcare systems and clinical data registries can analyze patterns in large datasets, optimizing health information programs and medical registries [10]. Collaboration between surgeons and data scientists is crucial for maximizing these benefits.

AI techniques are being developed to aid diagnosis and clinical decision-making. Imaging is vital in vascular surgery for confirming diagnoses, evaluating prognoses, and planning interventions. AI enhances image segmentation and pattern recognition, automating repetitive tasks and improving efficiency. AI-derived methods have improved aortic aneurysm segmentation [11,12] and developed automated pipelines for detecting vascular calcifications [13,14]. Computational programs assist in image segmentation and risk stratification for carotid artery stenosis [15,16].

AI offers promising prospects for image analysis, facilitating data acquisition and improving quantitative measurements in large patient datasets. Combining these methods helps assess patient risk and postoperative outcomes. New AI tools are needed to assist surgeons in complex cases, enabling the development of multi-variable scores that combine clinical, biological, and imaging characteristics to classify patient status and guide surgical decisions [17]. AI can also enhance medical training through simulation, with virtual reality simulators developed for training in endovascular procedures [18,19].

MATERIAL AND METHODS

This study aims to conduct a comprehensive bibliometric analysis of academic publications in AI applications within vascular surgery. It seeks to determine the field's infrastructure, intellectual framework, conceptual structure, and social network. Key objectives include identifying leading authors, predominant journals, citation patterns, prevalent research themes, productive countries, and network dynamics. By addressing these aims, the study maps the intellectual landscape of AI in vascular surgery, offering insights into impactful research, thematic trends, and international collaborations. The findings aim to inform researchers, clinicians, and policymakers about the evolving role and future prospects of AI in advancing vascular surgery.

Data Collection and Selection

All publications were retrieved and downloaded from the WoSCC database on 31 May 2024. We have chosen the Web of Science Core Collection (WOSCC) for screening the data because it provides access to the world's leading scholarly journals, books, and proceedings across various disciplines, including the sciences, social sciences, and arts and humanities. WOSCC offers a comprehensive citation network with fully indexed and searchable cited references for all publications, allowing us to search across all authors and their affiliations. Additionally, it enables us to track citation activity with citation alerts and visualize citation trends graphically with the citation report. The Analyze Results feature further aids in identifying trends and publication patterns, making WOSCC an invaluable resource for our bibliometric analysis.

The study focuses on vascular diseases typically treated by vascular surgeons. To ensure a focused and relevant dataset for the bibliometric analysis of AI in vascular surgery, a comprehensive search was conducted on the Web of Science (WoS) database using specific Boolean search criteria. A detailed preliminary study was conducted based on the insights and consensus of three expert and senior vascular surgeons on search and filtering criteria.

The search targeted articles with titles that included terms related to vascular and venous diseases, procedures, and conditions, while excluding terms associated with cardiology and ophthalmology, biometric identification technologies, botany, and oncology. Additionally, the search included abstracts and keywords related to AI technologies but excluded those containing terms related to the aforementioned irrelevant fields. Only articles published in English were included to maintain consistency and accessibility. The Boolean search string used was designed to capture relevant studies while filtering out unrelated topics, ensuring a precise focus on the application of AI in vascular surgery. The final search criteria included the following requirements:

- Titles must contain terms related to vascular diseases, such as Vascular*, Phlebology*, endovascular*, atherosclerosis*, thrombosis*, arterial*, artery*, or venous*,
- Titles must also include terms related to artificial intelligence, such as "artificial intelligence*", "deep learn*", "machine learn*", "neural network*", or "compu* Intelligen*",
- Titles must exclude terms related to cardiology, ophthalmology, biometrics, botany, and oncology, such as cardio*, cardiac*, ischemic*, coronar*, heart*, opthalm*, Biometr*, Retina*, Leaf, Cancer*, or Carcinom*,
- The term "vein" was excluded to avoid articles focused on "vein recognition" biometrics,
- The search was limited to documents written in English and published within the last 5 years.

We focused our search on the last five years to capture the most current trends and advancements in AI applications in vascular surgery. This period reflects recent innovations and emerging technologies that shape current practices and future directions in the field. Additionally, significant breakthroughs in AI during these years make it crucial for understanding its impact and potential in vascular surgery. Analyzing the latest publications provides relevant insights for researchers, clinicians, and policymakers. The search and screening process was implemented, yielding a total of 887 documents. All comprehensive records were imported into the "Biblioshiny" software (R version 4.3.0) of "Bibliometrix" to summarize, analyze and visualize the scientific literature [20].

