NARRATIVE REVIEW

Global research characteristics and trends of artificial intelligence for scoliosis: A bibliometric analysis (2014-2023)

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Abstract

The integration of Artificial Intelligence into medical fields is transforming clinical practices, but its role in scoliosis — a condition requiring complex diagnostic and management strategies — remains underexplored. The current narrative review was planned to analyse global research trends in Artificial Intelligence applications to scoliosis from 2014 to 2023 using a bibliometric approach. Data from 627 publications, authored by 562 researchers across 57 countries, was extracted from the Web of Science Core Collection, and analysed using CiteSpace 6.3.R1. Results revealed a surge in publications since 2017, peaking in 2021, with a thematic shift from surgical interventions to perioperative management. The United States leads in both contributions and advancements, with Spine as the top journal. Future research should focus on optimising Artificial Intelligence algorithms and integrating them into clinical decision-making to enhance scoliosis management and patient outcomes.

Keywords: Scoliosis, Artificial intelligence.

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Introduction

Scoliosis, a condition characterised by the lateral curvature of the spine, manifesting in either an S-shaped or C-shaped deformation[1,2] is diagnosable when the Cobb angle surpasses 10 degrees.[3] Studies have revealed that approximately 3% of the populace is affected by this malady, predominantly between the ages of 10 years and 20 years.[4,5] The earlier scoliosis appears, the more severe is its potential progression, with females facing a risk of exacerbation 4-10 times higher than males.[6,7] Often, mild cases of scoliosis may not necessitate treatment, or may be managed through physical therapy and the use of braces.[8-11] However, non-adherence to medical recommendations can lead to the worsening of the condition.[12] Should the curvature exceed 50 degrees, impacting respiratory and cardiac functions, surgical intervention is commonly advised.[13,14] Yet, the risks associated with surgery and the lengthy recovery process are sources of concern for many minors and their guardians.[15,16] Hence, early diagnosis and intelligent monitoring are crucial for enhancing therapeutic outcomes.

Artificial Intelligence (AI) has demonstrated significant advantages in the diagnosis, treatment planning, surgical assistance, and monitoring of therapeutic efficacy in scoliosis, garnering attention from both medical professionals and patients.[17,18] Algorithms based on deep learning (DL) are capable of precisely identifying spinal structures, measuring the Cobb angle, and assessing the presence and severity of scoliosis.[19] This automation significantly alleviates the burden on radiologists, enhancing the precision and efficiency of diagnoses. AI technology, by creating three-dimensional (3D) models from two-dimensional (2D) X-ray images, aids physicians in detailed pre-surgical planning. During surgery, AI-assisted robots can navigate with precision to place screws or implants, reducing surgical risks and shortening recovery times. Additionally, AI-enabled smartphone applications and wearable devices offer patients immediate feedback, allowing for the adjustment of treatment plans or the recommendation of physical exercises, as necessary.[20] With the rapid advancement of AI technology and the emergence of extensive research evidence, there is a pressing need for timely and effective analysis of literature to deepen researchers' understanding of the field, and guide future studies.[21]

Currently, research on the application of AI in scoliosis is limited, with only a few reviews and one meta-analysis publicly available. For instance, a systematic review incorporating nine studies demonstrated the significance and feasibility of this domain, with seven studies classified as high-level evidence. However, existing systematic reviews lack an assessment of detailed citation information behind publications and the core research hotspots' evolutionary trends over time. In contrast, bibliometric analysis, employing the theories and methods of bibliometrics and informatics, provides a more profound and insightful perspective, objectively and visually presenting the quantity, quality and impact of AI-related

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scoliosis publications through comprehensive and meticulous summaries of publication data, including trends in annual publication numbers, core key word clustering, authors, countries, institutions and journals.[22,23] The current narrative review was planned to objectively and visually summarise the publication data on AI applications in the scoliosis domain through BA.

Materials and Methods

The current narrative review was planned to analyse global research trends in Artificial Intelligence applications to scoliosis from January 1, 2014, to December 31, 2023. using a bibliometric approach sourced from the Web of Science Core Collection (WoSCC),[24,25] which is widely regarded as the gold standard in bibliometric research due to its comprehensive coverage of high-quality publications and detailed citation indexing.

