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Bibliometric analysis of transforaminal lumbar interbody fusion in lumbar spine surgery

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Abstract. – OBJECTIVE: The objective of this study is to conduct a bibliometric analysis to examine the current condition, areas of interest, and rising trends of transforaminal lumbar interbody fusion in lumbar spine surgery (TLIF), as well as its importance in associated research domains.

MATERIALS AND METHODS: An extensive collection of academic papers on the use of TLIF was obtained from the Web of Science between January 1, 2000, and November 5, 2023. Then, using a variety of tools like HisCite, VOSviewer, CiteSpace, and the bibliometrix package, a bibliometric study was carried out. This study included the collection of information on country, institution, author, journal, and keywords.

RESULTS: A comprehensive analysis was undertaken on a total of 1,907 publications obtained from 181 journals, encompassing the contributions of 7,232 authors affiliated with 1,775 institutes spanning 57 countries/regions. Notably, the USA exhibited the highest number of publications, with 763 (40.03%) articles on TLIF. The most productive institution was Rush University, with 96 (5.03%) publications. The author with the highest publication output was Singh, Kern with 75 (3.93%) publications. World Neurosurgery demonstrated the highest level of productivity, having published a total of 211 (11.06%) articles. The most frequently used keywords were "TLIF", "spondylolisthesis" and "complication". Meanwhile, "workflow", "technical note" and "hidden blood loss" have been identified as the research frontiers for the forthcoming years.

CONCLUSIONS: This paper provides a thorough evaluation of current research trends and advancements in TLIF. It includes relevant research findings and emphasizes collaborative efforts among authors, institutions, and countries.

Key Words:
Lumbar degenerative disease, Lumbar disc herniation, TLIF, Interbody fusion, Minimally invasive surgery.

Introduction

Lumbar degenerative diseases, including lumbar disc herniation, lumbar spinal stenosis, and lumbar spondylolisthesis, are prevalent conditions encountered in spinal surgery. These conditions often result in lumbar pain and leg pain[1-3]. Initially, the symptoms and signs of lumbar degenerative diseases are typically mild, and conservative treatments such as physiotherapy, medication, and rest can effectively slow down their progression[4]. However, in cases of severe lumbar disc herniation, unrelieved leg pain, numbness, weakened muscle strength, pronounced lumbar instability due to lumbar spondylolisthesis, neurological symptoms, or even cauda equina syndrome, conservative treatment is inadequate in managing the symptoms and may lead to a worsening of the condition. In such cases, active surgical intervention becomes necessary[5-7]. Lumbar interbody fusion has emerged as a well-established surgical procedure for the early-stage treatment of these diseases, yielding favorable outcomes. In 1982, Harms and Rolinger[8] introduced the concept of transforaminal lumbar interbody fusion (TLIF) utilizing an open transforaminal approach. Their technique involved performing decompression, bone graft fusion, and achieving reduction of surgical trauma through a unilateral approach. In 2002, Foley and Lefkowitz[9] initially introduced the concept of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF). They postulated that MIS-TLIF could effectively minimize intraoperative bleeding and soft tissue trauma, expedite postoperative recovery, and yield comparable clinical outcomes to conventional TLIF procedures.

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Bibliometric analyses have become a prominent tool in the scientific community for assessing published research and predicting future trends. These analyses utilize mathematical and statistical approaches to explore the relationships among scientific fields, countries, organizations, authors, and publications[10,11]. In recent years, there has been notable progress in the study of TLIF; however, bibliometric analysis of TLIF is lacking. This study aims to conduct a bibliometric analysis of TLIF research, leveraging knowledge maps to effectively analyze extensive data and extract valuable insights regarding the development and emerging patterns in this specific area of investigation. This methodology enhances the ability to identify research hotspots more effectively and facilitates a comprehensive exploration of research trends. Furthermore, this analysis holds the potential to provide valuable insights for future research endeavors and decision-making processes.

