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ORIGINAL RESEARCH

Global Trends and Hotspots of Minimally Invasive Surgery in Lumbar Spinal Stenosis: A Bibliometric Analysis

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Objective: The popularity of minimally invasive surgery for lumbar spinal stenosis (LSS) has been steadily increasing worldwide. This study aims to conduct a comprehensive bibliometric analysis to identify global trends and hotspots in the research related to this surgical approach.

Methods: Select articles related to the field that were retrieved from the Web of Science Core Collection (WoSCC) between January 1, 1993 and December 31, 2022. Visualization of networks and in-depth bibliometric analyses, including the number of publications, countries/regions, institutions, journals, authors, keywords, and references, were conducted using VOSviewer and CiteSpace software.

Results: A total of 1197 papers were identified over a three-decade period, with the highest production year being 2022, which saw 171 papers published. The most prolific countries/regions were the United States (279) and Harvard Medical School (59). Among journals, *Spine* (3289 citations) was the most cited, while *World Neurosurgery* (98 publications) had the highest number of publications. Lewandrowski, Kai-Uwe (29 publications) wrote the most articles, and Ahn, Y (239 citations) ranked first among cited authors. The most frequently used keyword was "discectomy", but recent years have shown a strong emergence of keywords such as "microendoscopic decompressive laminotomy", "foraminotomy" and "classification".

Conclusion: The United States and China have emerged as leaders in the field of minimally invasive surgery for LSS. Endoscopic spinal surgery is recognized as a critical approach, with ongoing research focused on indications, potential complications, minimally invasive anatomical approaches, and outcomes. Furthermore, there is a strong emphasis on optimizing the surgical process, which has become a trending and hot spot in current research. The improvement of surgical techniques is at the forefront of advancements in this field.

Keywords: bibliometric, endoscopes, hotspot, lumbar spinal stenosis, minimally invasive surgery

Introduction

Lumbar spinal stenosis (LSS) is a condition characterized by various clinical symptoms that arise from the narrowing of the lumbar spinal canal due to various causes. Degenerative changes in the lumbar spine are widely regarded as one of the primary causes of this stenosis.[1] LSS is one of the types of spine surgeons to diagnose and treat common geriatric clinical symptoms.[2] Although the precise incidence of LSS is uncertain, it is estimated that approximately 5 out of 100,000 adults over the age of 65 develop this condition each year. Additionally, studies indicate that around 14% of patients experiencing low back pain have LSS as the underlying cause.[3] In a population-based imaging study, LSS was

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detected in approximately 20% of subjects over the age of 60, and this prevalence increased to up to 80% among the 70 subjects aged 70 years or older.

Common symptoms associated with LSS include lower back and lower limb pain, numbness, as well as neurogenic intermittent claudication. This condition typically progresses slowly over time. The primary goal of treatment is to alleviate pain and preserve or enhance the patient's ability to carry out daily activities. Initially, conservative approaches are often employed, including bed rest, medication, acupuncture, and physical therapy. Surgical intervention is considered as an adjunct therapy option when patients experience severe pain or a progressive neurological disorder.[4] The decision regarding when surgery should be performed for LSS remains a topic of debate and controversy. There is no definitive consensus on the optimal timing for surgical intervention. The evaluation of the appropriateness of surgery is typically conducted on an individual basis, considering a range of factors. These factors include the patient's needs, the severity of symptoms, the patient's overall health, response to conservative treatment, and the impact of symptoms on daily activities. It is recommended that patients consult with their healthcare providers and specialists to determine the most suitable course of action based on their specific circumstances.[5,6] In a study conducted by Machado et al,[7] the effectiveness of surgical treatment for LSS was examined through a meta-analysis. The authors noted that the relative efficacy of different surgical treatments for LSS remains uncertain. However, it is important to highlight that LSS is the leading cause of spine surgery in individuals over 65 years of age.[8] Furthermore, the number of surgical procedures performed annually for LSS is on the rise, particularly for minimally invasive surgical approaches.[9,10] This trend can be attributed to the increased functional expectations and longer life expectancy of LSS patients.

The advantages of minimally invasive surgery for LSS are increasingly recognized by both doctors and patients. These advantages include shortening the duration of surgery, reducing the likelihood of procedure-related complications, and enabling early mobilization, among others.[11,12] Consequently, the indications for minimally invasive surgery are expanding.

Therefore, in recent years, there has been a growing academic interest worldwide in the field of minimally invasive surgery for LSS, resulting in a significant increase in related literature. Scholars seeking to gain a comprehensive understanding of this field face the challenge of effectively identifying influential papers. The rapid advancement of modern information technology has had a profound impact on medicine and public health, providing new opportunities for managing clinical knowledge. Bibliometrics, which is an early 20th-century statistical method combining linguistics, information science, and statistics within the realm of information science, allows for both quantitative and qualitative analysis of journal articles within specific research fields.[13] By assessing the distribution of information and utilizing scientific mathematical techniques to integrate and process data, bibliometric methods reveal advancements made in selected research areas while also predicting valuable avenues for future investigation.[14] However, previous bibliometric analyses evaluating the current state and trends in minimally invasive spinal surgery for LSS seem to be lacking.

In this study, we conducted a visual analysis of publications on minimally invasive surgery for LSS from the Web of Science Core Collection (WoSCC) over the past 30 years. Various aspects, including annual publication trends, countries/regions, institutions, authors, journals, references, and keywords, were examined. The aim of this analysis is to provide insights into the current status, trends, and hotspots in the field for researchers and clinicians interested in LSS, offering valuable references for further exploration and research.

Data Acquisition

In this study, a comprehensive search was conducted across all databases and journals available through the WoSCC. Various terms such as "lumbar spinal stenosis", "lumbar stenosis", "endoscopic", "endoscopy", "minimally invasive spine surgery", and "percutaneous" were used to conduct the search. The search period spanned from January 1, 1993 to December 31, 2022, with data extraction performed on April 1, 2023. A total of 1281 articles were identified. Only original research and review articles written in English were included in the analysis. Several types of publications such as meeting abstracts, editorials, letters, proceedings papers, corrections, news items, book chapters, case reports, retracted publications, reprints, and papers without a WoSCC number were excluded from the analysis. After applying these exclusion criteria, a final total of 1197 publications, consisting of 1035 articles and 162 review articles, were included in the analysis. These publications were then independently reviewed by two researchers.

Data Management Bibliometric Analysis

Following the retrieval and download of data from WoS, they were employed for subsequent bibliometric analysis. The characteristics of publications were examined using WoS, encompassing aspects such as year, country/region, institution, authorship, journal, funding source, citation frequency and H-index. Bibliometric and visual analysis were conducted utilizing VOSviewer 1.6.18 (Leiden University, The Netherlands) and CiteSpace 6.2.R2 (Drexel University, Philadelphia, Pennsylvania, USA). VOSviewer[15] generated knowledge graphs based on author keywords and total link strength (TLS) to evaluate the correlation between different entities like country/institution affiliations, core journals, keywords and references. Additionally, CiteSpace[16] facilitated visual analysis of authors and identification of keyword outbreaks in references. In the visual map created by CiteSpace, each node represents an author or analytical element while connections between nodes indicate collaboration (citation or co-citation), with colors representing different years. The parameters of CiteSpace were set as follows: time slicing (1993–2022), years per slice (1), term source (all selection), node type (choose one at a time), selection criteria (g-index: k = 10).