RESULTS

The study covers the period from 2020 to 2024, encompassing a sample of 815 documents, published in 426 sources related to AI in vascular surgery, showing an annual growth rate of 15%. These documents, averaging 1.71 years in age, have received an average of 4615 citations each, totaling 23247 references. The content includes 1396 Keywords Plus and 1892 Author's Keywords. Authorship involved 5039 contributors, with only 13 single-authored documents, and an average of 7.49 co-authors per document. International co-authorships accounted for 24.54%. Document types consisted primarily of 509 articles, including 29 early access articles.

Visualizing the annual distribution of the field's productivity within the study's data set plays a significant role in identifying the studies most likely to have the greatest impact.

Figure 1 shows a steady increase in the number of articles published on AI in vascular surgery over the five-year period from 2020 to 2024. In 2020, there were 87 articles published, which increased to 135 articles in 2021. The number of publications continued to rise significantly, reaching 202 in 2022 and peaking at 239 in 2023. In 2024, there was a slight decline, with 152 articles published, since the year has not ended yet. This trend indicates a growing interest and research activity in the field, with a notable peak in 2023.

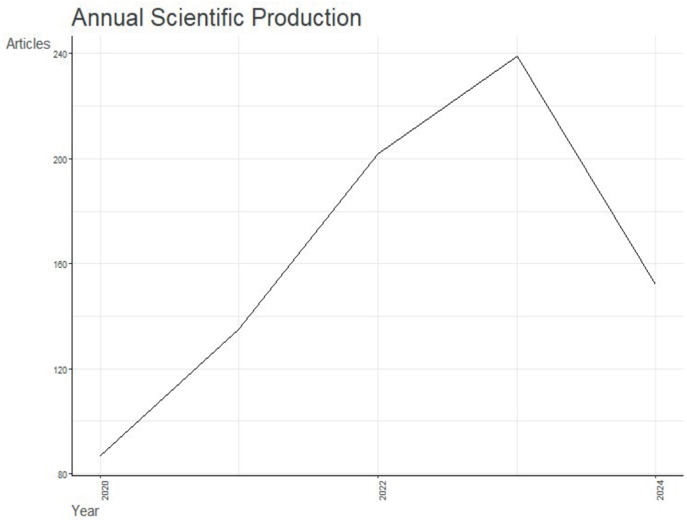

Figure 1. Annual distribution of scientific research production in the field

To identify influential publications within the study's data set, it is beneficial to examine the annual average citation rates of the published articles. In 2020, 87 articles had an average citation rate of 13.23. By 2021, 135 articles averaged 8.87 citations. In 2022, 202 articles saw an average of 4.77 citations. The trend continued with 239 articles in 2023, averaging 1.68 citations, and in 2024, 152 articles averaged 0.32 citations. This indicates a decline in citation rates despite the increasing number of published articles, which may be attributed to several factors: the shorter time frame for recent articles to accumulate citations, the saturation of research topics making it harder for newer articles to stand out, and a potential shift towards quantity over quality. Additionally, changes in research focus and increased competition among a larger pool of articles could also contribute to the observed decline in citation rates.

As seen from Figure 2, Lareyre, F. and Raffort, J. lead with 14 articles each. Li, B. follows closely with 10 articles. Other notable contributors include Guo, S. X., Wang, Y., Li, J., Li, X., and Li, Y. with 7 articles each. This indicates a diverse and active research community in the field. Lareyre, F. and Raffort, J. are the top contributors with 30 local citations each, followed by Adam, C. and Carrier, M. with 28 citations each. This suggests that Lareyre, F. and Raffort, J. have made significant contributions to this field, based on their leadership on the quantity of production and citation impact.