Materials and Methods

Search Strategy

Using the Web of Science Core Collection (WoSCC), a literature search was carried out at Dalian Municipal Central Hospital on November 5, 2023. The following search parameters were used to find results: (TS = (Transforaminal lumbar interbody fusion OR TLIF))) AND DT = (Article OR Review)) AND LA=(English). Articles that mentioned TLIF or its synonyms in their title, abstract, or keywords were found as a result of the search query. Articles and reviews published between January 1, 2000, and November 5, 2023 were the only document types included in the search; publications earlier than January 1, 2000, case reports, meeting abstracts, editorial materials, and other document types were not included. Documents written in the English language were the only ones that met the inclusion criterion.

Data Collection

On November 5, 2023, a literature search query was performed in order to retrieve data from the WoSCC. The information retrieved covered a wide range of features of the literature, including authorship, title, source, sponsorship, citation count, accession number, abstract, address, document type, and cited references. To aid further analysis, the data was collected in both txt and BibTex formats. Web of Science was used to obtain the H-index of the top 10 authors with the most publication output. Furthermore, the 2022 impact factor and Journal Citation Report category quartile of the ten key journals relevant to TLIF were obtained from Web of Science.

Statistical Analysis

HisCite (version 12.03.17), VOSviewer (version 1.6.18), CiteSpace (version 6.1.R3), and the bibliometrix package (version 3.2.1; https://cran.r-project.org/web/packages/bibliometrix/) based on R language (version 4.1.2) were used to analyze the bibliometric data. HisCite was used to calculate the total number of publications and citations for producing countries, institutions, and authors. In addition, using HisCite, the top ten papers with the highest citation count in TLIF were discovered. The yearly count of publications was calculated using HisCite and graphically represented in the R programming language using the ggplot2 package (version 3.3.6; https://github.com/tidyverse/ggplot2). VOSviewer was used to identify the top 10 keywords with the highest occurrence, bibliometric coupling within journals, and clustering of the top 30 keywords. CiteSpace was also used to create a dual-map overlay of the journals connected with TLIF. CiteSpace was used to assess the level of collaborative centrality among countries/regions, institutions, and authors. Following that, trend topic detection within the bibliomatrix program was used. This program was also used to build visual representations of publication volume and collaborative relationship networks.

Results

Overview

A comprehensive search was conducted in the WoSCC database, resulting in the identification of 1,907 publications pertaining to TLIF. The search period spanned from January 1, 2000, to November 5, 2023. Among these publications, 1,729 were categorized as original articles, while 178 were classified as review articles (Figure 1). Notably, the frequency of TLIF-related publications exhibited an irregular pattern, albeit showing an overall upward trend in terms of total citations (Figure 2A-B). It is worth mentioning that the proportion of original articles consistently surpassed that of review articles on an annual basis. The cumulative collection of published articles has garnered a total of 37,445 citations,