A comprehensive search term strategy was formed that was centred around "Artificial Intelligence" and "scoliosis" (Table 1). To maintain consistency with similar research methodologies, and facilitate comparison and verification, no restrictions were placed on the publishing country, while the language was specified as "English". and the research type was limited to "article".

For data analysis, CiteSpace 6.3.R1 was used. It is a visualisation tool that stands out among other BA research software for its ability to discern research hotspots and frontier domains, as well as to forecast the future dynamics of specific fields.[22,23] The process typically involves data collection, data analysis and the interpretation of results. Data included citations, abstracts and key words. After data deduplication and verification, node types (such as key words, authors, institutions, etc.) and thresholds were set. To enhance the clarity of the final visualisation and facilitate the observation of relationships between publications, the time slicing was set to "1 year", the g-index's k-value was set to 50, and the Pathfinder network was applied to scale the algorithm.[26,27] Subsequently, the generated network maps were adjusted and optimised to identify and analyse clusters. Finally, network maps and clusters were interpreted, analysing the key nodes and paths within the network map to identify research hotspots in the application of AI to the field of scoliosis.

Table-1: Topic search (TS) query.

Set	Results	Search Query
#1	11,780	TS=("scoliosis" OR "spinal curvature" OR "curvature of the spine" OR "lateral curvature of the spine" OR "spinal deformity") NOT ("kyphosis" OR "lordosis")
#2	1,797,795	TS=("Artificial Intelligence" OR "AI" OR "Machine Learning" OR "ML" OR "Deep Learning" OR "Neural Networks" OR "Supervised Learning" OR "Unsupervised Learning" OR "Reinforcement Learning" OR "Natural Language Processing" OR "NLP" OR "Computer Vision" OR "Pattern Recognition" OR "Predictive Analytics" OR "Algorithm" OR "Cognitive Computing")
#3	713	#1 AND #2
#4	627	#3 AND Article (Document Types) AND English (Languages)

Results

Of the 713 articles initially identified, 627(88%) were analysed in detail (Figure 1). Two distinct trends in the publication volume were observed: the first phase, prior to 2017, where the annual publication count ranged 30-36, suggesting that the application of AI in the scoliosis domain was still in its nascent and experimental stages; and the second phase, from 2017 to the present, that witnessed a rapid increase in publication numbers, particularly in 2021, indicating that the value of AI applications has been recognised in the field of scoliosis, suggesting that the number of publications was likely to reach new peaks in the years ahead (Figure 2).

A network relationship diagram was generated that had 597 key words and 1,772 connections (Figure 3). The top 10 most frequently occurring key words were listed separately

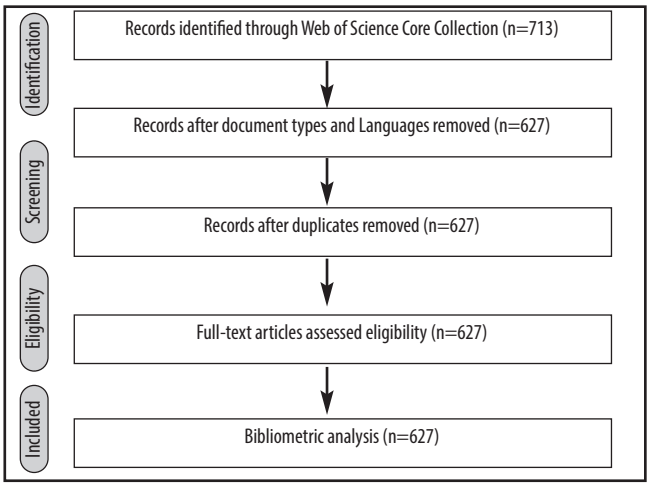

Figure-1: Literature screening process.

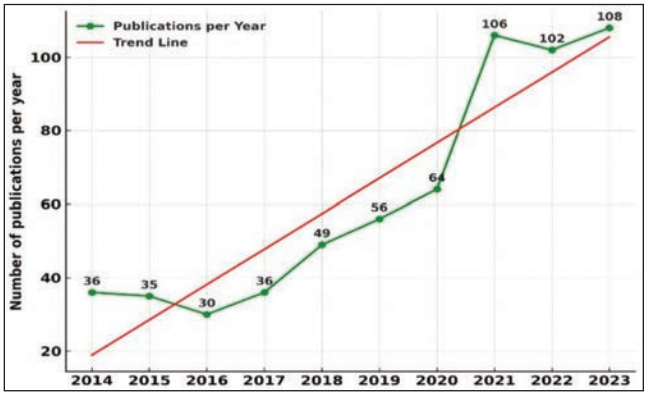

Figure-2: Annual publications related to Artificial Intelligence (AI) for scoliosis.

