Bibliometric Analysis

Research Focus Involving and Trends in Artificial Intelligence for Spinal Pain: A Bibliometric Analysis

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Background: Spinal pain is a pervasive global health issue that poses significant challenges because of the disability and economic burden it causes. Despite the availability of various treatments for the condition, a definitive cure for spinal pain remains elusive, underscoring the need for innovative approaches. Artificial intelligence (AI) is considered a potential method for facilitating relief for patients suffering from spinal pain.

Objective: This study utilized a bibliometric analysis to explore the impact of AI on spinal pain research, examining publication trends, collaboration patterns, author contributions, and keyword clusters, to analyze research focus and trends in this field.

Study Design: Bibliometric analysis.

Setting: Data were obtained from the Web of Science Core Collection (WoSCC).

Methods: The literature related to AI-assisted techniques in spinal pain treatment was collected from the WoSCC. The CiteSpace and R Bibliometrix software packages were used in the analysis.

Results: In total, 310 articles were included, with the number of publications and citations increasing progressively. The greatest number of publications and total citations came from the United States. The University of Washington was the institution associated with the most publications. Mork PJ was the byline that appeared most often in association with both publications and total citations. The European Spine Journal was the journal in which the most publications appeared, while Spine had the greatest number of citations. The literature with the most global citations was published by Jamalusin A in the *European Spine Journal*, while the literature with the most local citations was by Sandal LF on JMIR Research Protocols. The most frequent key words were "machine learning," "low back pain," "magnetic resonance imaging," etc.

Limitations: Only the English-language articles in the WoSCC database were included, and proceeding papers, meeting abstracts, and book chapters were excluded. Furthermore, we included no research about wearable sensors, virtual reality, and so on. Additionally, the articles from the other databases were not included.

Conclusion: The research of applying AI as a treatment for spinal injury has appealed to interdisciplinary efforts, reflecting the potential for self-management, imaging processing, and clinical decision-making. An overall perspective is shown in our study, which facilitates understanding and provides research focuses and trends in this field.

Key words: Spinal pain, artificial intelligence, bibliometric, CiteSpace

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Spinal pain, which includes pain in the cervical vertebrae, thoracic vertebrae, and lumbar vertebrae, is the primary cause of disability worldwide (1). Depending on various populations, regions, and methodologies, the economic impact of spinal pain can total up to billions of dollars, which creates a significant burden for both society and individuals (2). Listed as the fourth leading cause of disability-adjusted life years, low back pain and neck pain have become a global challenge, with an increase of 18.7% from 2005 to 2015 (3).

The treatments for spinal pain are comprehensive, such as reassurance, medication, acupuncture, and electrotherapy. (4). However, a definitive cure for spinal pain has yet to be discovered, leaving many patients struggling to find effective relief. The first-line medication, such as nonsteroidal anti-inflammatory drugs, merely alleviates the symptoms, while an estimated 19% to 23% of patients undergoing spinal surgery need repeat operations with a declining success rate (5). Long-term management of spinal pain is difficult. Patients are difficult to adhere to long-term follow-up, the adjustment and implementation of treatment, and the accurate evaluation and positioning of spinal pain, which requires a lot of time and energy (6).

Artificial intelligence (AI) represents computer systems that resemble and mimic human intelligence. Such technology has been used extensively in assessing medical images and data (7). In the field of spinal pain, AI could transform potentially heterogeneous variables into clinically useful data, thus improving patient management (8). For example, by analyzing and recording large amounts of physiological and behavioral data through artificial intelligence, we can establish pain evaluation models and treatment outcome prediction models, supervise the patients' pain management, and improve the quality of medical services (9,10). With the help of AI, the clinical practitioner could monitor opioid use, optimize stimulation parameters, and regulate the patient's emotions with a more personalized treatment (11).

As a quantitative and statistical technique, bibliometric analysis could assess the literature data for and evaluate the trends in a field (12,13). The literature concerning artificial intelligence for spinal pain has increased in recent years. However, there have been no relevant bibliometric studies that offer a comprehensive insight into the focus of the research and the trends in this field. This study seeks to generalize the trend of this field through bibliometric analysis, predict the field's future trends, and guide the future research focus.

Methods

Data Collection

Obtained from the Web of Science platform [Web of Science Core Collection (WoSCC)], the primary data were found through the search formula TS = ("neck pain*" OR "neckache*" OR "neck ache*" OR "cervicalgia" OR "trachelodynia" OR "cervicodynia" OR "cervical pain*" OR "back pain*" OR "back ache*" OR "backache*" OR "lumbago" OR "lumbar pain*" OR "spinal pain*" OR "musculoskeletal pain*" OR "pelvic pain*" OR "thoracic pain*" OR "thoracic spine pain*" OR "cervical spine pain*" OR "lumbar spine pain*") AND TS=("Machine Learning" OR "Artificial* Intelligen*" OR "Deep Learning" OR "Neural Network" OR "Natural Language" OR "computer vision" OR "virtual reality" OR "wearable device*" OR "wearable sensor*"). Additionally, only English-language publications were considered, and the type of publication was restricted to articles. Moreover, the temporal scope was not limited. Adhering strictly to the criteria, 2 researchers conducted the review of the articles about artificial intelligence for spinal pain. In cases of disagreement concerning the exclusion, a third researcher would evaluate the literature to decide whether to retain it or not. The whole process of data collection and evaluation is displayed in Fig. 1. The Web of Science Core Collection is a publicly available database that collects literature from various sources, and ethical approval is therefore not required.

Analysis Methods

Our study primarily utilized 2 techniques, the R software package Bibliometrix and the Java application CiteSpace. The Bibliometrix package serves mainly to summarize publications by and citations of various authors, institutions, and countries and to develop network maps of collaborations, historiography, strategic coordinate maps, trending topics, and the evolution of research themes. Additionally, by facilitating cluster analyses, CiteSpace enables the identification of key words and references with citation bursts.

Our focus encompassed the following areas:

1. Analyzing the current state of research on artificial intelligence for spinal pain through the literature and clusters of key words.
2. Identifying the research focus and trends through the citation analyses, with an emphasis on interdisciplinary information.
3. Identifying prominent authors and their respective research trajectories, while exploring the cooperation among countries, institutions, and authors.