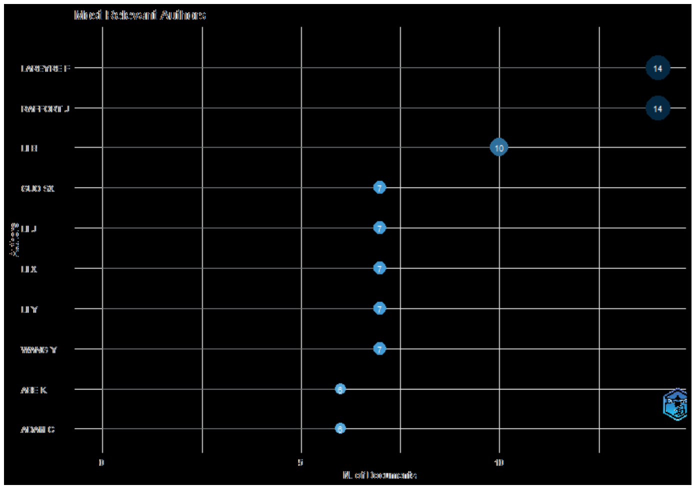

Figure 2. The most prolific authors

Table 1 depicts the primary sources of the literature on AI in vascular surgery, along with the quantity of publications they have contributed to this field. “Journal of Vascular Surgery” leads with 20 publications on AI in vascular surgery, followed by “Scientific Reports” with 19, and “Circulation” with 18. While “Diagnostics” and “Seminars in Vascular Surgery” have 10 publications each, “Blood” has 5, and several journals, including “European Heart Journal”, “Frontiers in Cardiovascular Medicine”, “Vascular”, “Stroke”, and “Magnetic Resonance in Medicine”, each have 8 publications. The findings also reveal that the “Journal of Vascular Surgery” is the most frequently cited source within the field, with 439 citations for its articles.

Table 1. Most relevant sources

Sources	Articles
Journal of Vascular Surgery	20
Scientific Reports	19
Circulation	18
Diagnostics	10
Seminars in Vascular Surgery	10
Blood	9
European Heart Journal	8
Frontiers in Cardiovascular Medicine	8
Magnetic Resonance in Medicine	8
Stroke	8

Table 2 displays annual publication rates from 2020 to 2024 for the top five journals in vascular surgery, highlighting increasing interest in AI applications. Publications were low in 2020 but grew noticeably in 2021, with a significant jump in 2022, especially in the Journal of Vascular Surgery. The peak in 2023 saw the highest publications, and mid-2024 indicates a continued upward trend, underscoring dynamic advancements in AI in vascular surgery.

Table 2. Annual publication rates of the top five journals

Year	Journal of Vascular Surgery	Scientific Reports	Circulation	Diagnostics	Seminars in Vascular Surgery
2020	2	1	3	0	0
2021	5	3	5	1	4
2022	14	7	13	4	4
2023	20	15	18	7	10
2024	20	19	18	10	10

Table 3 outlines the leading countries in AI research for vascular surgery. The USA leads with 921 publications, followed by China with 820, emphasizing their pivotal roles. Canada, Germany, and France follow with 170, 160, and 140 publications respectively, underscoring their significant contributions. This data underscores global interest and collaborative efforts in advancing AI technologies for vascular surgery, with notable growth trends observed across all five countries from 2020 to 2024.

Table 3. Countries' scientific production

Country	Frequency
USA	921
China	820
Canada	170
Germany	160
France	140
Japan	136
Uk	130
Spain	94
Italy	92

Table 4 lists highly cited documents in the field, with Zamanian et al.'s study on rituximab treatment leading with 89 citations [21]. Chen et al.'s work on deep learning robotic guidance follows with 83 citations, and Wang et al.'s research on 3D printing for vascular regeneration has 82 citations [22,23]. Jain et al.'s hybrid deep learning models for atherosclerotic plaque received 72 citations, while Li et al.'s systematic review on machine learning in vascular surgery garnered 64 citations [24,25]. These studies underscore their significant impact and recognition across vascular surgery, AI, and medical research domains.

Table 4. Most cited documents

Document	Citations
Zamanian RT, 2021, Am J Resp Crit Care	89
Chen AI, 2020, Nat Mach Intell	83
Wang PJ, 2021, Bio-Des Manuf	82
Jain PK, 2021, Comput Biol Med	72
Li B, 2022, Npj Digit Med	64
Xie DF, 2020, Magn Reson Imaging	61
Castellazzi G, 2020, Front Neuroinform	60
Perosa V, 2022, Acta Neuropathol	51
Venugopal K, 2021, Acs Sensors	49

Figure 3 tracks the evolving trend topics in AI applications within vascular surgery over the past five years. In early 2020, "quantification" and "algorithm" emphasized foundational work in precise measurements and computational methods crucial for AI integration. By 2021, "3D" highlighted advances in modeling and printing for surgical planning and prosthetic design. Concurrently, "risk," "classification," and "management" gained prominence, addressing patient-specific risk factors using AI. In 2022, focus shifted to "diagnosis," "risk factors," and "outcomes" for enhanced accuracy and patient care. By 2023, terms like "flow" and "computed tomography" underscored AI's role in advanced imaging analysis and diagnostic improvements in vascular surgery.