Results

Publication Outputs and Citation Trends

From 1993 to 2022, the number of annual papers in the field of minimally invasive surgery in LSS increased from 0 to 171, while the number of annual citations increased from 0 to 3723 (Figure 1). Both indicators demonstrate a consistent growth trend over time, with both reaching their peak in 2022.

The evolution of the number of publications can be divided into two distinct stages. The first stage is characterized by slow and steady growth before 2017, with no more than 60 papers published per year, except for 62 papers published in 2017. The second stage represents a period of rapid and substantial growth from 2018 to 2022, with an average of more than 100 publications per year.

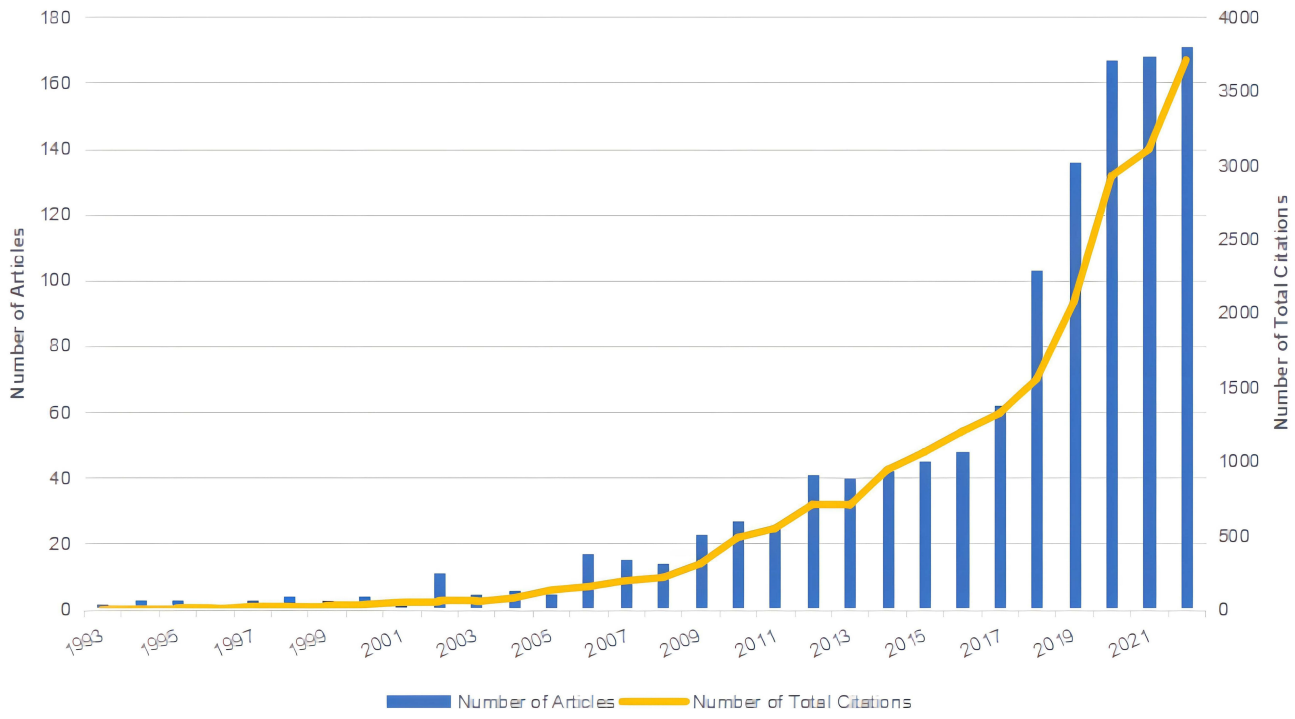

Figure 1 The graph displays the trends in the number of publications and citations from 1993 to 2022 in the field of minimally invasive surgery in LSS. The horizontal axis represents the years, while the left vertical axis represents the number of articles published per year. The right vertical axis indicates the number of total citations per year. The blue bar graph illustrates the number of articles published per year, while the yellow line represents the total number of citations per year.

Analysis of the Countries/Regions

A total of 62 different countries/regions contributed to the study. Table 1 lists the top 10 countries/regions in terms of number of publications. The United States leads with the highest number of papers (n=279; 23.3%), and China (n=237; 19.8%), and South Korea (n=178; 14.9%). In terms of citations, the United States ranks first with 7477 citations, followed by South Korea (3829), and Japan (2197). The United States also has the highest citation average per article (26.8), followed by Germany (24.35), and South Korea (21.51). Additionally, the United States holds the highest academic impact with an h-index of 50, followed by South Korea with an h-index of 36, and Japan ranking third with an h-index of 27. Figure 2 illustrates the analysis of international cooperation between different countries/regions. In Figure 3, a VOSviewer generated overlay visualization map showcases country/region co-authorship analysis, focusing on 32 countries/regions with cooperative relationships. According to the visual analysis, the United States exhibits the highest total link strength (n=170), followed by South Korea (n=92), and Germany (n=75).

Analysis of the Institutions

Table 2 presents the top 10 institutions based on publication numbers. Harvard Medical School (n=59), Rush University (n=25), and Capital Medical University (n=25) emerged as the top three, indicating their significant scientific achievements and research capabilities. Figure 4 depicts a visual analysis of 93 institutions with cooperative relations. Among them, Sanitas University Foundation exhibited the highest total link strength (n=74), followed by Surgical Institute of Tucson (n=71), and Desert Institute for Spine Care (n=67). These findings highlight the prominence of these institutions in the collaborative network.

Analysis of the Journals

Table 3 presents an overview of the range of journals with the most published articles in the field of minimally invasive surgery for LSS. The journal with the highest number of publications is *World Neurosurgery*, with a total of 98 articles. Following closely are *Spine* with 57 articles and *Pain Physician* with 56 articles. However, it is important to note that despite having fewer total publications compared to *World Neurosurgery, Spine* has the largest number of total citations, with 3289 citations. Additionally, *Spine* has the highest average number of citations per article (57.7) and boasts the highest H-index value of 26, indicating its significant impact and influence in the field. Figure 5 visually represents the co-citation relationships among journals, focusing on journals with a minimum of 20 citations. In this analysis, the top three co-cited journals are *Spine* (1086 co-citations), *European Spine Journal* (825 co-citations), and *Journal of Neurosurgery-Spine* (774 co-citations). These findings further underscore the influential role and collaboration among these journals within the field of minimally invasive surgery in LSS.

Table 1 Top 10 Countries/Regions in Terms of Publication Counts

Rank	Country/Region	Publication (%)	Citations	Average Article Citations	H-Index
1	USA	279 (23.3)	7477	26.80	50
2	China	237 (19.8)	1465	6.18	19
3	South Korea	178 (14.9)	3829	21.51	36
4	Japan	140 (11.7)	2197	15.69	27
5	Germany	49 (4.1)	1193	24.35	20
6	Italy	39 (3.3)	752	19.28	15
7	Taiwan	19 (1.6)	172	9.06	8
8	India	18 (1.5)	165	9.14	7
9	Singapore	8 (0.6)	67	8.36	5
10	Brazil	4 (0.3)	28	7.04	3

Note: H-index represents the maximum number "h" of their articles that have garnered "h" or more citations each.