Results

Publication and Citation Trends

As shown in Fig. 2A, the annual publications (blue bars) change slightly before 2012 and begin a trend of significant increase from 2012 to 2023. Moreover, the cumulative publications curve (red curve) also shows a turning point around 2019, after which the number of cumulative publications soars dramatically. Fig. 2B depicts the fluctuation of average citations per year, which have

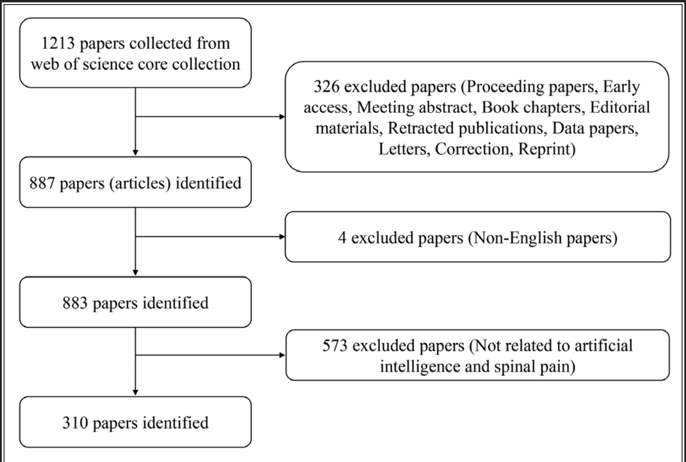

Fig. 1. *The screening process for the literature selected for this study.*

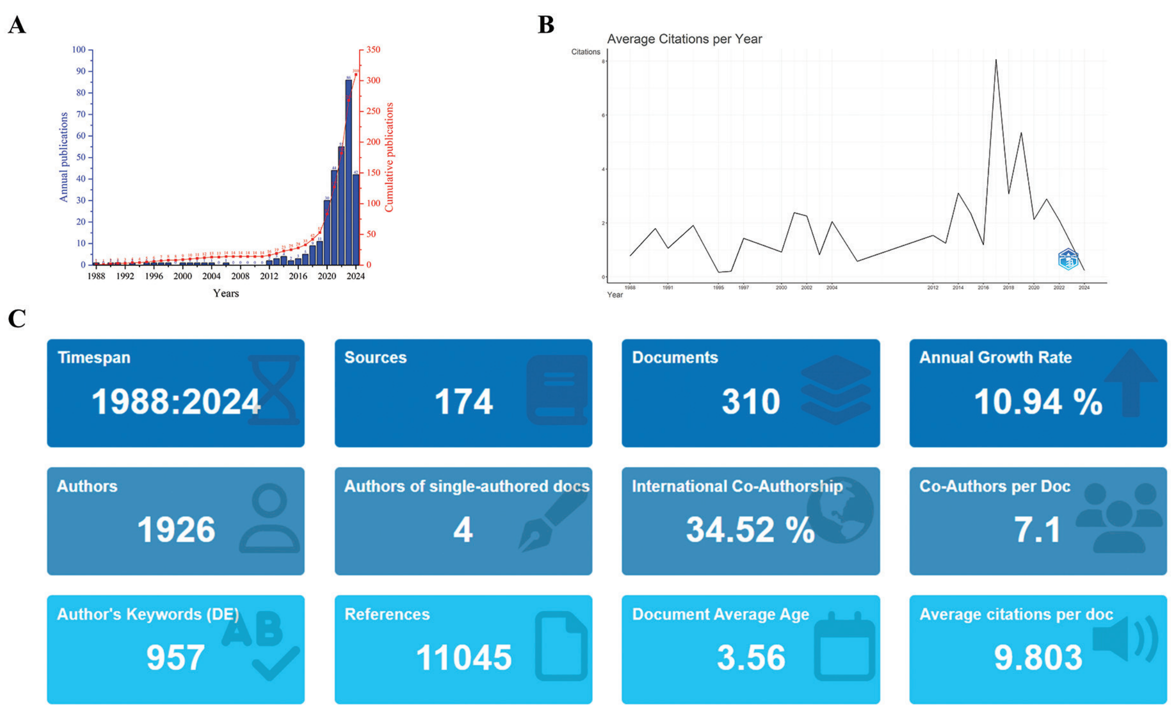

Fig. 2. *(A) Annual trends in publications. (B) Average citations per year. (C) Main information of data for bibliometric analysis.*

obviously increased since 2016. The main information of this bibliometric analysis is showcased in Fig. 2C.

Analysis of Institutions and Countries

As illustrated in Fig. 3A, the inter-country collaboration is represented by connecting lines, with circles indicating countries with particularly strong collaborative ties. The USA and UK, the respective centers of the red circle and purple circle, have significant cooperation with each other and close collaboration with the other countries within their circles. Fig. 3B delineates the collaborative efforts among various institutions, and the main institutions contain Harvard University, the University of California system, the Norwegian University of Science and Technology, the University of Zurich, and so on. The primary research focuses of the countries and institutions are represented in Fig. 3C, in which countries, key words, and institutions are positioned on the left, center, and right, respectively. Moreover, the thickness of the lines that link these items reflects the number of studies undertaken by respective countries or institutions.

In accordance with the publications and citations, 20 countries are ranked respectively in Table 1. The country with the most publications is the US (67), followed by China (43) and Germany (24). As for the citations, the total citations associated with the US are 1,049, followed by the UK (374) and the Netherlands (244). The US takes the lead in this field with the highest number of both publications and citations. China takes the second place in number of publications but ranks fourth in terms of citations. Furthermore, most of the countries in the lists are developed countries.

As shown in Table 2, the institutions that have published the greatest number of articles are the University of Washington (40) and University of Washington Seattle (40), followed by the University of California system (35) and State University System of Florida (17). Most of the listed institutions are situated in the US.

Analysis of Authors

As illustrated in Fig. 4A, the diameter of the dots corresponds to the quantity of articles, while the intensity of color indicates the total number of citations per year. Most authors listed in Fig. 4A have exhibited a stable production period in recent years, and Bach K, Mork PJ, and Liew BXW, et al have high recent rates of production and citations. Table 3 shows that Bach K and Mork PJ have