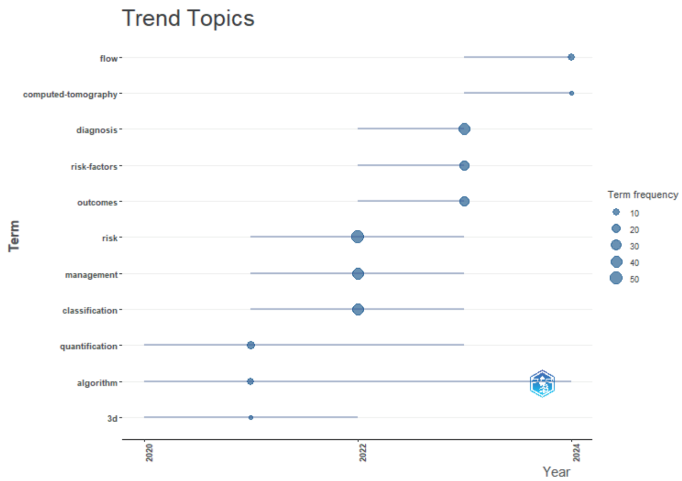

Figure 3. Trend topics

The word cloud in Figure 4 cloud illustrates the most frequently occurring terms in publications on AI in vascular surgery. The most common words are risk, classification, diagnosis, management, and disease. This indicates that recent research in this field heavily focuses on assessing and managing risks, classifying various conditions, improving diagnostic methods, and overall disease management, highlighting the critical areas where AI is being applied to enhance vascular surgery outcomes. Furthermore, co-occurrence network reveals the clustering of terms, which also provides insight into specific research focuses within the field: Cluster 1 includes terms related to diagnosis and management, reflecting efforts to use AI in clinical decision-making; Cluster 2 focuses on risk factors and outcomes, emphasizing predictive analytics; Cluster 3 involves blood flow and stroke, indicating advancements in imaging and time-sensitive interventions; Cluster 4 includes classification and segmentation, crucial for image analysis; Cluster 5 highlights risk prediction and disease modeling, central to preventive care; Cluster 6 and beyond delve into cellular-level research and advanced imaging techniques like CT and MRI. This clustering reveals a multifaceted approach to applying AI in vascular surgery, addressing both clinical and technical aspects to improve patient care and outcomes.

Figure 4. Word cloud

Figure 5 presents a historiographic network depicting the evolution of AI applications in vascular surgery. It organizes recent advancements into thematic clusters: Cluster 1 focuses on improving MRI techniques with deep learning methods, such as denoising arterial spin labeling MRI [26] and automated generation of cerebral blood flow maps [27]. Cluster 2 explores AI's role in diagnosing and managing thrombosis, including studies on deep-vein thrombosis diagnosis [28] and thrombosis research [29,30]. Cluster 3 examines AI applications in cardiovascular diseases, predicting complications post-endovascular aneurysm repair [31] and managing peripheral artery disease with natural language processing [32]. Cluster 4 centers on predictive modeling in vascular surgery, particularly in forecasting post-endovascular aneurysm repair complications [33,34]. Cluster 5 investigates fundamental AI concepts and applications for vascular surgery, such as AI fundamentals [17] and automated segmentation of the vascular system [35]. These clusters highlight AI's broad impact on enhancing diagnostic precision, treatment planning, and patient care in vascular surgery.