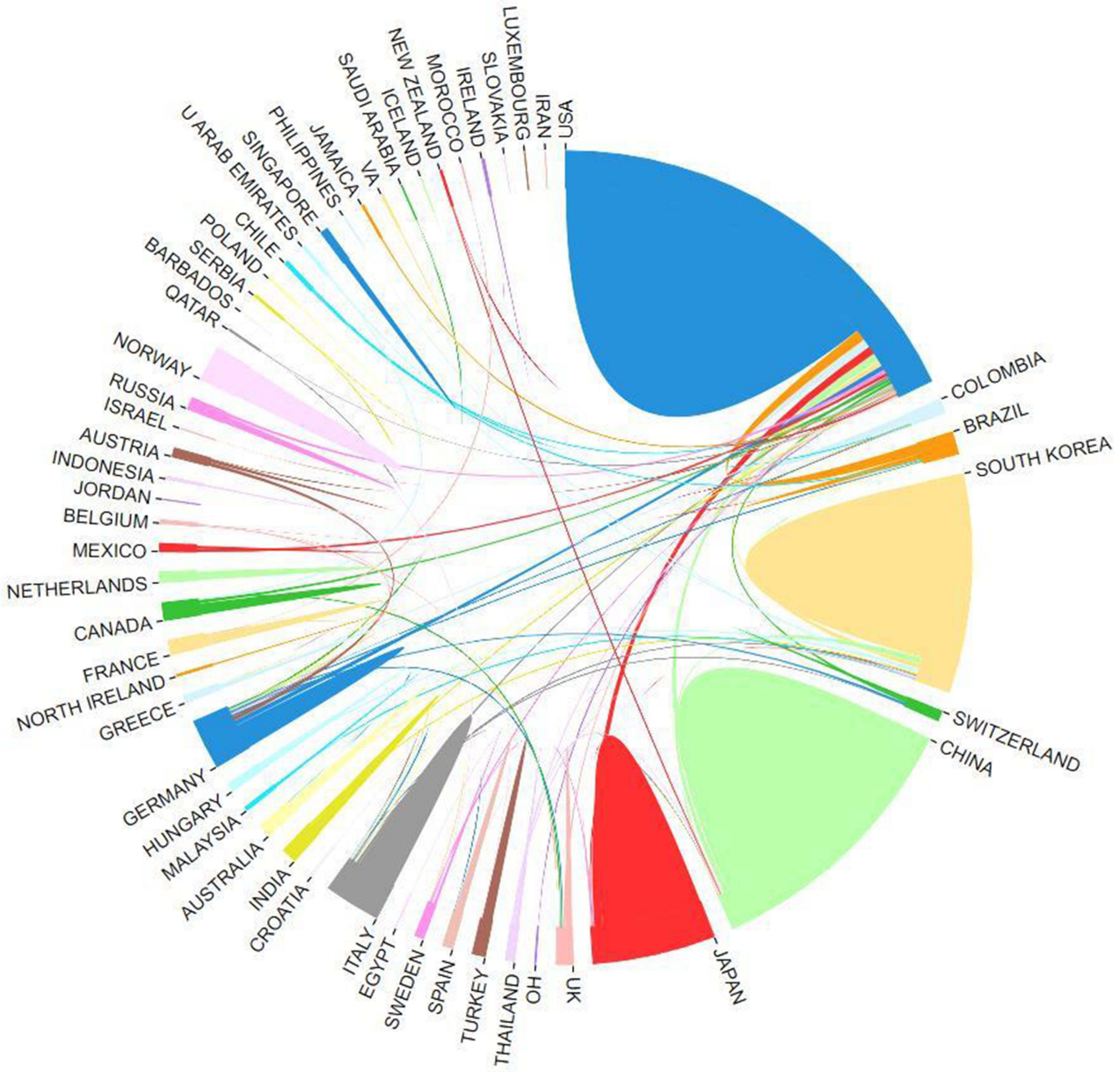

Figure 2 The map depicts the international cooperation network between countries/regions in the field of minimally invasive surgery in LSS. The analysis was conducted using an online bibliometric analysis platform. Different colors represent different countries/regions, with the size of the percentage indicating the number of publications from each country/region. The lines on the map represent connections between countries/regions.

Analysis of the Authors

Table 4 lists the 10 most active and prolific authors in the field, drawn from 731 authors of 1192 papers. Lewandrowski is the most prolific author, with 29 articles to their name. They are followed by Kim Hyeon Sung, who has published 26 articles, and Jang II-Tae, who has contributed 21 articles to the field. Additionally, Table 4 lists the top 10 cited authors based on the number of citations they have received. Ahn, Y is ranked first with 823 citations, followed by Ruetten, S with 227 citations, and Weinstein, JN with 205 citations. The location map of the cited author network, as depicted in Figure 6, encompasses a total of 974 nodes (representing authors) and 6109 links (representing cocitation relationships between authors). This network visualization helps illustrate the interconnectedness and collaboration among authors in the field, highlighting their collective impact in advancing research and development in minimally invasive surgery for LSS.

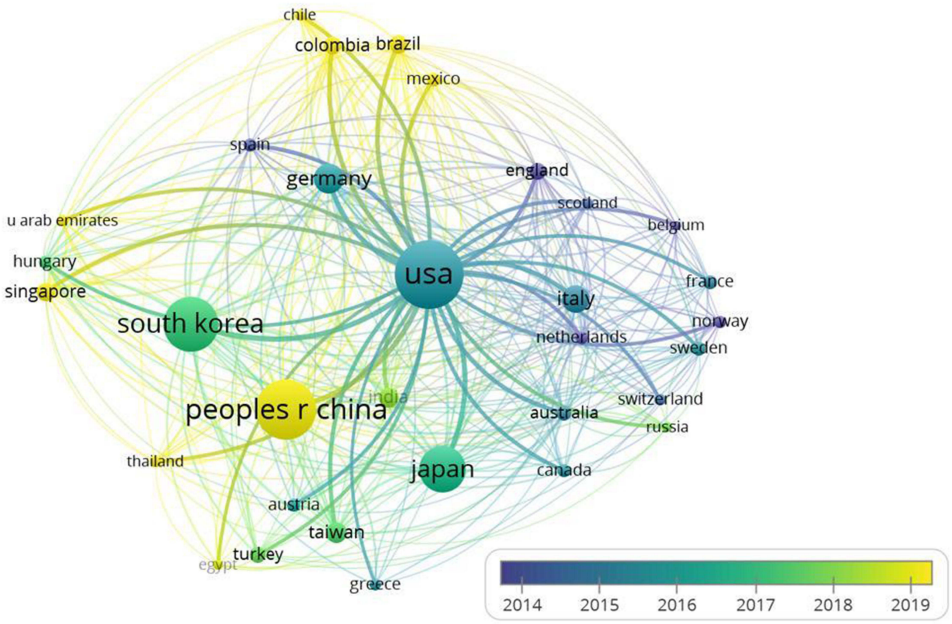

Figure 3 The overlay visualization map illustrates the co-authorship analysis of countries/regions. Larger frames represent a higher number of collaborations for the respective countries/regions. Terms highlighted in blue indicate earlier appearances compared to those highlighted in yellow.

Analysis of References and Cocitations

A total of 17,680 references were utilized across 1197 papers. Table 5 presents the references with the highest citation counts, highlighting the top 10 most cited works. The study by Kim et al, published in *World Neurosurgery* in 2017, stands out as the most cited reference with 64 citations. Table 6 provides an overview of the 10 most-cited articles, with the total number of citations ranging from 172 to 475. Notably, the top three articles have received a minimum of 310 citations each. The article authored by Yeung et al, published in *Spine* in 2002, holds the highest citation count among the top 10 articles. Following closely is the work by Schwender et al, published in the *Journal of Spinal Disorders and Techniques* in 2005. The third most cited article was written by Manchikanti, Laxmaiah et al and published in *Pain Physician* in 2009.