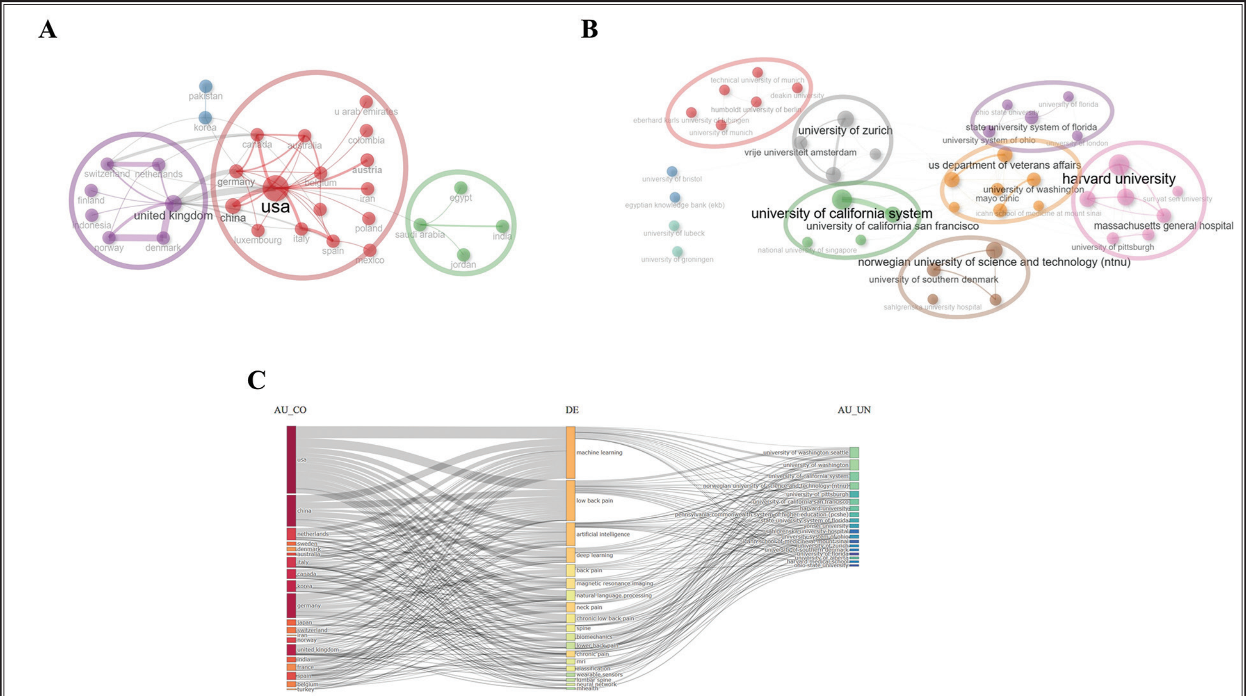

Fig. 3. *The analysis of the countries and institutions. (A) Network map of collaborations among different countries. (B) Network map of collaborations among different institutions. (C) The 3-field plot of countries, institutions, and keywords.*

Table 1. *The top 20 countries with the most publications and citations.*

Ranking	Country/Region	Articles	Developed	Country/Region	Total Citations	Average Article Citations	Developed
1	USA	67	Yes	USA	1049	15.7	Yes
2	China	43	No	United Kingdom	374	16.3	Yes
3	Germany	24	Yes	Netherlands	244	20.3	Yes
4	United Kingdom	23	Yes	China	235	5.5	No
5	South Korea	19	Yes	Germany	135	5.6	Yes
6	Canada	13	Yes	Denmark	104	17.3	Yes
7	Italy	12	Yes	Korea	100	5.3	Yes
8	Netherlands	12	Yes	Canada	95	7.3	Yes
9	India	11	No	Iran	95	13.6	No
10	Japan	9	Yes	Italy	93	7.8	Yes
11	Norway	8	Yes	Japan	71	7.9	Yes
12	Iran	7	No	India	43	3.9	No
13	Australia	6	Yes	Jordan	35	17.5	No
14	Denmark	6	Yes	Singapore	30	15	Yes
15	Spain	4	Yes	Sweden	30	7.5	Yes
16	Sweden	4	Yes	Turkey	27	6.8	No
17	Turkey	4	No	France	25	12.5	Yes
18	Austria	3	Yes	Switzerland	24	8	Yes
19	Belgium	3	Yes	Australia	20	3.3	Yes
20	Switzerland	3	Yes	Spain	19	4.8	Yes

Table 2. *The top 10 institutions by number of publications.*

Ranking	Affiliation	Articles	Country/Region
1	University of Washington	40	America
2	University of Washington Seattle	40	America
3	University of California System	35	America
4	State University System of Florida	17	America
5	University of Alberta	21	Canada
6	Harvard University	25	America
7	Norwegian University of Science and Technology (NTNU)	35	Norway
8	Pennsylvania Commonwealth System of Higher Education (PCSHE)	18	America
9	University of Pittsburgh	18	America
10	University of California San Francisco	28	America

published the greatest number of articles at 8 papers, followed by Liew BXW and Nordstoga A (6 articles each). Fig. 4B ranks the authors based on their local impact by the H index, which serves as an indicator of their scientific productivity and research influence. According to the H index, Mair FS and Wood K emerge as the top 2 authors, with high levels of production and citation. The network map presented in Fig. 4C illustrates the collaborative relationships among the authors. Based on the local citations, both Bach K and Nordstoga A have 25 total citations, followed by Bach K (24 citations), Mair FS (21 citations), and Wood K (21 citations). Notably, the authors within the purple circle and the blue circle exhibit strong connections, such as Mork PJ and Wool K.

Analysis of Journals

Fig. 5A illustrates the temporal trends in publication output for different sources, which indicates a significant increase in the number of publications around the year 2020 across nearly all listed journals. As shown