(Table 2). A timeline diagram illustrated the relationship between the key words and their development over time (Figure 4). Further analysis identified 6 core clusters: #0 focussed mainly on the application of AI, such as DL artificial and intelligence diagnosis; #1 concentrated on adolescent idiopathic scoliosis and paediatric spine deformity among other scoliosis topics; #2 addressed surgical strategies, like intensive care unit (ICU) and spinal fusion; #3 dealt with medical expenses, notably cost-effectiveness and value-based care; #4 explored DL algorithms, including AI diagnosis and automated analysis; and #5 looked at other risk factors, such as cerebral palsy (CP) and intellectual disability.

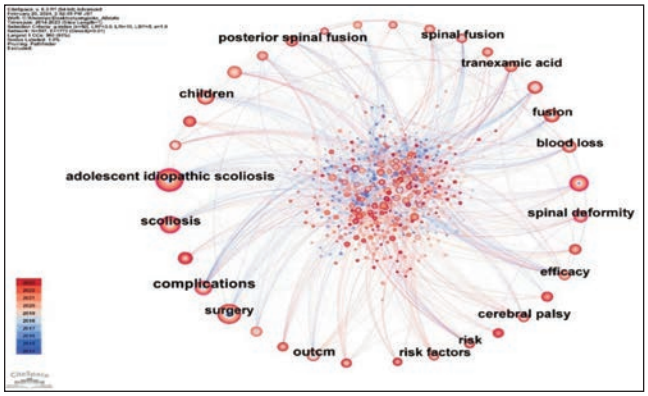

Figure-3: Keywords related to Artificial Intelligence (AI) for scoliosis.

Table-2: Top 10 frequency and centrality of key words related to Artificial Intelligence (AI) for scoliosis.

Rank	n	Keywords	Rank	Centrality	Keywords
1	131	adolescent idiopathic scoliosis	1	0.15	complications
2	97	surgery	2	0.13	scoliosis
3	75	scoliosis	3	0.12	adolescent idiopathic scoliosis
4	65	idiopathic scoliosis	4	0.11	spinal deformity
5	58	complications	5	0.1	idiopathic scoliosis
6	54	children	6	0.09	children
7	51	fusion	7	0.09	outcome
8	47	blood loss	8	0.09	cerebral palsy
9	45	adult spinal deformity	9	0.09	brace
10	39	management	10	0.08	adult spinal deformity

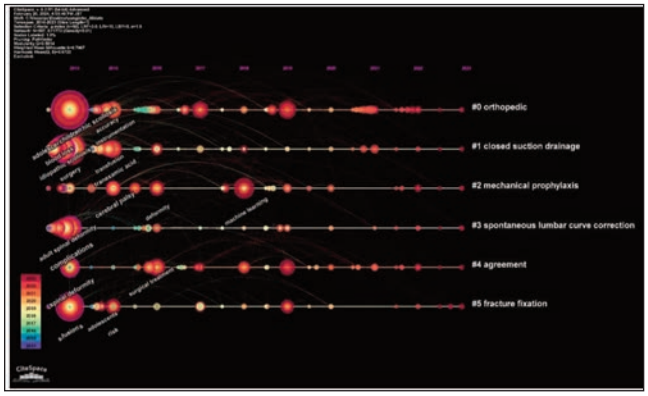

Figure-4: Keywords timeline.

Additionally, Strongest Citation Bursts revealed a thematic shift over two periods. Before 2019, the application of surgical treatments in scoliosis garnered the most attention, whereas, after this period, the focus shifted to the diagnosis and management of scoliosis using various AI algorithms, especially DL (Figure 5). Moreover, it was found that the key word "learning curve" had the longest burst duration (4 years), while "surgery" and "deep learning" had the highest burst strengths, with each reaching 4.09.