Analysis of the Keywords and Research Hotspots

Through keyword listings analysis, research hotspots in the field of minimally invasive treatment for LSS can be effectively identified. In this study, a total of 5651 keywords were analyzed. Only keywords with a minimum of 15

Table 2 Top 10 Institutions in Terms of Publication Counts

Rank	Institutions	Countries/ Regions	Publication
1	Harvard Medical School	USA	59
2	Rush University	USA	25
2	Capital Medical University	China	25
4	Cornell University	USA	24
5	Seoul National University	South Korea	23
5	Catholic University of Korea	South Korea	23
7	University of Miami	USA	21
8	Weill Cornell Medicine	USA	18
8	Seoul St. Mary's Hospital	South Korea	18
10	University of California System	USA	17
10	National University of Singapore	Singapore	17

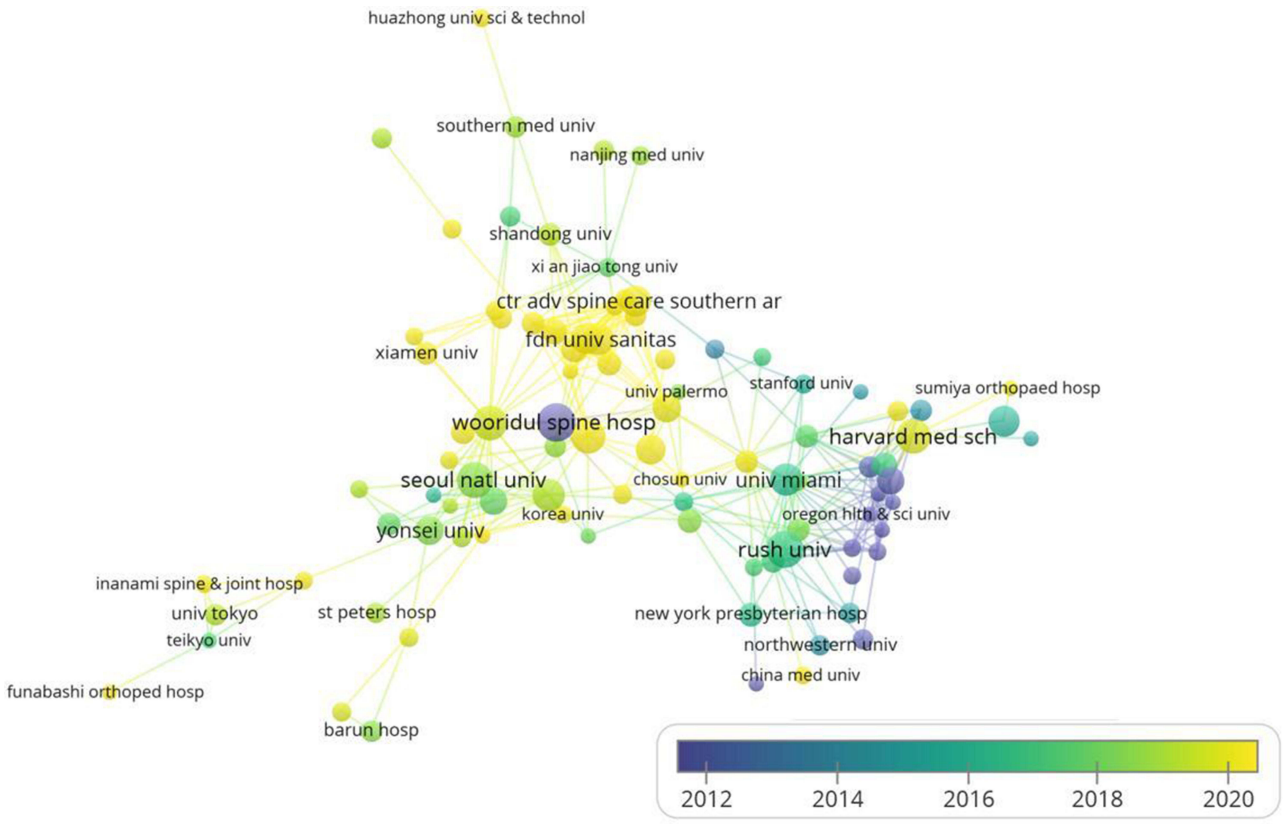

Figure 4 In the overlay visualization map, different institutions would be represented as nodes, and their relationships based on co-authorship would be depicted through links or lines connecting the nodes. The weight of the links would indicate the strength of the co-authorship relationship, typically measured using citation counts. Additionally, the color of the nodes could represent the average publication year of the institution's contributions. Terms or nodes appearing in blue would signify earlier publication years, while those in yellow would indicate more recent publications.

occurrences were visualized, resulting in the selection of 120 keywords that met the criteria. These keywords were then stratified into four clusters, as shown in Figure 7. Notably, meaningful keywords with high occurrence frequencies were identified within each cluster. For Cluster 1, the most prominent keywords were "surgery" (2148 occurrences) and "spinal

Table 3 Top 10 Journal with Publication Counts in the Field of Minimally Invasive Surgery for LSS

Rank	Journal	Publication	Citations	Average Number of Citations	H-Index
1	*World Neurosurgery*	98	1070	10.92	20
2	*Spine*	57	3289	57.70	26
3	*Pain Physician*	56	2068	36.93	26
4	*Journal of Neurosurgery-Spine*	51	1541	30.22	23
5	*European Spine Journal*	49	1362	27.80	22
6	*International Journal of Spine Surgery*	40	146	3.65	7
7	*Medicine*	35	156	4.46	6
8	*Spine Journal*	31	799	25.77	16
9	*Journal of Neurological Surgery Part A-Central European Neurosurgery*	28	168	6.00	7
10	*Journal of Spinal Disorders and Techniques*	26	1410	54.23	18

Note: H-index represents the maximum number "h" of their articles that have garnered "h" or more citations each.