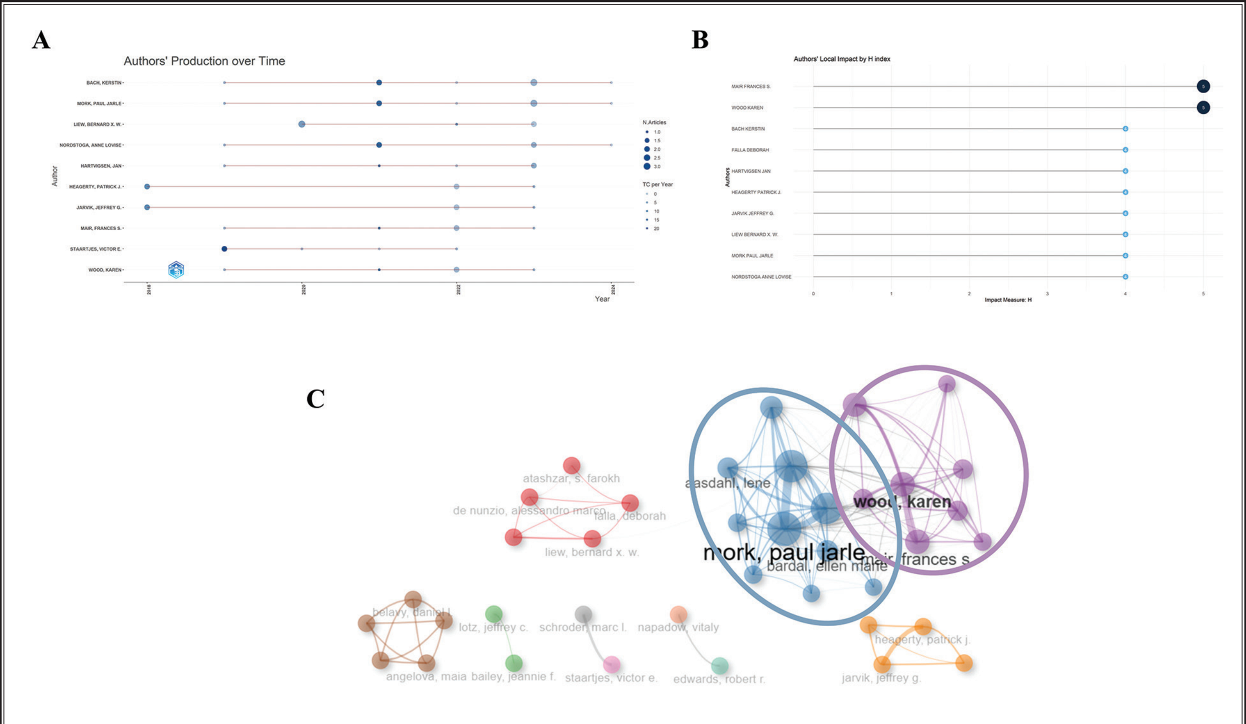

Fig. 4. *The analysis of the authors. (A) The authors' production over time that with the most publications. (B) The authors' impact by H index. (C) Network map of collaborations among different authors.*

Table 3. *The top 15 authors by number of publications and local citations.*

Authors	Articles	Country/Region	Author	Local Citations	Country/Region
Bach, Kerstin	8	Norway	Mork, Paul Jarle	25	Norway
Mork, Paul Jarle	8	Norway	Nordstoga, Anne Lovise	25	Norway
Liew, Bernard X. W.	6	England	Bach, Kerstin	24	Norway
Nordstoga, Anne Lovise	6	Norway	Mair, Frances S.	21	England
Hartvigsen, Jan	5	Denmark	Wood, Karen	21	England
Heagerty, Patrick J.	5	USA	Hartvigsen, Jan	20	Denmark
Jarvik, Jeffrey G.	5	USA	Overas, Cecilie K.	19	Norway
Mair, Frances S.	5	England	Sandal, Louise Fleng	19	Denmark
Staartjes, Victor E.	5	Switzerland	Sogaard, Karen	19	Denmark
Wood, Karen	5	England	Cooper, Kay	18	England
Aasdahl, Lene	4	Norway	Kjaer, Per	18	Denmark
Falla, Deborah	4	England	Rasmussen, Charlotte Diana Norregaard	18	Denmark
Lotz, Jeffrey C.	4	USA	Sjogaard, Gisela	18	Denmark
Nilsen, Tom Ivar Lund	4	Norway	Stochkendahl, Mette Jensen	18	Denmark
Schroder, Marc L.	4	Netherlands	Svendsen, Malene Jagd	18	Denmark

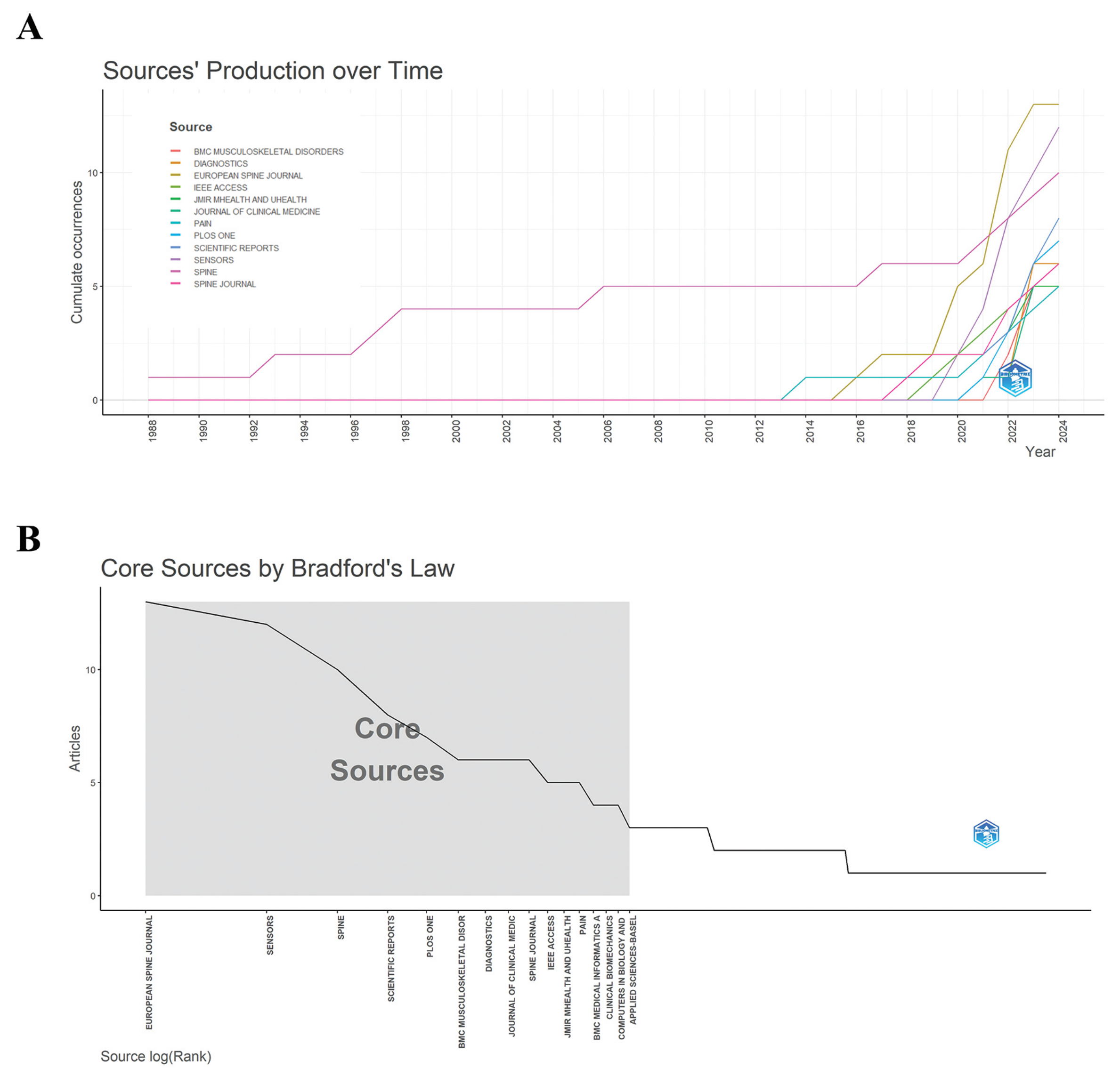

Fig. 5. *The analysis of the journals. (A) The journals' production over time that with the most publications. (B) The core journals based on Bradford's law.*

in Table 4, the *European Spine Journal* (13 publications, Q1, IF2.6), *Sensors* (12 publications, Q2, IF3.4), and *Spine* (10 publications, Q1, IF2.6) are the leading journals in terms of publication volume. Following Bradford's law, Fig. 5B identifies the core journals within the field that have published some of its most influential findings. Furthermore, according to the local citations listed in Table 5, *Spine* (673 citations, Q1, IF2.7) takes the lead, followed by *Pain* (362 citations, Q1, 5.9) and the *European Spine Journal* (310 citations, Q1, IF2.6).