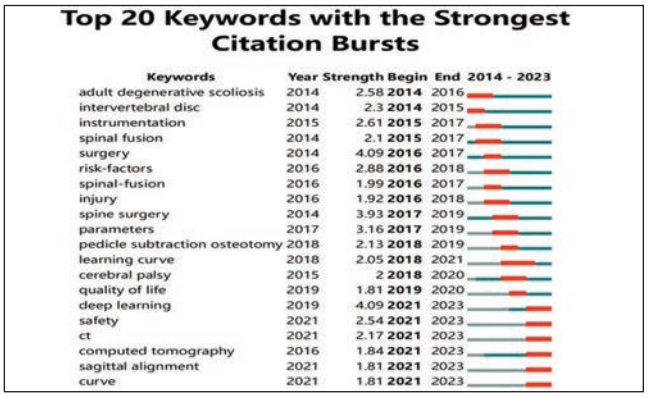

Figure-5: Top 10 key words with the strongest citation bursts.

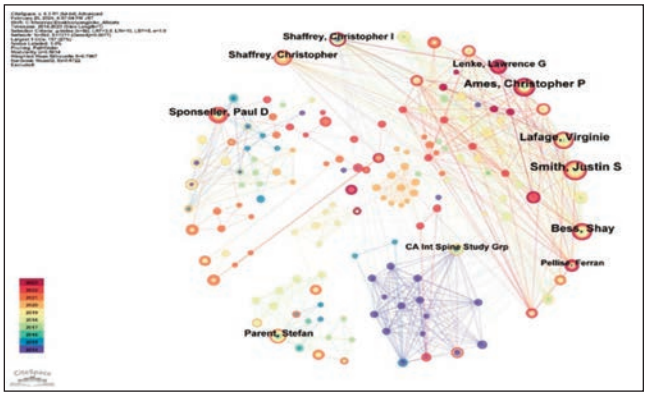

Figure-6: Map of authors related to Artificial Intelligence (AI) for scoliosis.

Table-3: Top 10 authors related to Artificial Intelligence (AI) for scoliosis.

Rank	Author	n	Year	Country
1	Smith, Justin S	17	2014	USA
2	Ames, Christopher P	15	2014	USA
3	Lafage, Virginie	14	2014	USA
4	Bess, Shay	13	2014	USA
5	Sponseller, Paul D	12	2015	USA
6	Shaffrey, Christopher	10	2018	USA
7	Bertoncelli, Domenico	10	2018	Italy
8	Parent, Stefan	9	2015	Canada
9	Shaffrey, Christopher I	9	2014	USA
10	Lenke, Lawrence G	9	2014	USA

A total of 562 authors were found to have contributed to publications, forming a collaborative network with 1,211 connections (Figure 6). The top 10 authors by publication count were noted separately (Table 3), highlighting the United States' dominance in terms of talent reserve in the field.

The papers were published from 57 countries and there were 114 collaborative relationships depicting the international network in AI applications to scoliosis (Figure 7). The list of top 10 countries by publication count was headed by the USA (233 publications), followed by China (146), Canada (46), France (37), Japan (33), Italy (26), South Korea (25), India (24), Turkiye (23) and Germany (18) (Table 4).

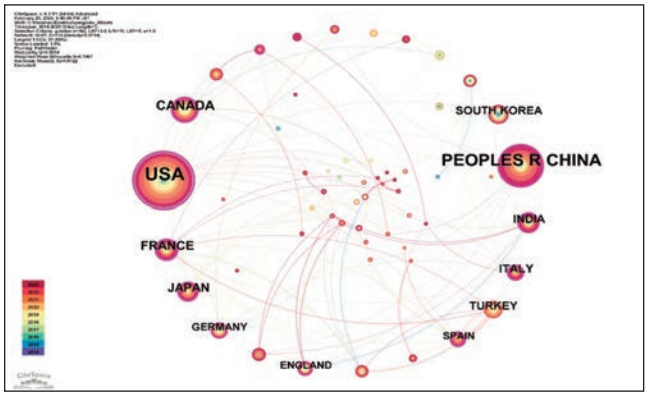

Figure-7: Countries related to Artificial Intelligence (AI) for scoliosis.

Table-4: Top 10 frequency and centrality of countries related to Artificial Intelligence (AI) for scoliosis.