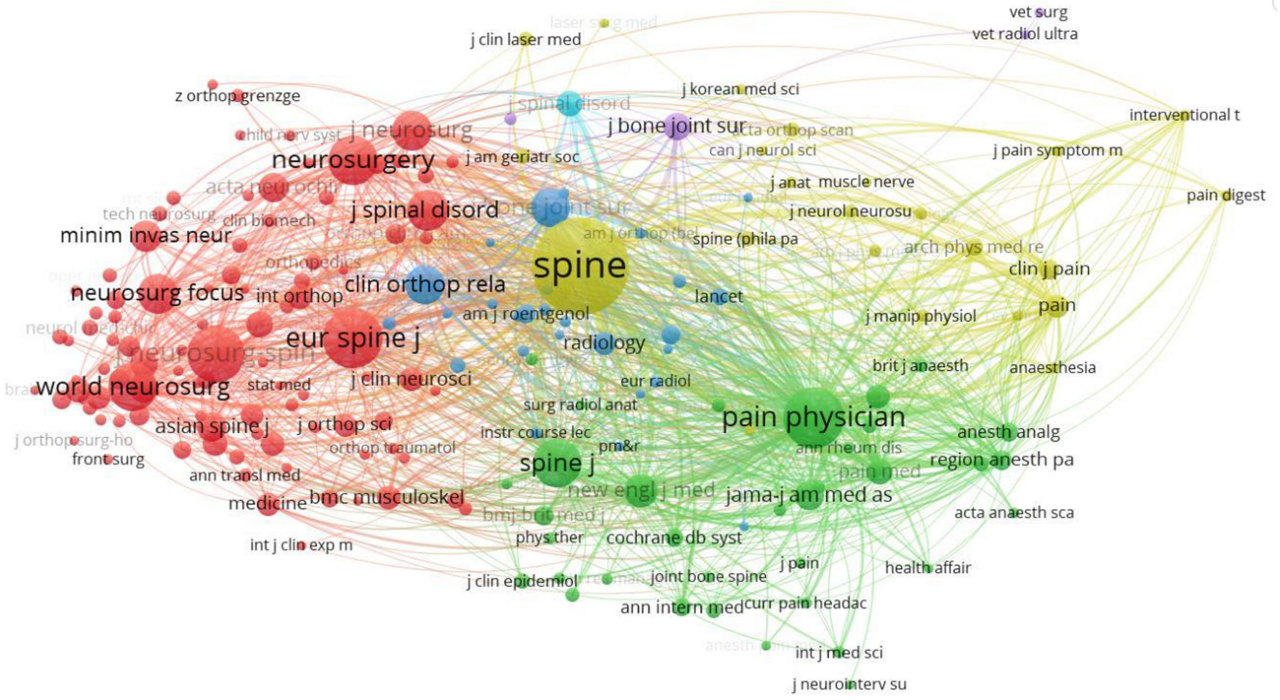

Figure 5 Network visualization of co-citation analysis for journals in minimally invasive surgery of LSS. The size of nodes represented the number of citations, and the lines between nodes indicated the relationship of co-citation.

stenosis" (1612 occurrences). In Cluster 2, the significant keywords were "decompression" (1498 occurrences) and "stenosis" (1166 occurrences). For Cluster 3, the noteworthy keywords were "complications" (1159 occurrences) and "spine" (680 occurrences). Lastly, for Cluster 4, the relevant keywords were "management" (677 occurrences) and "low-back-pain" (549 occurrences). Figure 8 presents a timeline viewer analysis of clustering in the lower right corner, revealing the research hotspots and evolution trends in this field. The primary research focus and direction have progressively shifted from early topics like "follow-up", "discectomy", "experience", and "excision" to middle-stage topics such as "decompression", "complications", "surgery", and "diskectomy". In recent years, the focus has moved towards topics including "interlaminar", "endoscopic spine surgery", "lateral recess stenosis", and "risk factors". Furthermore, Figure 9 highlights the top 10 keywords with the strongest citation bursts, indicating a rapid increase in research topics during specific periods. In the earlier stages, keywords like "discectomy", "lumbar spine", "follow-up", "minimally invasive surgery", "nonsurgical management", "low back pain", and "percutaneous adhesiolysis" showed the

Table 4 Top 10 Most Productive Authors and Cocited Authors in the Field of Spine Surgery

Rank	Author	Count	Cited Author	Total Number of Citations
1	Lewandrowski, Kai-Uwe	29	Ahn, Y	239
2	Kim, Hyeun Sung	26	Ruetten, S	227
3	Jang, Il-Tae	21	Weinstein, JN	205
4	Kim, Jin-Sung	20	Deyo, RA	194
5	Manchikanti, Laxmaiah	19	Kambin, P	152
6	Wu, Pang Hung	16	Foley, KT	138
7	Ahn, Yong	16	Katz, JN	132
8	Choi, Dae-Jung	13	Kim, HS	129
9	Kim, Ju-Eun	12	Komp, M	126
10	Yeung, Anthony	12	Yeung, AT	123

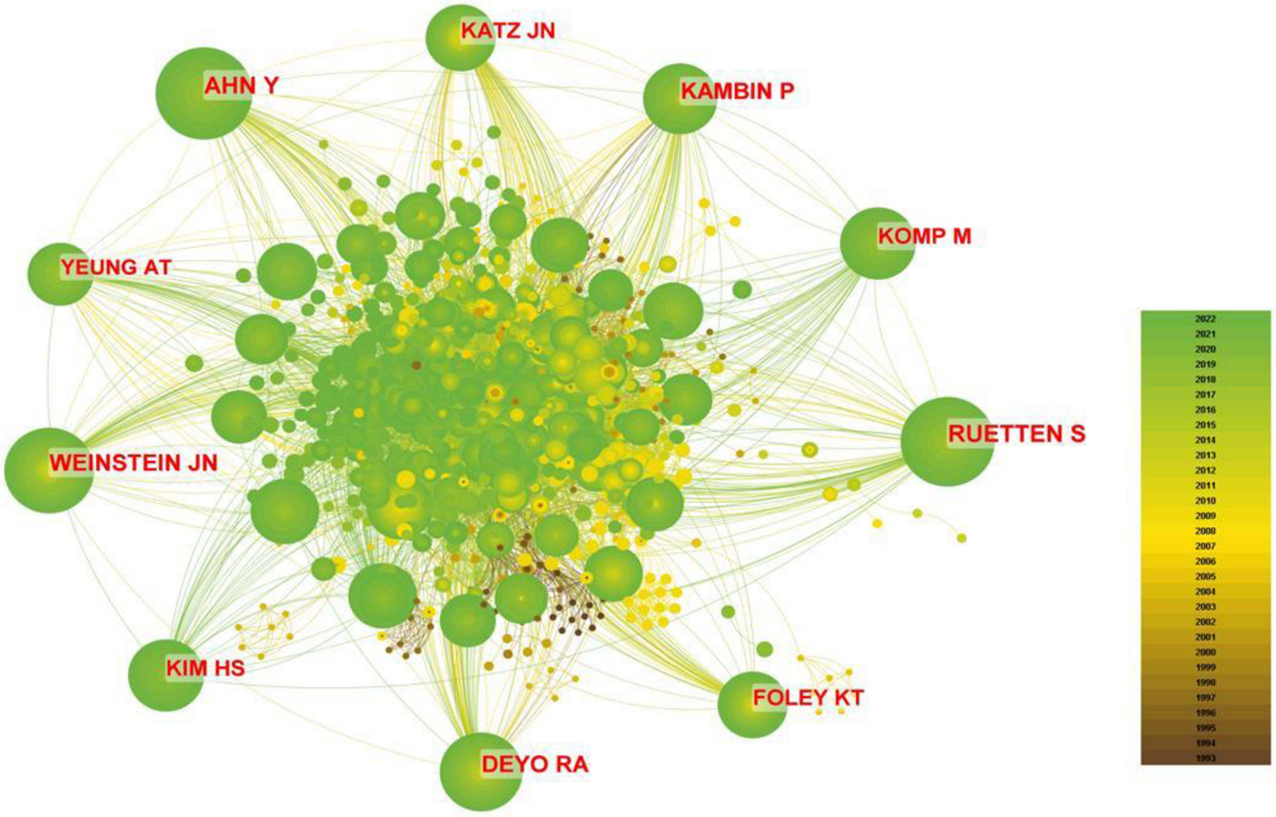

Figure 6 The network map of cited authors provides a visual representation of author density and the presence of clusters within the field of minimally invasive surgery in LSS. In this map, each node represents an author, serving as the analytical elements of CiteSpace. The links connecting two nodes indicate a cocitation relationship, suggesting that these authors are frequently cited together in the literature.

strongest burst values. As research has progressed, keywords like "unilateral laminotomy", "nonoperative treatment", "management", "neurogenic claudication", and "implant" have emerged with the strongest burst values. In recent years, the keywords indicating strong bursts include "microendoscopic decompressive laminotomy", "technical note", "randomized controlled trial", "foraminotomy", "classification", "transforaminal approach", and "degenerative spine". These

Table 5 Top 10 Most Cited References

Rank	Article	Journal	First Author	Year	Counts
1	Percutaneous full endoscopic bilateral lumbar decompression of spinal stenosis through uniportal-contralateral approach: techniques and preliminary results	*World Neurosurgery*	Kim HS	2017	64
2	Percutaneous biportal endoscopic decompression for lumbar spinal stenosis: a technical note and preliminary clinical results	*Journal of Neurosurgery-Spine*	Eum JH	2016	59
3	Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar versus microsurgical laminotomy technique: a prospective, randomized, controlled study	*Pain Physician*	Komp M	2015	53
4	Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: technical note and preliminary clinical results	*Neurosurgical Focus*	Heo DH	2017	46

(*Continued*)

Table 5 (Continued).