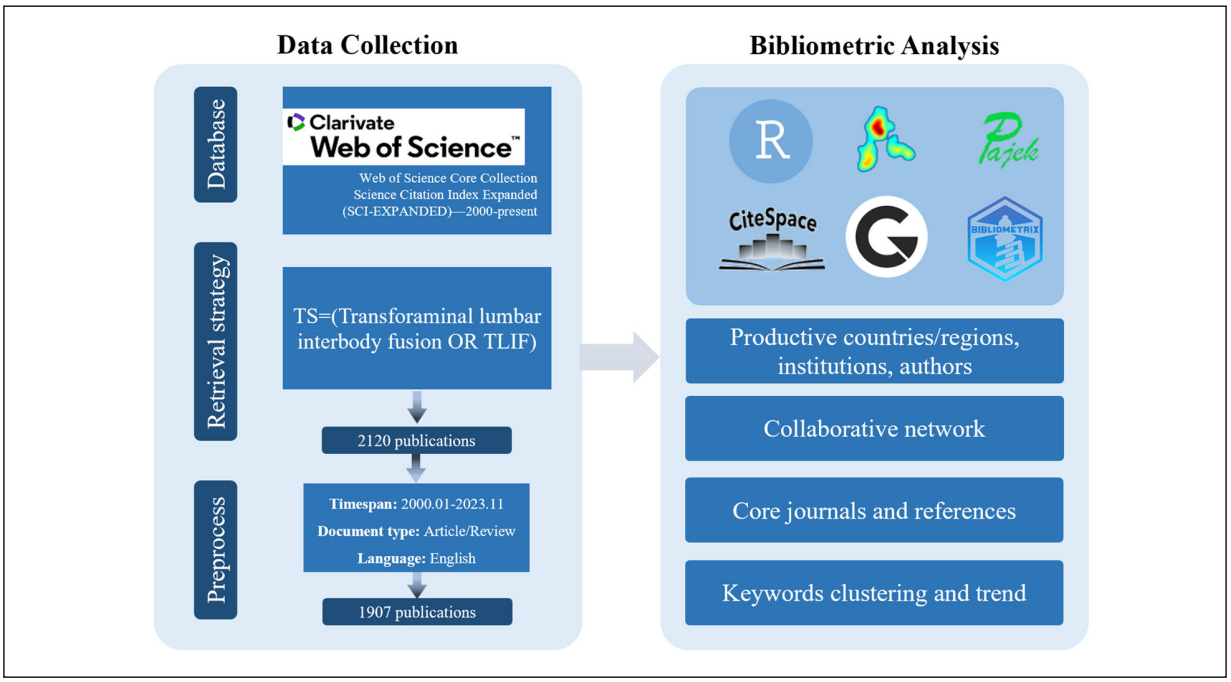


Figure 1. Hierarchical chart depicting the process of publication selection.

resulting in an average of 19.64 citations per article, which holds significant scholarly value.

Leading Countries/Regions

From January 1, 2000, to November 5, 2023, scholarly articles on TLIF were disseminated across 57 countries/regions spanning six continents. Notable collaboration was observed among East Asia, North America, and Western Europe (Figure 2C). This study highlights the top 10 countries in terms of productivity in publishing articles on TLIF. The USA emerged as the most prolific country, with 763 (40.03%) articles, followed by China with 642 (33.67%) articles, South Korea with 126 (6.61%) articles, Japan with 389 (4.67%) articles, and Germany with 75 (3.93%) articles. It is noteworthy that articles originating from the United States received the highest total number of citations, amounting to 21,525, while articles from Australia had the highest average number of citations per article, with 39.04, (Figure 2D-F) (Table I).

Active Institutions and Authors

Through an extensive investigation, a total of 1,907 publications were identified, authored by 7,232 individuals affiliated with 1,775 institutes across 57 countries/regions. Among the identified institutes, Rush University in the USA emerged as the most prolific, contributing 96 (5.03%) publications. This was followed by the University of California, San Francisco, with 40 (2.09%) publications, the Hospital for Special Surgery with 39 (2.04%) publications, Tongji University with 36 (1.89%) publications, and the University of Miami with 32 (1.68%) publications. Notably, among the top ten institutions, six were located in the USA and four in China (Table II). The study also revealed six distinct clusters of institutional collaboration, with Rush University, Tongji University, and the University of California, San Francisco, exhibiting the highest level of collaboration (Figure 3A). Regarding authors, the most prolific author identified was Singh, Kern, with 75 (3.93%) publications, followed by Zhou, Yue with 30 (1.57%) publications, and Wang, Michael Y. with 27 (1.42%) publications. Among the top ten most productive authors, eight were affiliated with institutions in the USA, one with institutions in China, and one with an institution in South Korea. University of California, San Francisco demonstrated the highest total citations, accounting for 1,498 (Figure 3B). Notably, Vaccaro, Alexander R. from the USA had the highest H-index of 82 (Table III). The authors demonstrated a notable level of cooperation, as evidenced by the presence of six clusters. Singh, Kern, Wang, Michael Y. Vaccaro, Alexander R.