Rank	n	Countries	Rank	Centrality	Countries
1	233	USA	1	0.67	USA
2	146	China	2	0.24	France
3	46	Canada	3	0.2	Canada
4	37	France	4	0.16	Germany
5	33	Japan	5	0.15	China
6	26	Italy	6	0.15	Saudi Arabia
7	25	South Korea	7	0.13	Italy
8	24	India	8	0.12	Japan
9	23	Turkey	9	0.11	India
10	18	Germany	10	0.11	Spain

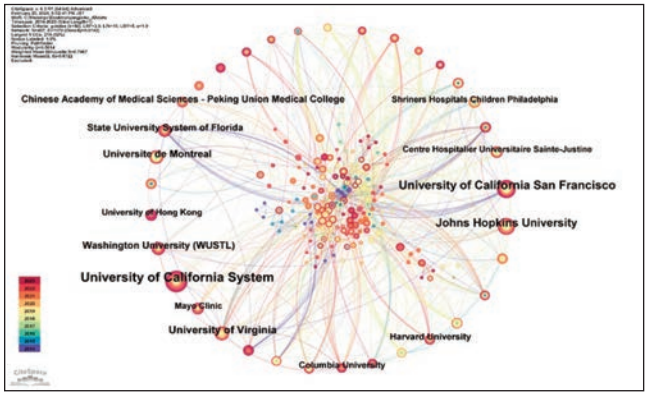

Figure-8: Institutions related to Artificial Intelligence (AI) for scoliosis.

A visual analysis of the academic institutions corresponding to the top 10 countries revealed a closely-knit collaborative network (Figure 8) among top 10 academic institutions (Table 5).

Analysis of cited journals showed 838 cited journals and 3,936 connections (Figure 9). The top 10 journals by citation

Table-5: Top 10 publications of institutions related to Artificial Intelligence (AI) for scoliosis.

Rank	n	Year	Institutions
1	53	2014	University of California System
2	36	2014	University of California San Francisco
3	31	2015	Johns Hopkins University
4	24	2014	University of Virginia
5	19	2015	Universite de Montreal
6	18	2014	Washington University (WUSTL)
7	16	2014	Chinese Academy of Medical Sciences - Peking Union Medical College
8	16	2014	State University System of Florida
9	14	2015	Harvard University
10	13	2017	Columbia University

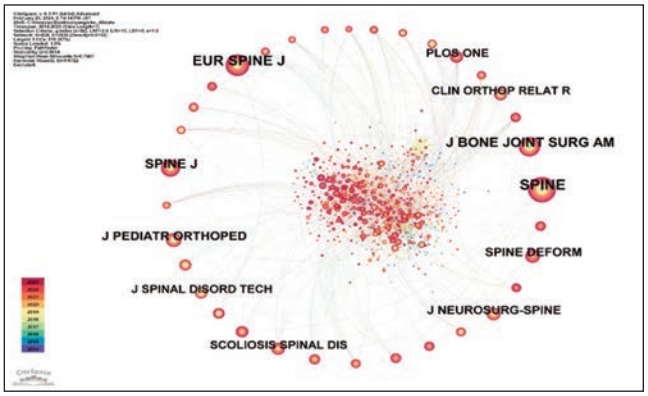

Figure-9: Cited journals related to Artificial Intelligence (AI) for scoliosis.

Table-6: Top 10 frequency of cited journals related to Artificial Intelligence (AI) for scoliosis.

Rank	n	Year	Cited Journals
1	482	2014	SPINE (http://journals.lww.com/spinejournal/pages/default.aspx)
2	367	2014	EUR SPINE J (https://www.springer.com/586)
3	281	2014	J BONE JOINT SURG AM (http://jbjs.org/)
4	240	2014	SPINE J (http://www.thespinejournalonline.com/)
5	174	2014	J PEDIATR ORTHOPED (http://journals.lww.com/pedorthopaedics/pages/default.aspx)
6	159	2016	SPINE DEFORM (https://www.springer.com/43390)
7	139	2014	J NEUROSURG-SPINE (http://thejns.org/)
8	119	2014	SCOLIOSIS SPINAL DIS (https://scoliosisjournal.biomedcentral.com/)
9	119	2014	CLIN ORTHOP RELAT R (http://www.editorialmanager.com/corr/)
10	115	2014	J SPINAL DISORD TECH (http://journals.lww.com/jspinaldisorders/pages/issuelist.aspx)