Rank	Article	Journal	First Author	Year	Counts
5	Efficacy and safety of full-endoscopic decompression via interlaminar approach for central or lateral recess spinal stenosis of the lumbar spine: a meta-analysis	*Spine*	Lee CH	2018	43
6	A Randomized, Controlled Trial of Fusion Surgery for Lumbar Spinal Stenosis	*New England Journal of Medicine*	Forsth P	2016	43
7	Laminectomy plus Fusion versus Laminectomy Alone for Lumbar Spondylolisthesis	*New England Journal of Medicine*	Ghogawala Z	2016	40
8	Percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar decompression for lateral recess stenosis through transforaminal approach: Technique notes and 2 years follow-up	*Clinical Neurology and Neurosurgery*	Li ZZ	2016	38
9	Comparative analysis of three types of minimally invasive decompressive surgery for lumbar central stenosis: biportal endoscopy, uniportal endoscopy, and microsurgery	*Neurosurgical Focus*	Heo DH	2019	36
10	Can Percutaneous Biportal Endoscopic Surgery Achieve Enough Canal Decompression for Degenerative Lumbar Stenosis? Prospective CaseeControl Study	*World Neurosurgery*	Heo DH	2018	36

Table 6 Top 10 Cited Articles with Most Cocitation Counts

Rank	Article	Journal	First Author	Year	Counts
1	Posterolateral endoscopic excision for lumbar disc herniation - Surgical technique, outcome, and complications in 307 consecutive cases	*Spine*	Yeung, AT	2002	457
2	Minimally invasive transforaminal lumbar interbody fusion (TLIF) - Technical feasibility and initial results	*Journal of Spinal Disorders and Techniques*	Schwender, JD	2005	374
3	Comprehensive Evidence-Based Guidelines for Interventional Techniques in the Management of Chronic Spinal Pain	*Pain Physician*	Manchikanti, Laxmaiah	2009	310
4	Microendoscopic decompressive laminotomy for the treatment of lumbar stenosis	*Neurosurgery*	Khoo, LT	2002	267
5	The Cochrane review of surgery for lumbar disc prolapse and degenerative lumbar spondylosis	*Spine*	Gibson, JNA	1999	251
6	Early outcomes and safety of the minimally invasive, lateral retroperitoneal transpsoas approach for adult degenerative scoliosis	*Neurosurgical Focus*	Dakwar, Elias	2010	237
7	Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9-mm endoscopes - A prospective, randomized, controlled study	*Spine*	Ruetten, Sebastian	2008	204
8	Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: Surgical technique, outcome, and prognostic factors of 43 consecutive cases	*Spine*	Ahn, Y	2004	192
9	A minimally invasive technique for decompression of the lumbar spine	*Spine*	Guiot, BH;	2002	173
10	Disc Regeneration Therapy Using Marrow Mesenchymal Cell Transplantation A Report of Two Case Studies	*Spine*	Yoshikawa, Takafumi	2010	172

findings provide valuable insights into the evolving research landscape and topics within minimally invasive treatment for LSS.

Discussion

The bibliometric analysis of literature on minimally invasive surgery for LSS reveals a significant increase in the number of annual publications and citations from 1993 to 2022. The development of this field can be categorized into a slow rise in the early stage and a rapid rise in the late stage. It is worth mentioning that the increase in publications in 2018 can be

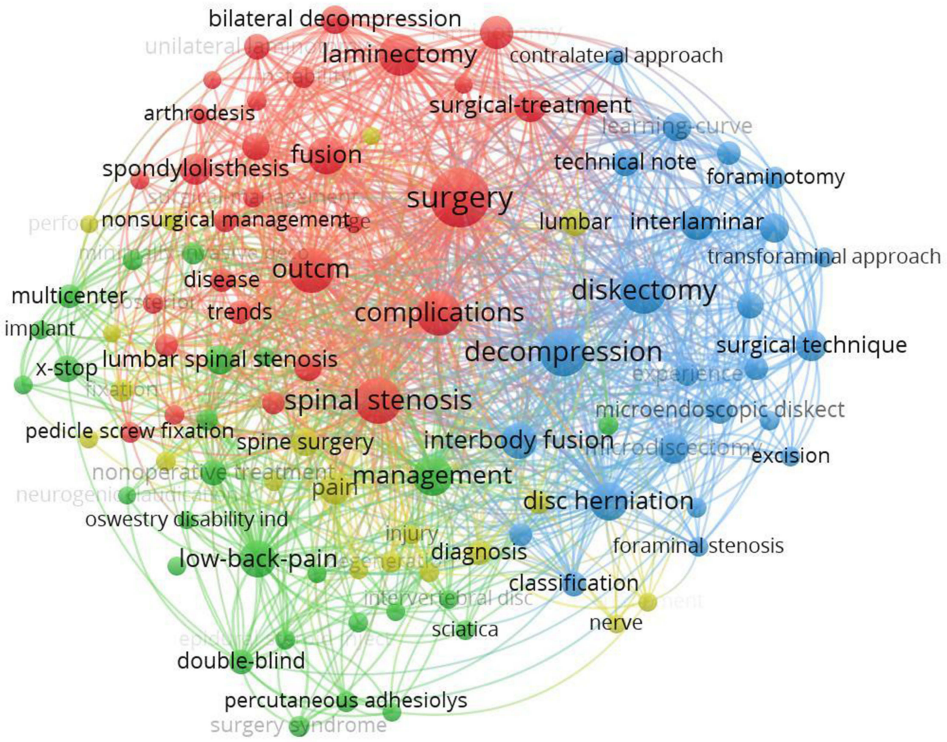

Figure 7 The network visualization map of keyword co-occurrence analysis with minimally invasive surgery in LSS. The four different clusters were described in four colors. The size of nodes represents the number of keywords cited, and the lines between nodes indicated the relationship of co-occurrence.

attributed to the rapid expansion of research on LSS minimally invasive surgery in China. With the continuous advancements in medical science and technology, LSS minimally invasive surgery has been widely promoted and implemented across China, leading to a significant improvement in both the quantity and quality of relevant studies. This trend is expected to continue in the future, further driving global progress in LSS minimally invasive surgery.

The United States (n=279) has published the highest number of articles in this field, followed by China (n=237) and South Korea (n=178). The United States, South Korea, and Japan rank at the top in terms of total citations and H-index. Notably, although China ranks second in the number of publications, it ranks fourth in total citations and fifth in H-index, indicating relatively lower average article citation. This suggests that while China has an advantage in publication quantity, the quality of publications may be comparatively lower, resulting in lower average citation rates. The visual web map shows that the United States remains the most active country, but there has been a significant increase in activity from China in recent years. Consequently, China and the United States have become the main contributors in this research field. Therefore, it is crucial to focus on improving the quality of papers among Chinese scholars in the future. Firstly, it is imperative to enhance the research capabilities and expertise of researchers, encompassing the refinement of their theoretical knowledge, honing experimental skills, and advancing research methodologies. Researchers should be driven to engage in profound and systematic original investigations rather than settling for superficial inquiries. Additionally, it is vital to augment investments in scientific research, modernize equipment, and establish cutting-edge platforms in order to enhance the scientific research environment. Moreover, China should further strengthen its evaluation mechanism for scientific accomplishments to guide researchers towards prioritizing paper quality over quantity while amplifying China's impact within the global academic community.