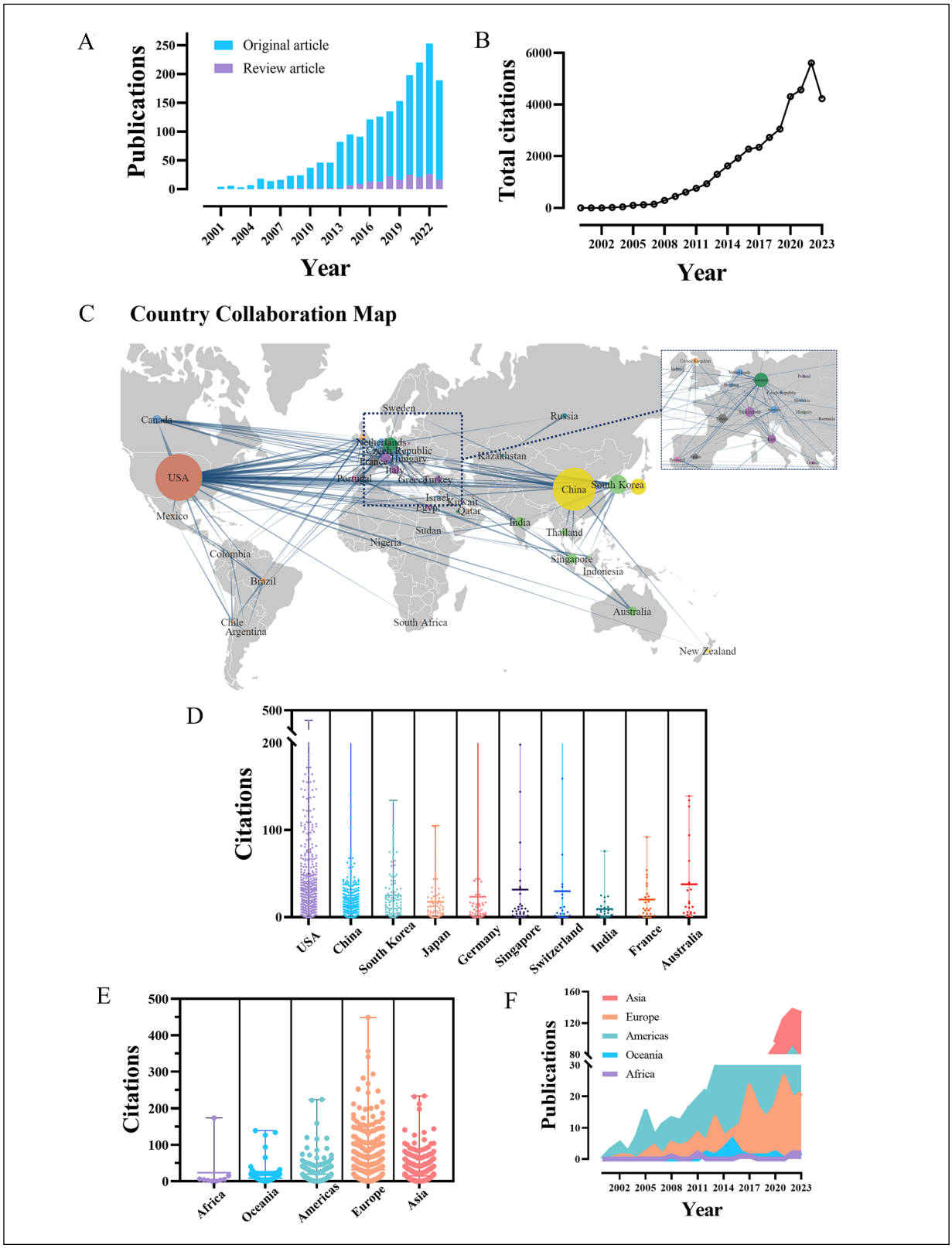


Figure 2. The yearly quantity, citations of publications pertaining to TLIF and country collaboration clustering. **A**, The yearly quantity pertaining to TLIF. **B**, The yearly citations pertaining to TLIF. **C**, Country collaboration map. **D**, Total citations to each country. **E**, Total citations to each continent. **F**, The early publications of each continent.