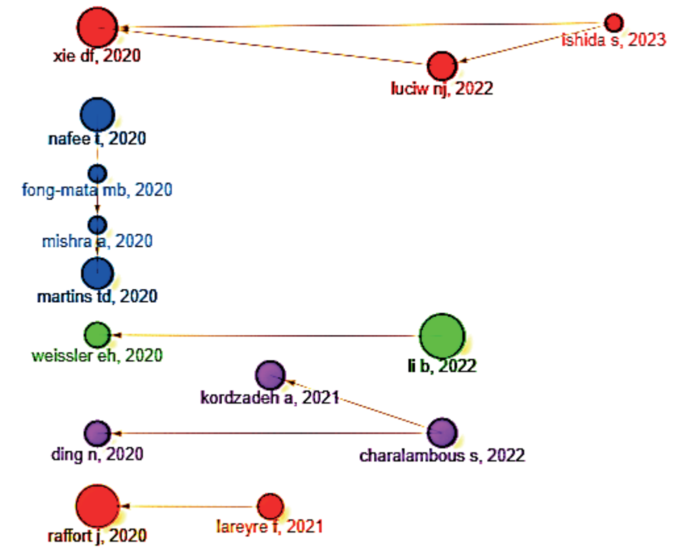

Figure 5. Historiographic network of intellectual structure

Table 5 exhibits countries' collaboration, which refers to how often researchers from different countries work together on research projects or publications, reflecting global research networks and international knowledge sharing, highlighting the most common partnerships. The USA shows substantial collaboration with China, the United Kingdom, Germany, and Canada, with the highest collaboration frequency noted with China at 23 instances. Germany also collaborates significantly with the United Kingdom and the Netherlands, underscoring strong scientific ties within Europe. These collaborations indicate robust international networks aimed at advancing research through shared expertise and resources across borders.

Table 5. The frequency of countries' collaboration

From	To	Frequency
USA	China	23
USA	United Kingdom	18
USA	Germany	15
USA	Canada	14
Germany	United Kingdom	12
France	United Kingdom	11
USA	Italy	11
China	United Kingdom	9
China	Canada	8
Germany	Netherlands	8
USA	Spain	8
USA	Switzerland	8

DISCUSSION

The findings align with previous studies, such as those by Vuong et al. (2019) who categorized AI applications in medicine, including the physical and virtual branches [8]. The growth in AI publications in vascular surgery mirrors trends in other medical fields, like oncology and ophthalmology [9]. Additionally, the increasing application of AI in diagnostics and imaging supports the conclusions drawn by Lareyre et al. (2022) regarding AI's potential to transform clinical practice [6]. Future research could benefit from incorporating these insights and exploring AI's impact across various medical specialties.

The ultimate goal is to fill a significant gap in the literature and offer a valuable guide for those interested in AI's role in vascular surgery, by offering a targeted analysis that highlights the unique contributions and trends within this domain. The findings are expected to serve as a valuable resource for researchers, clinicians, and policymakers interested in the advancements and future potential of AI in vascular surgery. The article contributes to the literature by providing a comprehensive bibliometric analysis of recent advancements in AI applications within vascular surgery, providing a comprehensive bibliometric analysis, highlighting key contributors, influential journals, and emerging research themes, and revealing a rapidly growing and collaborative research landscape. It offers valuable insights into the field's growth, collaboration patterns, and thematic evolution, aiding researchers in understanding current trends and identifying potential research gaps. The study is limited to publications indexed in the Web of Science database and covers only a five-year period, which may exclude relevant research from other sources or earlier years. Additionally, the citation analysis may not fully capture the impact of newer publications due to their shorter citation window. Future research should expand the bibliometric analysis to include additional databases and a longer time frame. Investigating the qualitative aspects of high-impact studies and exploring the practical applications of AI in vascular surgery will also be beneficial.

CONCLUSION

This bibliometric analysis offers a detailed overview of AI applications in vascular surgery from 2020 to 2024. The research output has grown significantly, with a peak in 2023, reflecting heightened interest and advancements in AI technology. Despite the increase in publications, the average citation rate per article has declined, possibly due to shorter time frames for citations, increased competition, and topic saturation. The field is highly collaborative, with an average of 7.49 co-authors per document and 24.54% international co-authorship. Leading authors like Lareyre F. and Raffort J. have made substantial contributions in both quantity and citation impact. Key journals, especially the "Journal of Vascular Surgery," dominate the publication landscape, indicating their critical role in disseminating influential research. Geographically, the USA and China are the top contributors, underscoring their strong research infrastructure and investment in AI. European countries also play significant roles, highlighting global collaborative efforts. Key research themes include risk assessment, diagnostic methods, and patient management, showing a shift from foundational AI technologies to practical applications.

Ethics Committee Approval: There is no human and experimental studies in this paper. Therefore, there is no need to take ethics committee permission.

Patient Consent for Publication: Patient consent is not required as the study does not involve any use of patient data or information.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed equally to the article.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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