Among the top 10 most productive organizations, six are from the United States, three are from South Korea, and one each from China and Singapore. This highlights the strong influence of the United States in this field. The analysis of institutions co-authorship shows limited collaboration between institutions from different countries/regions, which hinders the progress of research on minimally invasive surgery for LSS. Therefore, strengthening communication and cooperation between different regions and organizations is essential.

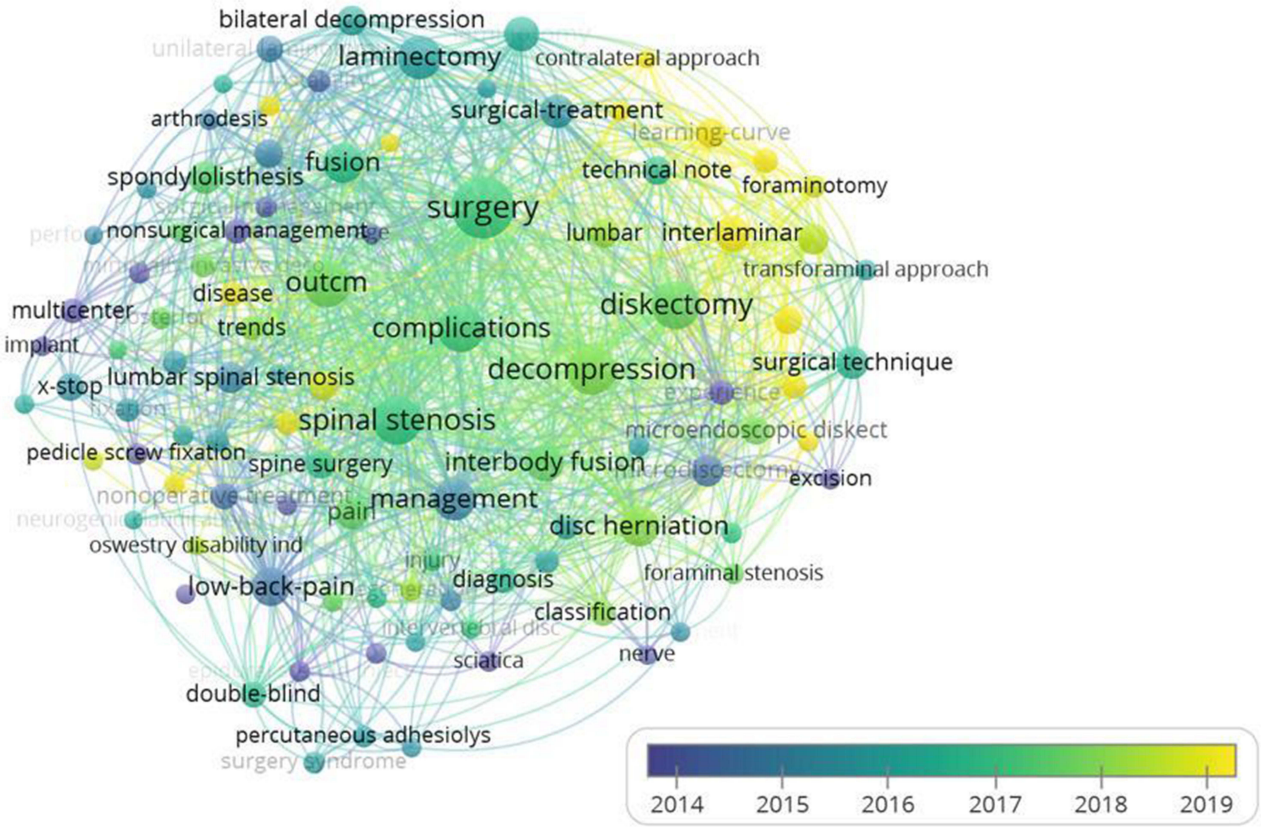

Figure 8 The overlay visualization map of keyword co-occurrence analysis showed trends of keyword frequency over time in the area of minimally invasive surgery in LSS. Colours were assigned according to the average year in which keywords appeared in articles, blue indicated earlier keywords, and yellow indicated recent keywords.

The analysis of journals helps identify influential and productive journals in the field of minimally invasive surgery for LSS, facilitating researchers in finding the most suitable journal for their articles. Journals such as *World Neurosurgery, Spine, Pain Physician, European Spine Journal*, and *Journal of Neurosurgery-Spine* are among the most influential and productive journals in this field and should be considered by researchers.

In terms of authors, Lewandrowski, Kai-Uwe, Kim, Hyeun Sung, Ahn, Y, and Ruetten, S were found to be the most active authors in the field of minimally invasive surgery for LSS research, based on publication counts and co-authorship analysis.

An in-depth analysis of the top 10 cited articles reveals a focus on the feasibility and safety of endoscopic spine surgery for treating LSS, as well as comparisons of postoperative therapeutic effects with traditional open surgery. These articles were published before 2010 when endoscopic spine surgery was still in its exploratory stage, and its advantages and surgical effects were not yet recognized. Recent articles have shifted towards comparative analyses of short-term and long-term efficacy and complications of different endoscopic spinal surgery methods, as well as improvements in surgical procedures. Clinicians aim to develop further on the basis of endoscopic spinal surgery and explore differences between various endoscopic surgery methods. Continuous advancements in endoscopic surgery techniques aim to achieve better therapeutic outcomes.

The visual analysis of keywords indicates that “discectomy” appeared earlier, suggesting more literature on the application of discectomy for spinal canal decompression in the early stages of LSS surgical treatment. Over time, “minimally invasive surgery”, “implant”, and “lumbar intervertebral fusion” have become research hotspots as surgeons’ concepts and techniques evolve. Commonly used interbody fusions are classified as anterior, posterior, posterolateral, and posterior foraminal. Spinal interbody fusion stabilizes the unstable lumbar spine and effectively alleviates pain caused by disc and facet diseases, garnering recognition from both patients and clinicians. Recent hotspots include