Table I. The top 10 countries/regions with the highest productivity.

Rank	Country	Publications N (%)	Total citations	Average citations	Collaborative centrality
1	USA	763 (40.03%)	21,525	28.21	0.79
2	China	642 (33.67%)	7,034	10.96	0.07
3	South Korea	126 (6.61%)	2,779	22.06	0.20
4	Japan	89 (4.67%)	1,470	16.52	0.00
5	Germany	75 (3.93%)	1,633	21.77	0.13
6	Singapore	37 (1.94%)	932	25.19	0.04
7	Switzerland	35 (1.84%)	751	21.46	0.06
8	India	34 (1.78%)	374	11.00	0.07
9	France	31 (1.63%)	573	18.48	0.00
10	Australia	28 (1.47%)	1,093	39.04	0.00

Table II. The top 10 productive institutions.

Rank	Institution	Country	Publications N (%)	Total citation	Average citation
1	Rush University	USA	96 (5.03%)	1,244	12.96
2	University of California, San Francisco	USA	40 (2.09%)	1,498	37.45
3	Hospital for Special Surgery	USA	39 (2.04%)	670	17.18
4	Tongji University	China	36 (1.89%)	471	13.08
5	University of Miami	USA	32 (1.68%)	1,249	39.03
6	Fudan University	China	30 (1.57%)	280	9.33
7	Duke University	USA	29 (1.52%)	960	33.10
8	Shanghai Jiao Tong University	China	28 (1.47%)	566	20.21
9	Shandong University	China	27 (1.41%)	136	5.04
10	St. Joseph's Hospital	USA	27 (1.41%)	606	22.44

displayed a significant degree of collaborative centrality (Figure 3C).

Core Journals and References

A total of 181 journals have published research on TLIF. Among these journals, World Neurosurgery demonstrated the highest productivity, publishing 211 (11.06%) articles related to TLIF. This was followed by Spine with 168 (8.80%) articles, European Spine Journal with 127 (6.66%) articles, Journal of Neurosurgery-Spine with 103 (5.40%) articles, and Clinical Spine Surgery with 85 (4.45%) articles. Notably, the Journal of Spinal Disorders & Techniques achieved the highest average citation rate, with an average of 54.00 citations per article (Table IV). Bradford's Law, a bibliometric principle, describes the distribution of scientific literature in a specific field. It suggests that a few core information sources or journals contribute significantly to the published research in that field. In the context of TLIF research, three clusters were identified: World Neurosurgery, Spine, and European Spine Journal emerged as the top three influential journals, while Spine demonstrated the highest total citations (Figure 4A-C). The dual-map overlay revealed a single citation pathway among the numerous inter-domain linkages between journals. Interestingly, publications in Medicine/Medical/Clinical were primarily referenced by publications in Psychology/Education/Social. Clusters located on the right-hand side, characterized by a higher incidence of red nodes, indicate a greater prevalence of recent references. The clusters labeled "#2" and "#5" were found to be the most temporally proximate (Figure 5A). A list of the top 10 papers with the most citations can be found in Table V. Moreover, reference burst detection was employed to identify research frontiers and emerging references. The study examined the top 25 references with the most robust emergent properties. The reference "doi: 10.1016/j.spinee.2017.06.018." "Transforaminal lumbar interbody fusion (TLIF) versus posterior lumbar interbody fusion (PLIF) in lumbar spondylolisthesis: a systematic review and meta-analysis"[22]