Analysis of References

As shown in Fig. 6A, several clusters are distinguished by various colors, which can be categorized into spinal pain (#0, mHealth; #1, sciatica; #4, functional regression; #3, nociceptive withdrawal reflex) and artificial intelligence (#2, active contour model; #5, support vector machine; #7, probabilistic neural network; #11, artificial neural network). The historiograph in Fig. 6B shows the most important literature (dots) in the development (arrows) of this field.

Table 4. *The top 10 journals by number of publications.*

Ranking	Journal	Frequency	JCR Category	Category rank 2023	Category quartile 2023	IF 2023
1	European Spine Journal	13	Orthopedics; Clinical Neurology	30/136; 122/280	Q1; Q2	2.6
2	Sensors	12	Chemistry, Analytical; Engineering, Electrical & Electronic; Instruments & Instrumentation	34/106; 122/353; 24/76	Q2; Q2; Q2	3.4
3	Spine	10	Orthopedics; Clinical Neurology	27/136; 112/280	Q1; Q2	2.7
4	Scientific Reports	8	Multidisciplinary Sciences	25/134	Q1	3.8
5	PLoS ONE	7	Multidisciplinary Sciences	32/134	Q1;	2.9
6	BMC Musculoskeletal Disorders	6	Orthopedics; Rheumatology	42/136; 29/57	Q2; Q3	2.2
7	Diagnostics	6	Medicine, General & Internal	59/329	Q1	3.0
8	Journal of Clinical Medicine	6	Medicine, General & Internal	59/329	Q1	3.0
9	Spine Journal	6	Orthopedics; Clinical Neurology	5/136; 35/280	Q1; Q1	4.9
10	IEEE Access	5	Engineering, Electrical & Electronic; Computer Science, Information Systems; Tele communications	122/352; 87/250; 47/119	Q2; Q2; Q2	3.4

Table 5. *The top 10 journals by number of local citations.*

Ranking	Journal	Frequency	JCR Category	Category Rank 2023	Category Quartile 2023	IF 2023
1	Spine	673	Orthopedics; Clinical Neurology	27/136; 112/280	Q1; Q2	2.7
2	Pain	362	Anesthesiology; Clinical Neurology; Neurosciences	4/64; 24/280; 34/310	Q1; Q1; Q1	5.9
3	Eur Spine Journal	310	Orthopedics; Clinical Neurology	30/136; 122/280	Q1; Q2	2.6
4	Spine Journal	207	Orthopedics; Clinical Neurology	5/136; 35/280	Q1; Q1	4.9
5	Lancet	185	Medicine, General & Internal	1/329	Q1	98.4
6	PLoS ONE	161	Multidisciplinary Sciences	32/134	Q1	2.9
7	BMC Musculoskel Disorders	139	Orthopedics; Rheumatology	42/136; 29/57	Q2; Q3	2.2
8	Journal of Biomechanics	119	Biophysics; Engineering, Biomedical	46/77; 73/123	Q3; Q3	2.4
9	Neuroimage	117	Neuroimaging; Neurosciences; Radiology, Nuclear Medicine & Medical Imaging	1/15; 63/310; 22/204	Q1; Q1; Q1	4.7
10	Lecture Notes in Computer Science	101	/	/	/	/

The top 25 references by number of strong citation bursts are listed in Fig. 6C, which shows 2 burst timings around 1996 and 2020 with concentrated outcomes. Table 6 and Table 7 show the literature with the most global citations and local citations, respectively.

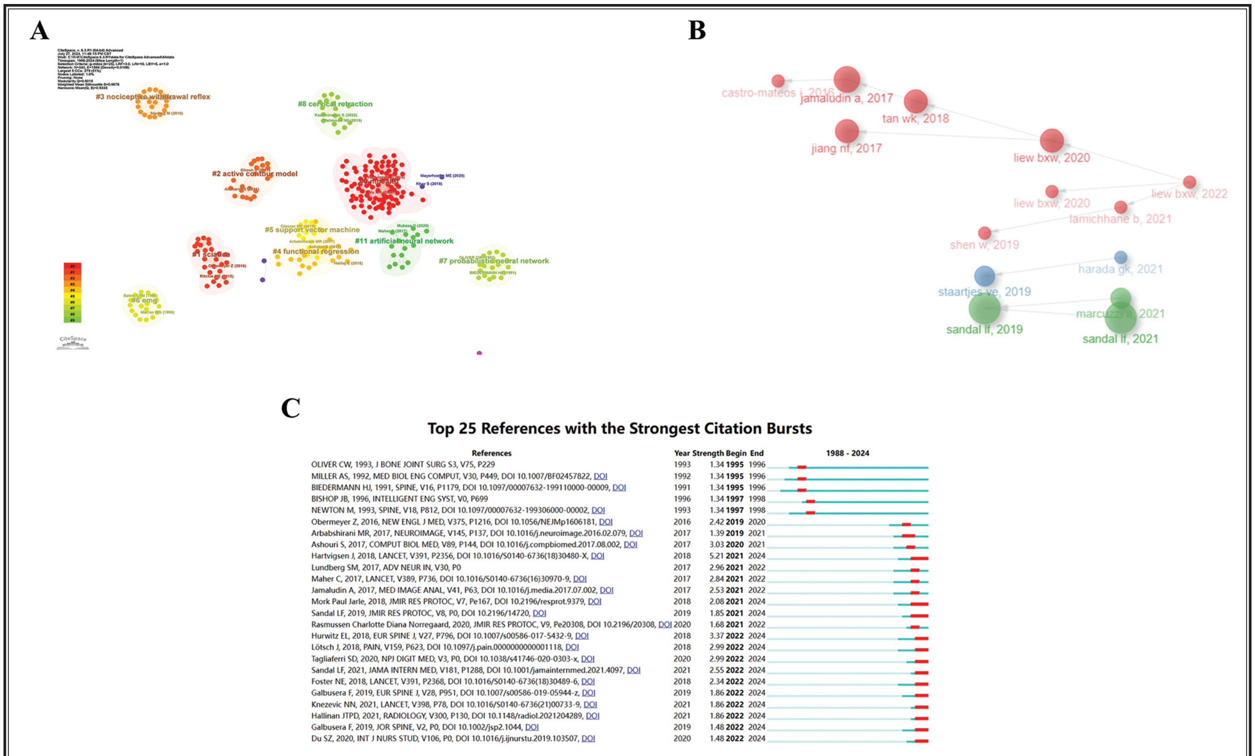

Fig. 6. *The analysis of the references. (A) The cluster of references in the field. (B) The historiographs in the field. (C) Top 25 references with the strongest citation bursts.*