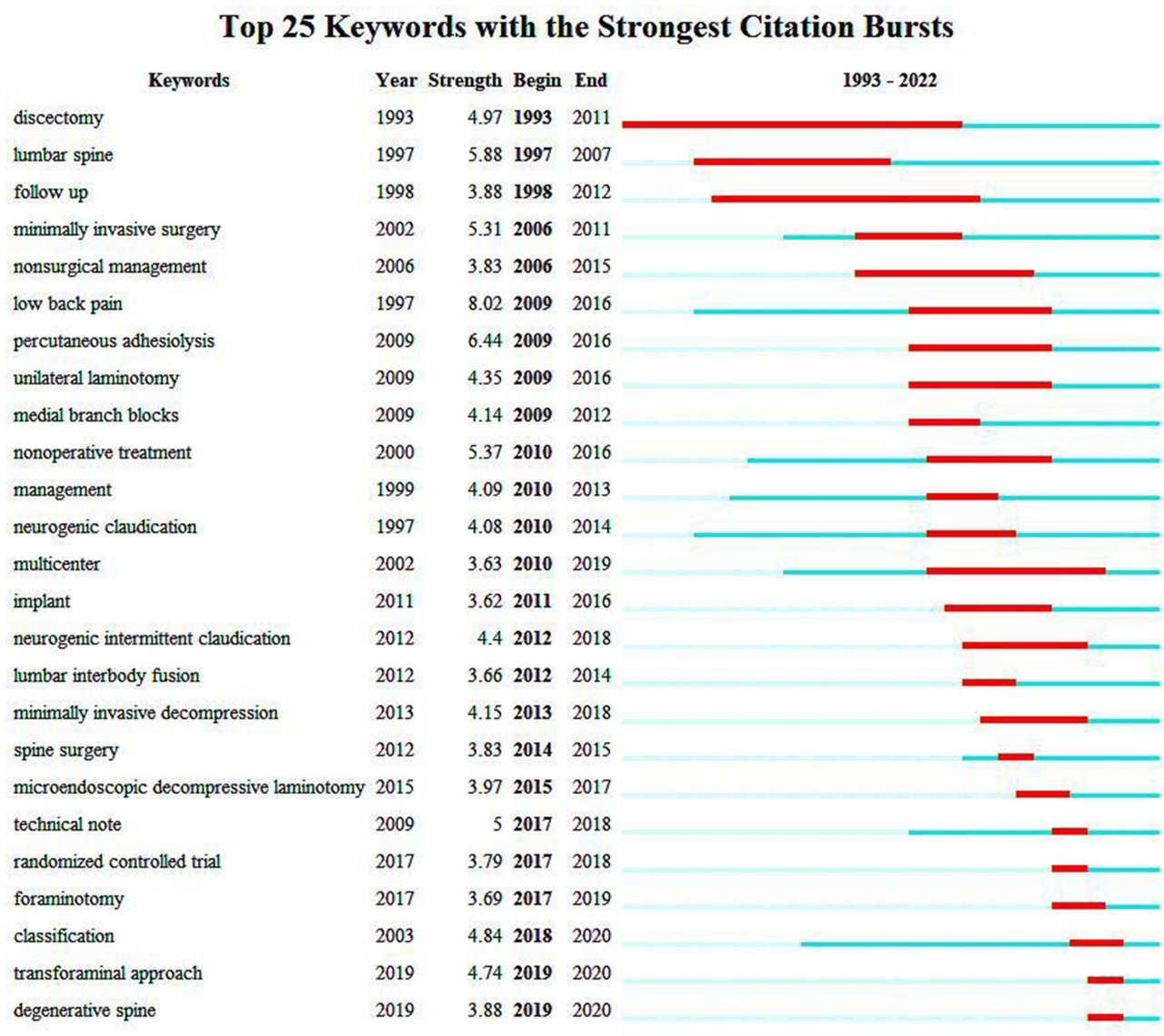

Figure 9 Top 25 keywords with the strongest citation bursts in the field of minimally invasive surgery in LSS by citespace. The strongest citation burst means that a variable changes greatly in a short period. "Begin" and "End" year between the keywords influential period. A light blue year indicates that the keyword has not yet appeared, a dark blue year indicates that the keyword is less influential, and a red year indicates that the keyword is more influential.

"microendoscopic decompression laminotomy", "technical specification", "randomized controlled trial", "foraminotomy", "classification", and "foraminal approach". However, performing spinal decompression in a minimally invasive manner requires good visibility and adequate bone removal. Technological advancements in drills, optical design, and other instruments have made full endoscopic decompression for spinal stenosis surgery possible. Endoscopic spine surgery offers several advantages: 1) smaller incisions with less dissection of posterior spinal tissue and reduced muscle damage, 2) enhanced visualization of the surgical field, 3) decreased anesthesia risk, intraoperative blood loss, and surgical time leading to faster patient recovery, and 4) reduced postoperative epidural fibrosis and scar formation due to less intraoperative dural irritation.[17–20] However, minimally invasive surgery has its limitations, including limited exposure, technical difficulty, and potential complications such as nerve root injury, cerebrospinal fluid leakage, and others. Spinal surgeons must have a comprehensive understanding of minimally invasive spinal anatomy, continuously learn and refine technical operations, and strictly adhere to surgical indications.[20–25] Therefore, future research priorities in minimally invasive surgical interventions for lumbar spinal stenosis are likely to focus on reducing the learning curve, addressing complications, and enhancing treatment consistency. The identification of these areas of research provides

a clear direction for advancing minimally invasive surgical treatments for this condition and aligns with the focal points of funding agencies in this field. Considering continuous advancements in science and technology, significant progress can be anticipated on these subjects in the forthcoming years, thereby elevating the standard of minimally invasive surgical interventions for lumbar spinal stenosis.

A bibliometric analysis by Wu et al[26] on endoscopic discectomy (ED) indicates that the next research focus in ED is the clinical effectiveness of ED for LSS treatment and the surgical technique of percutaneous endoscopic lumbar discectomy (PELD). The indications of ED can be expanded to include LSS.[27–30] Some scholars are beginning to explore techniques to simplify surgery, shorten operation time, and reduce the learning curve. This finding aligns with ours, emphasizing the trend toward improving surgical techniques.

A study conducted by Liu et al[31] shows that while the number of publications on endoscopy research continues to increase, the citation rate of endoscopy-related papers has declined over the past 30 years. More guidelines for developing standards have been published, indicating the gradual maturity of total endoscopic spinal surgery.

The concepts and techniques of LSS therapy are constantly evolving, especially with the emergence of a large body of literature in recent years, which contributes to field development.[17–20,32–35] However, the sheer volume of literature makes it challenging for researchers to identify meaningful studies. Bibliometrics assists in estimating the scientific impact and quantitative characteristics of publications.

Overall, this revised abstract provides an overview of the bibliometric analysis of literature on minimally invasive surgery for LSS. It highlights the growth trends, publication patterns of different countries/regions, influential journals, active authors, and key research topics in the field. The findings emphasize the need for collaboration between institutions and regions to foster further advancement in minimally invasive surgery for LSS.

Limitations

While we acknowledge that bibliometric analysis is an effective method for measuring the influence of articles, it is important to recognize that our current study has certain limitations. The first is a relatively single literature search database (WoSCC), and in the future we will need to consider some other databases as well. Second, WoSCC is a global citation analysis database based mainly on English and does not include literature in other languages, which may result in some relevant articles being overlooked. Third, self-citation is not excluded in citation analysis, which may bias the results of citation analysis and confuse the audience about whether the article is more influential or just frequently self-cited. Despite these limitations, bibliometric analysis still has some advantages. We can help researchers identify high-quality articles, identify research hotspots in the past period, and use this to predict future research trends and hotspots, providing some insights into minimally invasive surgery research in LSS.

Conclusions

In summary, the number of publications on LSS minimally invasive surgery has been growing every year since 1993. From the point of view of the quality and quantity of published literature, the United States, China and South Korea are the main contributors in this field. This study reveals the institutions, journals, countries/regions, authors and their cooperation in this field in the past 30 years, and believes that the selection of different minimally invasive surgical methods, indications, complications, outcomes and surgical process optimization will be the focus of future research. It is hoped that this study can provide good guidance for the future research in this field. In addition, we need more high-quality articles on minimally invasive surgery for LSS so that scholars can better understand the field.

Author Contributions

Dacheng Sang and Jinyang Guo are co-first authors of the paper. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no conflicts of interest in conducting this work.

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