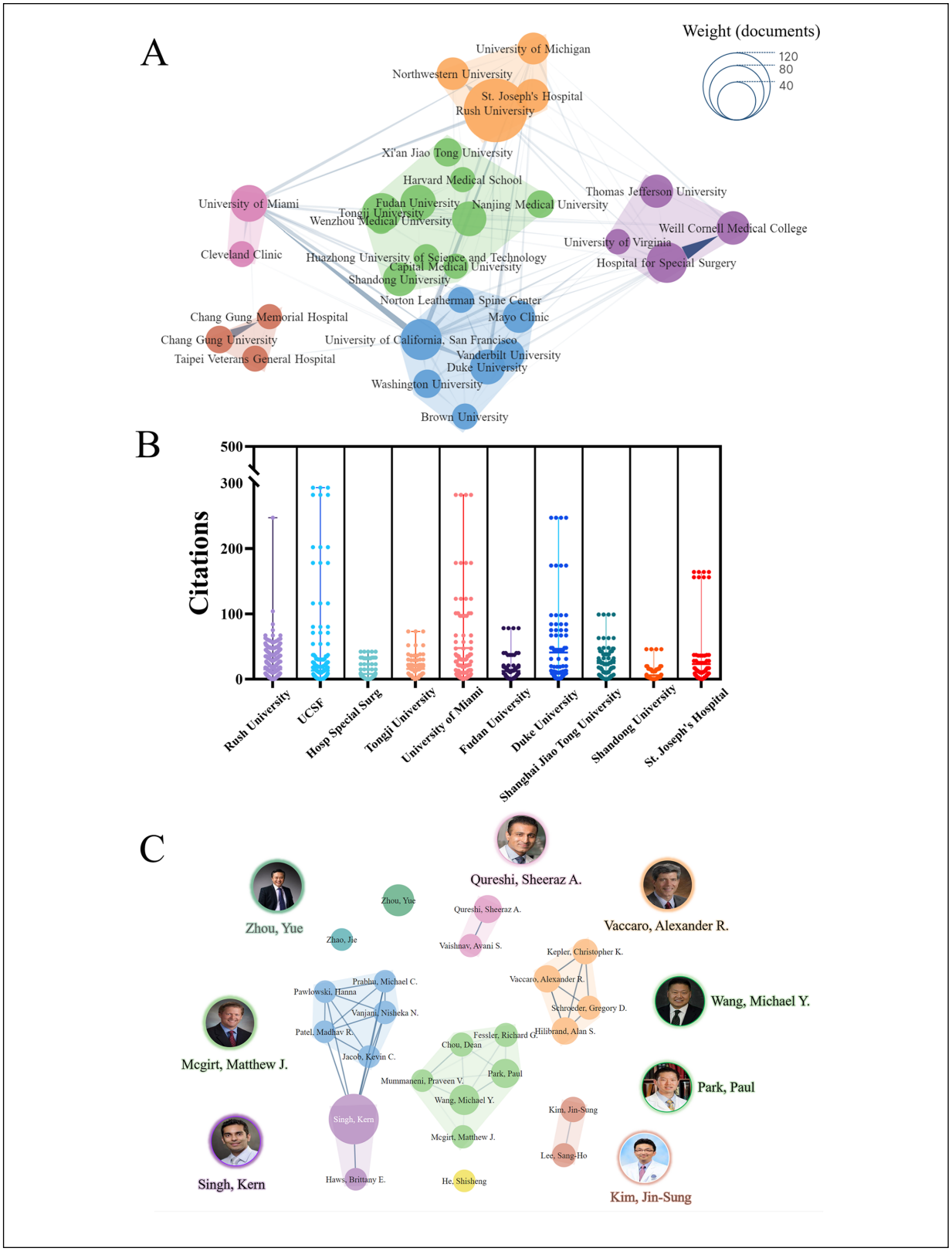


Figure 3. Collaborative clustering of institutions and authors. **A**, Collaborative clustering of institutions. **B**, Total citations to each institution. **C**, Collaborative clustering of authors.