Analysis of Key Words

There are 4 main clusters in Fig. 7A, distinguished by various colors. The red region is related to artificial intelligence, encompassing motion analysis, neural networks, pattern recognition, and so on. The items in the purple clusters are mainly related to spinal pain, while the red region includes items about Mobile Health (mHealth). In Fig. 6B, the timeline view of cluster analysis shows the trends of various research orientations. Machine learning (ML), low back pain (LBP), and magnetic resonance imaging have drawn significant attention in recent years. Trending topics for key words are depicted in Fig. 7C. The diameters represent the quantity of documents, while the line represents their spans. The first quartile in the strategic coordinate map stands for high development and attention, while the fourth quartile reveals the potential of research. As shown in Fig. 7D, the mHealth, neural network, data augmentation, etc. are in the first quartile, while the ML, deep learning, etc. are in the fourth quartile, indicative of their status as subjects receiving focus but lacking investigation.

As demonstrated in Fig. 8A, the evolution of research themes depicts the development and variations of the hotspots. Furthermore, the top 25 key words by number of citation bursts are listed in Fig. 8B, depicting the variations in the research focus over time.

Discussion

Over the past years, the advancement of the application of AI in the domain of spinal pain has been enhanced significantly through interdisciplinary collaborations among the fields of clinical medicine, computer science, engineering, and others. Through the utilization of bibliometric methodologies, this study is designed to investigate the trends surrounding and current status of AI in the treatment of spinal pain.

Due to breakthroughs in the AI field, the annual and cumulative publications faced a turning point around 2019, which was consistent with the peak of the average citations. Most of the countries listed were developed, and every institution included belonged to such a country, reflecting the imbalance among nations. Although the number of publications in China is only slightly lower than in the US, the number of citations in Chinese sources is much lower, indicating a relative deficiency in innovation and creativity. The

Table 6. *The top 10 articles by number of global citations.*

Ranking	Article	Total Citations	TC per Year	First Author (year)	Journal	Country
1	ISSLS Prize In Bioengineering Science 2017: Automation of reading of radiological features from magnetic resonance images (MRIs) of the lumbar spine without human intervention is comparable with an expert radiologist musculoskeletal pain	121	15.13	Jamaludin A (2017)	Eur Spine Journal	England
2	Deep learning-based preoperative predictive analytics for patient-reported outcomes following lumbar discectomy: feasibility of center-specific modeling	70	11.67	Staartjes Ve (2019)	Spine Journal	Netherlands
3	A Comparison of Neural Network and Other Pattern-Recognition Approaches to the Diagnosis of Low-Back Disorders	63	1.80	Bounds Dg (1990)	Neural Networks	England
4	Visual network alterations in brain functional connectivity in chronic low back pain: A resting state functional connectivity and machine learning study	62	10.33	Shen W (2019)	Neuroimage-Clinical	USA
5	Initial-Impression Diagnosis Using Low-Back-Pain Patient Pain Drawings	61	1.91	Mann Nh (1993)	Spine	USA
6	Effectiveness of app-delivered, tailored self-management support for adults with lower back pain-related disability: A selfBACK randomized clinical trial	60	15.00	Sandal Lf (2021)	JAMA Internal Medicine	Denmark
7	Lumbar loading during lifting: A comparative study of three measurement techniques	57	2.38	Kingma I (2001)	Journal of Electromyography and Kinesiology	Netherlands
8	Multivariate resting-state functional connectivity predicts responses to real and sham acupuncture treatment in chronic low back pain	54	9.00	Tu Yh (2019)	Neuroimage-Clinical	USA
9	Relationship between pain and vertebral motion in chronic low-back pain subjects	52	2.26	Dickey Jp (2002)	Clinical Biomechanics	Canada
10	Machine learning-based preoperative predictive analytics for lumbar spinal stenosis	50	8.33	Siccoli A (2019)	Neurosurgical Focus	Netherlands

Chinese papers in this field lack pioneering research and focus mainly on the application of existing technical models. AI research in China started at a relatively late time. In contrast, the US, the nation associated with the most citations, was earlier in beginning its AI research, occupies a leading position in this area, and has a relatively strong academic influence (14). It is also possible that in the countries associated with low numbers of citations, relatively little cooperation occurs among researchers and academic exchanges are not sufficiently close, which may cause papers written by authors from these nations to have less impact. We also find that the institutions from the US have an intense collaboration with others. Notably, the institutions where intense cooperation takes place also have higher numbers of publications, such as the University of California system (35 articles). This finding indicates the essential status of cooperation.

Paul Jarle Mork was the author whose byline appeared on the greatest number of publications and in the largest quantity of citations, showing a long devotion to the application of AI. Through the utilization of ML, patient-reported outcome measurements were applied to clinical decision-making (15). Based on AI algorithms, the selfBACK app offers weekly health recommendations personalized by patients' states, reducing pain-related disability (16). The selfBACK app could support self-management of spinal pain, a practice facilitated by action plans and health factors and weakened by the mode and novelty (17). Notably, the top 2 authors by number of collaborations in the work described above come from Norway. Researchers can study the results published by the authors listed in Table 3, which stands for the leading edge of the field.

Of the top 10 journals by number of publications and citations, most were above Q2 and belonged to the category of clinical neurology. Moreover, the various categories of journals reflected the efforts of researchers in clinical medicine,