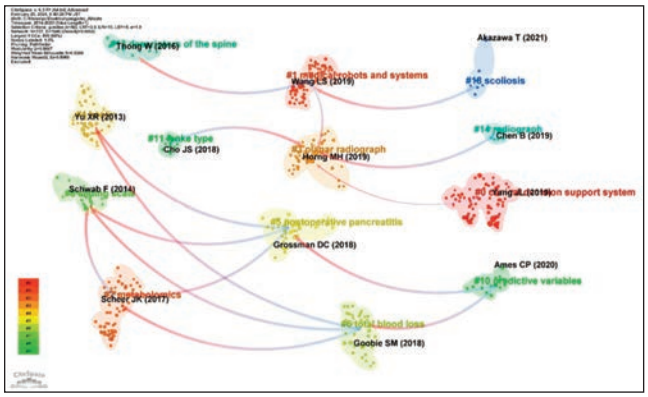

Figure-10: Reference of cluster dependencies related to Artificial Intelligence (AI) for scoliosis.

count were noted separately, with the diversity of cited journals highlighting the interdisciplinary nature of the research area, spanning fields such as orthopaedics, neurosurgery and paediatric spine deformities (Table 6).

Citation network analysis revealed strong connectivity among the journals, indicating an active exchange of knowledge and a cohesive research community. This interconnectedness facilitates the dissemination of AI-driven innovations in scoliosis management, bridging gaps between clinical applications and technological advancements. Such insights underscore the foundational contributions of these journals to the evolving landscape of AI applications in spinal research.

A disciplinary development relationship diagram was generated based on references, using arrows to illustrate the developmental relationships between different disciplines. The tail of each arrow represented recent knowledge frontiers, while the head indicated the origins of foundational literature (Figure 10). The analysis revealed a richly diverse disciplinary development network within the field of AI applications to scoliosis, characterised by both interdisciplinary integration and the refinement of major disciplinary branches.

For example, cluster #8, originating in 2014, has evolved into disciplines #2, #5 and #6, highlighting its foundational role in subsequent research developments. Similarly, cluster #5, formed in 2018, emerged from the intersection of disciplines #2, #4 and #8, showcasing the importance of cross-fertilisation in advancing research frontiers. These interconnected clusters reflect the dynamic interplay between established fields, such as orthopaedics and computer science, and emerging areas, including machine learning algorithms tailored for scoliosis diagnostics and management.

The observed interdisciplinary integration drives the exploration of frontier directions. For instance, the convergence of AI and medical imaging is fostering innovations in automated scoliosis screening, while the integration of biomechanics and data analytics is refining perioperative decision-making. Additionally, the fusion of AI-driven predictive modelling with clinical practices is opening new avenues for personalised treatment strategies. Such interdisciplinary collaborations are instrumental in addressing the complex diagnostic and management needs of scoliosis, ensuring that AI applications continue to evolve towards more sophisticated, patient-centred solutions.

Discussion

The current narrative review adopted a meticulous and holistic approach to delve into the application and development trajectory of AI technology in the field of scoliosis research over the decade spanning 2014-2023. Through extensive search and analysis of the WoSCC database, the study not only aggregated a vast array of publication data, but also employed advanced data visualisation techniques to objectively reveal the deep-seated changes in the knowledge structure and development trends within this disciplinary field.

The study discovered a significant surge in scoliosis research within the realm of AI starting from 2017, with a notable growth rate of 65.56% in 2021. This trend indicates the increasingly recognised potential of AI technology in the diagnosis, treatment and management of scoliosis by a growing number of researchers and medical professionals. The rapid advancement of AI technology, especially in image recognition, data analysis, and machine learning algorithms, opens new possibilities for the precise diagnosis and personalised treatment of scoliosis.[28,29]

Analysis of the key word network identified the primary focal points of scoliosis research. The frequent occurrence of key words, such as adolescent idiopathic scoliosis, surgery and complications, reflects the core domains of current research. Notably, key words with high centrality, such as complications and scoliosis, underscore the research community's intense focus on improving treatment outcomes and reducing surgical risks. Cluster analysis revealed the diversified applications of AI technology in scoliosis treatment strategies, diagnostic methods, and medical cost-effectiveness analysis. Moreover, the shift in research focus from surgical treatment methods to AI algorithms may reflect changes in technological advancement and medical practice needs, potentially impacting future clinical decisions and treatment strategies significantly.