Table 7. *The top 10 articles by number of local citations.*

Ranking	Literature	Local Citations	First Author (Year)	Journal	Country
1	An app-delivered self-management program for people with low back pain: Protocol for the selfBACK randomized controlled trial	9	Sandal LF (2019)	JMIR Res Protoc	Denmark
2	Effectiveness of app-delivered, tailored self-management support for adults with lower back pain-related disability: A selfBACK randomized clinical trial	9	Sandal LF (2021)	JAMA Intern Med	Denmark
3	Supervised methods for detection and segmentation of tissues in clinical lumbar MRI	7	Ghosh S (2014)	Comput Med Imag Grap	USA
4	ISSLS Prize in Bioengineering Science 2017: Automation of reading of radiological features from magnetic resonance images (MRIs) of the lumbar spine without human intervention is comparable with an expert radiologist	6	Jamaludin A (2017)	Eur Spine J	England
5	A machine learning-based surface electromyography topography evaluation for prognostic prediction of functional restoration rehabilitation in chronic low back pain	5	Jiang NF (2017)	Spine	China
6	Comparison of natural language processing rules-based and machine-learning systems to identify lumbar spine imaging findings related to low backpain	5	Tan WK (2018)	ACAD Radiol	USA
7	Interpretable machine learning models for classifying low back pain status using functional physiological variables	5	Liew BXW (2020)	Eur Spine J	England
8	Prediction of low back pain with two expert systems	4	Sari M (2012)	J Med Syst	Turkey
9	Evaluation of three machine learning models for self-referral decision support on low back pain in primary care	4	Nijeweme-D'hollosy WO (2018)	Int J Med Inform	Netherlands
10	Boundary delineation of MRI images for lumbar spinal stenosis detection lough semantic segmentation using deep neural networks	4	Al-Kafri AS (2019)	IEEE Access	England

engineering, and computer science. As did the analysis of countries and institutions, the journals' quantity of production also experienced a sharp increase around 2020. Therefore, the researchers from the above disciplines could study the outcomes published in those journals and contribute their own work to the field of AI in spinal pain.

The research focuses we generalized based on the clustering of literature and key words are as follows.

Mobile Health

In recent years, the continuing development of computer hardware technology has greatly improved the performance of computers and provided hardware support for the training of complex AI models. At the same time, the ongoing generation and iteration of new AI technologies have also provided new strategies and ideas for the development of AI applications in the medical field (18-20). With the popularization of mobile phones, mHealth is expanding its application settings, benefitting from its mobility, instantaneous access, and direct communication (21). SelfBACK, an AI-based mobile phone app, is designed to offer recommendations including education, physical activity, and exercises, aiming at improving the self-management of LBP patients (22). A series of research has been conducted to evaluate the effectiveness of selfBACK, study the factors of implementation, and investigate the effects of baseline duration and intensity of LBP, which display the good performance and potential of AI-based apps in public self-management (22-25). Moreover, an AI-assisted health program that sends exercise instructions to users via a chatting app (LINE) has been proven to improve patients' symptoms (26). Currently, more efforts are put into self-management rather than pharmacological and surgical therapies (27). We speculate that the AI-assisted self-management app will become part of a mainstream lifestyle, substituting for traditional therapies to some extent in the future.

Magnetic Resonance Imaging

Because of its excellent tissue contrast, magnetic resonance imaging (MRI) can assess the spinal cord and its surrounding tissues directly, providing imaging of lesions of intrinsic focal intrasubstance (28). Based on 12,018 data points graded by a radiologist, a system

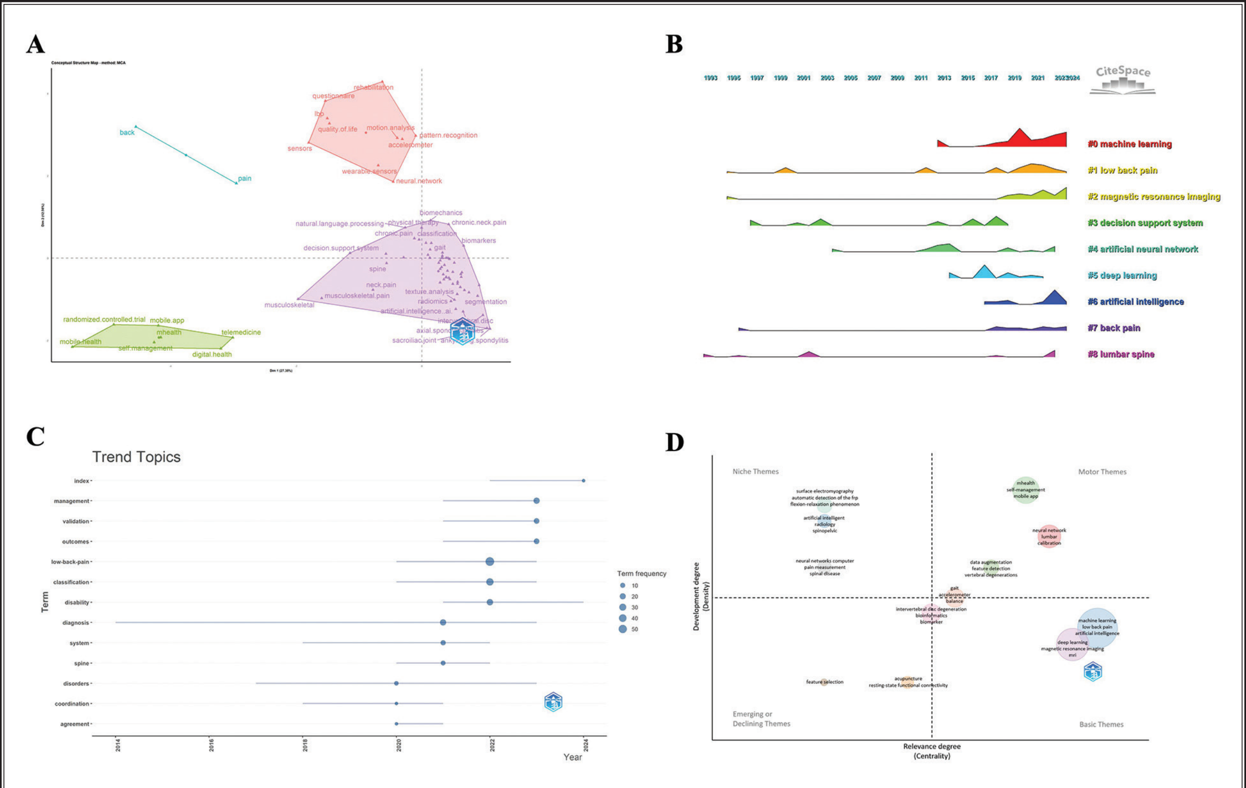

Fig. 7. *The analysis of the key words. (A) The cluster of key words. (B) Timeline view of cluster analysis of key words. (C) Trending topics for key words. (D) The strategic coordinate map of key words.*