The study also unveiled a robust collaboration network comprising 562 authors, indicating that scoliosis research

is a highly collaborative and interdisciplinary field. Particularly, research institutions and authors from the United States have taken a leading role in this domain, possibly due to their comprehensive advantages in medical technology, research funding, and talent development.

Analyses of national collaboration networks and academic institutions further underscore the crucial role of international cooperation in advancing scoliosis research. The leading positions of countries like the United States, China and Canada, along with the active participation of top-tier academic institutions, such as the University of California and Johns Hopkins University, demonstrate the widespread global attention and investment in scoliosis research.

Cited journal network analysis showed that research outcomes in the field of scoliosis were primarily concentrated in some high-impact professional journals, facilitating the dissemination and application of the latest research findings. Simultaneously, the disciplinary development relationship diagram revealed how AI technology had promoted the interdisciplinary integration of scoliosis research, providing a rich scientific foundation for the development of innovative treatment methods and diagnostic tools in the future.

The application research of AI technology in the field of scoliosis was characterised by a rapid growth trend. Through in-depth analysis of key word networks, citation bursts, collaboration networks, and the distribution of countries and journals, the global, interdisciplinary cooperation trend in this field was observed, along with the immense potential of AI technology in advancing the diagnosis and treatment of scoliosis. For researchers, these findings not only unveil the current research dynamics and trends, but also offer crucial clues to future research directions.

Through summarising citation information and cluster relationships, two primary research hotspots were identified in the application of AI in the field of scoliosis: AI in the screening and diagnosis of scoliosis, and AI in the perioperative assistance and evaluation of scoliosis.

The screening of scoliosis has garnered global attention in recent years, primarily because it concerns the physical and mental health and future development of the adolescent population. Early detection and intervention are the best approaches to treating this condition. AI technology can automatically identify and analyse spinal X-ray images, measure Cobb angles, and detect the presence and severity of scoliosis. This automated process can significantly reduce the workload of radiologists, and improve the accuracy and efficiency of diagnoses.[30,31] Several studies have applied AI algorithms specifically for measuring Cobb angles.[32-34] Diverse AI algorithms have been extensively applied. For example, a DL model developed by Zhang T. et al.,[35] which uses patients' back X-rays and smartphone photos, can complete accurate diagnoses. Vergari[36] used a convolutional neural network (CNN) with an accuracy rate of 98.3%. Other researchers[37] developed a deep transfer learning model with an accuracy rate exceeding 98%. Moreover, the Multiview Consistency Network (MVC-Net) architecture,[38] the Contrastive Language-Image Pre-training (CLIP) system[39] and automated analysis platforms[40] have also been effectively validated.

Thanks to the efficiency and accuracy of AI technology, it offers significant value not only in the precise screening and diagnosis of scoliosis patients, but also in providing effective assistance and evaluation in the perioperative period. Specifically, preoperatively, AI can help doctors develop personalised surgical plans based on the patient's specific conditions, such as the curvature of the spine, physical condition, etc.[41-43] Intraoperatively, robots can provide real-time imaging guidance to help doctors more accurately locate and place implants, and monitor the surgical process in real-time to warn of potential risks and complications.[44,45] Postoperatively, by analysing patients' activity data, pain levels and other information, AI can evaluate rehabilitation progress and adjust rehabilitation plans.[46,47] For instance, a U-Net DL model achieved screw placement angle accuracy within 1° during surgery.[48] A study[49] demonstrated that the deviation rate of robot-placed pedicle screws was 1.6%, lower than that of navigation. Similar research,[50] comparing robot technology with navigation and manual techniques, reached the same conclusion. The current research further supports the significant application value of AI in the perioperative period for scoliosis patients.

Building on the identified research hotspots, the application of AI in scoliosis presents several promising future directions, emphasising its transformative potential in clinical and research settings.

For instance, AI has the capacity to revolutionise scoliosis management by facilitating truly personalised treatment plans. Future advancements in predictive modelling and machine learning algorithms could enable the integration of genetic, biomechanical and imaging data to develop customised treatment protocols. These AI-driven insights could guide decisions, such as optimal timing for surgical interventions or targetted rehabilitation strategies, ensuring treatments are tailored to the unique needs of each patient.