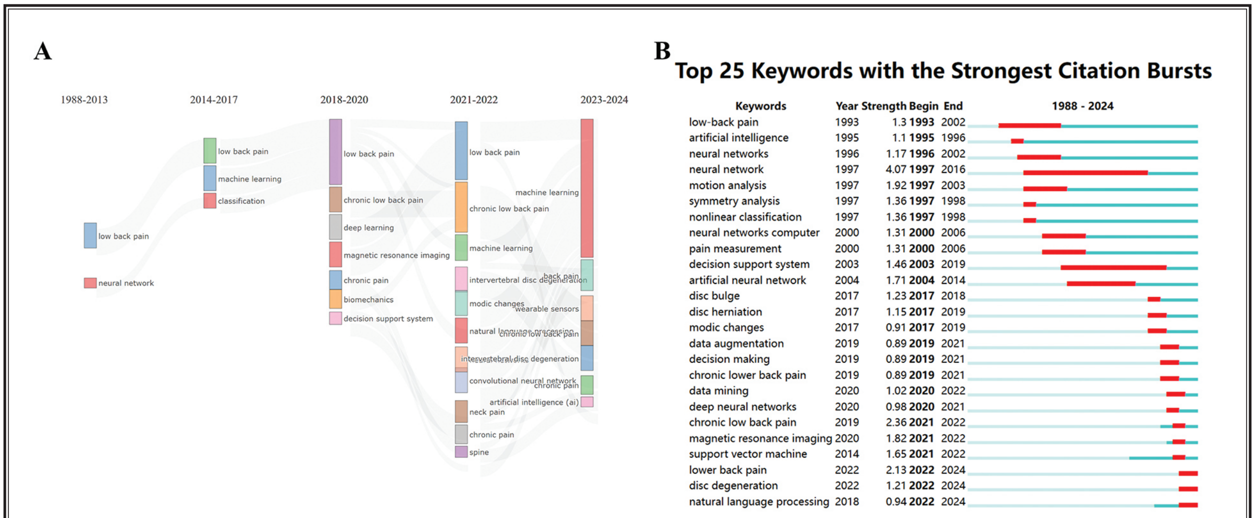

Fig. 8. *The analysis of the research themes. (A) Evolution of research themes in the field from 1988 to 2024. (B) Top 25 key words with the most citation bursts.*

for detecting and labeling anatomical structures and a convolutional neural network model for radiological gradings were established. The system and model achieved 95.6% accuracy (29). This outcome received the ISSLS Prize in 2017, reflecting the potential of AI-assisted MRI techniques. Moreover, with the utilization of image segmentation, boundary delineation is applied to the locating of 4 important anatomical structures, with great performance and interrater agreement (30). Besides its excellent performance in analysis, classification, and grading, AI can also be adopted for the purpose of imaging, which may reduce the amount of time spent and improve image quality (31).

Furthermore, spinal pain can cause structural and functional changes in the brain, which may be detected by MRI. Cerebral cortical thickness, resting-state functional connectivity, disruptions in cortical functional connectivity, and habenular connectivity patterns have been verified as potential imaging biomarkers of chronic low back pain (cLBP). In the above studies, the support vector machine (SVM) was applied extensively in the classification of patients' pain conditions (32-34). As a supervised ML method, the SVM has exhibited great performance in classifying dysfunctional patterns of the brain (35). In the classification of cLBP and HCs, SVM achieved an accuracy of 75.9% in the training dataset, which ranks second compared to linear regression and random forest plots (34). In addition to the analysis of images, natural language processing (NLP) is appealing to researchers for its ability to analyze imaging reports. Based on radiology reports that include x-ray, CT, and MRI results, the NLP system may discover findings related to LBP and thus potentially affect clinical decision-making and large-scale research (36).

The combination of AI and medical imaging may have great potential, especially in improving the diagnosis, classification, and prediction of spinal pain.

Clinical Decision-Making

Having expanded beyond its applications in medical imaging, AI is entering the medical domain in many ways, including being used to diagnose rare and common diseases (37). Large amounts of AI and ML techniques have been tested, including the XGBoost algorithm, regression tree (CART) analysis, random forest, and so on, which show great potential as supportive clinical tools to facilitate patients' treatments and lower medical costs (38-40). Even ChatGPT, a popular chatbot program developed by OpenAI, could generate a questionnaire about LBP, with robust correlations with 4 clinical questionnaires (41). Though not mature enough, the possibility still shows great potential. Combinations of clinical diagnosis and AI is of great promise in assistant treatments for spinal pain.

Citation burst analysis, strategic coordinate maps of key words, topic evolution analysis, and historiography can be used in the analysis of research focus and trends in spinal pain treatment. The outbreak of AI has brought rapid development into this field. Deep learning networks, one of the topics to see a citation burst in the papers studying the management of chronic pain, have no need for specific feature representations and detectors to be able to analyze data holistically, unlike other ML techniques (42). Applied extensively in the identification of back pain, deep learning networks utilize kinematic or static data collected by various sensors, differentiating patients from one another and providing medical feedback (42-44).

In the development of AI-assisted spinal pain therapies, 3 pathways can be identified based on the historiograph. Firstly, the diagnosis, classification, and prediction combined with AI are the most active domains. Despite originating from MRI assistant applications, the medical use of AI is no longer limited to imaging. The scenarios in which AI can be applied have increased, including the prediction of post-surgical recovery, the establishment of prognostic modeling, and the analysis of functional physiological variables (45-47). The second orientation is the development of self-management apps, especially the selfBACK app, which facilitates management for people with disabilities related to spinal pain (17,23,48). Finally, the lumbar discectomy, an effective therapy for lumbar disc herniation, can be used to predict a patient's improvement prospects and risk of recurrence, allowing for the avoidance of unnecessary surgeries and reducing relative risks (49,50). Machine learning can process and analyze huge data sets and extract valuable information from them, thus establishing more accurate and effective models for prediction. Moreover, machine learning systems are self-adaptive and can constantly optimize their performance to adapt to different scenarios and environments during training (51-53). Of course, there are also some practical problems to be solved in the application of AI in the medical field, especially the problems related to data quality, patient privacy, and the division of responsibility for accidents in clinical work assisted by AI tools (54,55). Due to uneven data quality or the limitations of the algorithm itself (56), the models trained by AI are biased, which also limits the breadth of its application to a certain extent.

Limitations

To the best of our knowledge, this study is the first bibliometric analysis of the use of AI for spinal pain treatment that shows the research focuses and trends in the field. However, there are also some limitations in this study. Only the English-language articles in the WoSCC database are included, and proceeding papers, meeting abstracts, and book chapters are excluded. Additionally, no articles from other databases were included.

Conclusion

The appearance of AI has altered the field of pain medicine and eased the burden on the public. Interdisciplinary researchers, from clinical medicine, computer science, and engineering, are devoted to the field of AI. Through its good performance, AI has shown its potential in various domains of the treatment of spinal pain. In conclusion, AI has brought expansive prospects to pain medicine, and the related interdisciplinary efforts indicate improvements in the treatment of spinal pain

Author Contributions

This study was designed by Sheng Yang, Guoxin Fan and Xiang Liao. Chaobo Feng, Zhuoxi Zhou and Yongen Miao were involved in data curation, methodology, visualization, and the writing of original draft, and the results were critically examined by all authors. The manuscript was edited by Guoxin Fan and Xiang Liao. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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