Also, the integration of wearable devices and AI algorithms offers significant potential for real-time monitoring of scoliosis progression. For instance, AI-powered wearables could continuously track spinal curvature and biomechanical parameters, providing early warnings for patients at risk of rapid curve progression. Such systems would empower patients and clinicians with actionable insights, enabling timely adjustments to treatment plans and potentially reducing the need for invasive interventions.

Further, AI-driven robotics are expected to become even more sophisticated, with capabilities extending beyond intraoperative guidance. Future developments could include fully autonomous robotic systems capable of executing complex surgical manoeuvres with unparalleled precision. These systems could adapt dynamically to patient-specific anatomical variations, further enhancing the safety and efficacy of scoliosis surgeries.

Moreover, postoperative rehabilitation could be transformed by integrating AI with virtual reality (VR) and augmented reality (AR) technologies. These tools could create immersive, interactive environments for patients to perform targetted rehabilitation exercises, with AI algorithms analysing real-time feedback to adjust difficulty levels and ensure optimal recovery. Besides, predictive models could identify patients at risk of poor outcomes, enabling clinicians to intervene proactively.

AI has the potential to bridge gaps in global healthcare access, particularly in resource-limited regions. By developing cost-effective, AI-powered diagnostic tools — such as smartphone-based imaging systems — clinicians in underserved areas could diagnose and monitor scoliosis with greater accuracy and efficiency. This democratisation of AI technologies could significantly reduce disparities in scoliosis care worldwide.

Finally, future advancements in AI for scoliosis will likely benefit from the integration of large-scale, multi-centre databases. These platforms could consolidate data from imaging, genetic studies, electronic health records, and wearable devices, creating a comprehensive ecosystem for scoliosis research and care. AI algorithms trained on such datasets could identify novel biomarkers, refine treatment protocols, and accelerate the development of predictive tools.

It is clear that the future of AI in scoliosis lies in its ability to enhance precision, efficiency and accessibility across all stages of care — from early detection and diagnosis to personalised treatment and long-term monitoring. Continued interdisciplinary collaboration and technological innovation will be essential in realising these applications, ultimately improving patient outcomes and advancing the field towards a new era of AI-driven scoliosis management.

This current narrative review has several limitations. First, bibliometric analysis typically relies on literature from a single database, such as the WoSCC. While comprehensive, this reliance limits the scope of the analysis, as it excludes relevant studies from other significant databases. The exclusion of these resources may lead to the omission of important studies, thereby affecting the completeness and accuracy of the results. Future research could expand the range of databases used to provide a more robust and inclusive analysis. Second, the analysis is constrained by the temporal scope of the chosen data, which may overlook historical developments or newer trends that emerged after the selected period. Future studies could consider expanding the timeframe to include both earlier foundational research and the latest studies to capture a broader evolution of the field. Third, bibliometric analysis generally cannot assess the quality of individual studies in depth. This limitation means that both high-quality and low-quality research are often given equal weight, which could introduce bias into the visualized results. Future research could benefit from incorporating methods to evaluate study quality more rigorously, potentially through the integration of systematic review techniques. Finally, the rapid advancement of research in AI presents a dynamic challenge, particularly when applied to specific medical fields. The speed of new developments can make it difficult for bibliometric analysis to remain up-to-date. Expanding future studies to include a more frequent update cycle or adopting real-time analytics might help mitigate this issue and provide more timely insights.

Conclusion

AI technology has achieved significant accomplishments in the screening, diagnosis, and perioperative assistance and evaluation of scoliosis. These advancements not only enhance the accuracy and efficiency of diagnoses, but also provide patients with personalised treatment plans, significantly improving surgical safety and rehabilitation outcomes. While AI technology brings numerous benefits, its application also faces challenges in technology, ethics and law, such as data security, privacy protection, and the fairness and transparency of algorithms. These issues necessitate a collaborative effort among the scientific, legal, and ethical communities to ensure the healthy development and application of the technology. Research on AI in the treatment of scoliosis should focus on long-term outcome evaluation, algorithm optimisation, and integration with the clinical decision-making process.

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