Table III. The top 10 productive authors.

Rank	Author	Institution	Country	Publications N (%)	Total citation	Average citation	H-index
1	Singh, Kern	Rush University	USA	75 (3.93%)	869	11.59	35
2	Zhou, Yue	Army Medical University Xinqiao Hospital	China	30 (1.57%)	747	24.90	32
3	Wang, Michael Y.	University of Miami	USA	27 (1.42%)	1,100	40.74	42
4	Park, Paul	University of Michigan	USA	25 (1.31%)	829	33.16	45
5	Qureshi, Sheeraz A.	Hosp Special Surg	USA	23 (1.21%)	214	9.30	30
6	Hilibrand, Alan S.	Jefferson University	USA	22 (1.15%)	476	21.64	60
7	Vaccaro, Alexander R.	Jefferson University	USA	22 (1.15%)	507	23.05	82
8	Kepler, Christopher K.	Jefferson University	USA	19 (0.99%)	192	10.11	39
9	Kim, Jin-Sung	Yonsei University	South Korea	19 (0.99%)	564	29.68	38
10	Chou, Dean	Columbia University	USA	17 (0.89%)	254	14.94	41

was identified as the most emergent reference in 2023 (Figure 5B).

An Analysis of Keywords

An examination of the trend topics from 2000 to 2023 identified "workflow", "technical note" and "hidden blood loss" as the research frontiers for the upcoming years (Figure 6A). After consolidating synonymous terms, we presented the thirty most frequently appearing keywords in TLIF research, with "TLIF" being the most commonly referenced (Figure 6B). An analysis of keyword co-occurrence among the top 30 keywords revealed the presence of three distinct clusters. The cluster consisting of "TLIF", "spine", "cancer" and "complication" exhibited the highest frequency of occurrence (Figure 6C).

Discussion

TLIF is a surgical intervention commonly employed in the treatment of lumbar degenerative diseases. The procedure of TLIF involves a systematic anatomical approach. Initially, a midline incision is made along the spinous process of the posterior aspect, followed by an incision of the deep fascia. Subsequently, the paravertebral muscles are carefully dissected subperiosteally to gain access to the lamina and facet joints. Alternatively, the midline incision is made, and then the skin is bilaterally opened, with subsequent deep fascial incision performed through the intermuscular approach between the multifidus and longissimus muscles (Wiltse approach). This approach allows for visualization of the facet joints. The subsequent steps involve the removal of the inferior facet of the upper vertebral body and the superior facet of the lower vertebral body. Additionally, a portion of the lateral ligamentum flavum is excised to expose the dural sac and nerve roots. Finally, the intervertebral disc is accessed from the region of the intervertebral foramen. This entire process is depicted in Figure 7. This operation has demonstrated favorable outcomes in terms of decompression efficacy, restoration

Table IV. The top 10 core journals.

Rank	Journal	Publications N (%)	Total citations	Average citations	2022 JCR category quartile	2022 IF
1	World Neurosurgery	211 (11.06%)	2,828	13.40	Q3	2.0
2	Spine	168 (8.80%)	6,270	37.32	Q2	3.0
3	European Spine Journal	127 (6.66%)	3,566	28.08	Q2	2.8
4	Journal of Neurosurgery-Spine	103 (5.40%)	3,821	37.10	Q2	2.8
5	Clinical Spine Surgery	85 (4.45%)	703	8.27	Q3	1.9
6	Spine Journal	84 (4.40%)	3,010	35.83	Q1	4.5
7	Global Spine Journal	60 (3.15%)	453	7.55	Q3	2.4
8	Journal of Spinal Disorders and Techniques	52 (2.73%)	2,808	54.00	--	--
9	Neurosurgical Focus	49 (2.57%)	1,691	34.51	Q1	4.1
10	Orthopedic Surgery	47 (2.46%)	218	4.64	Q3	2.1

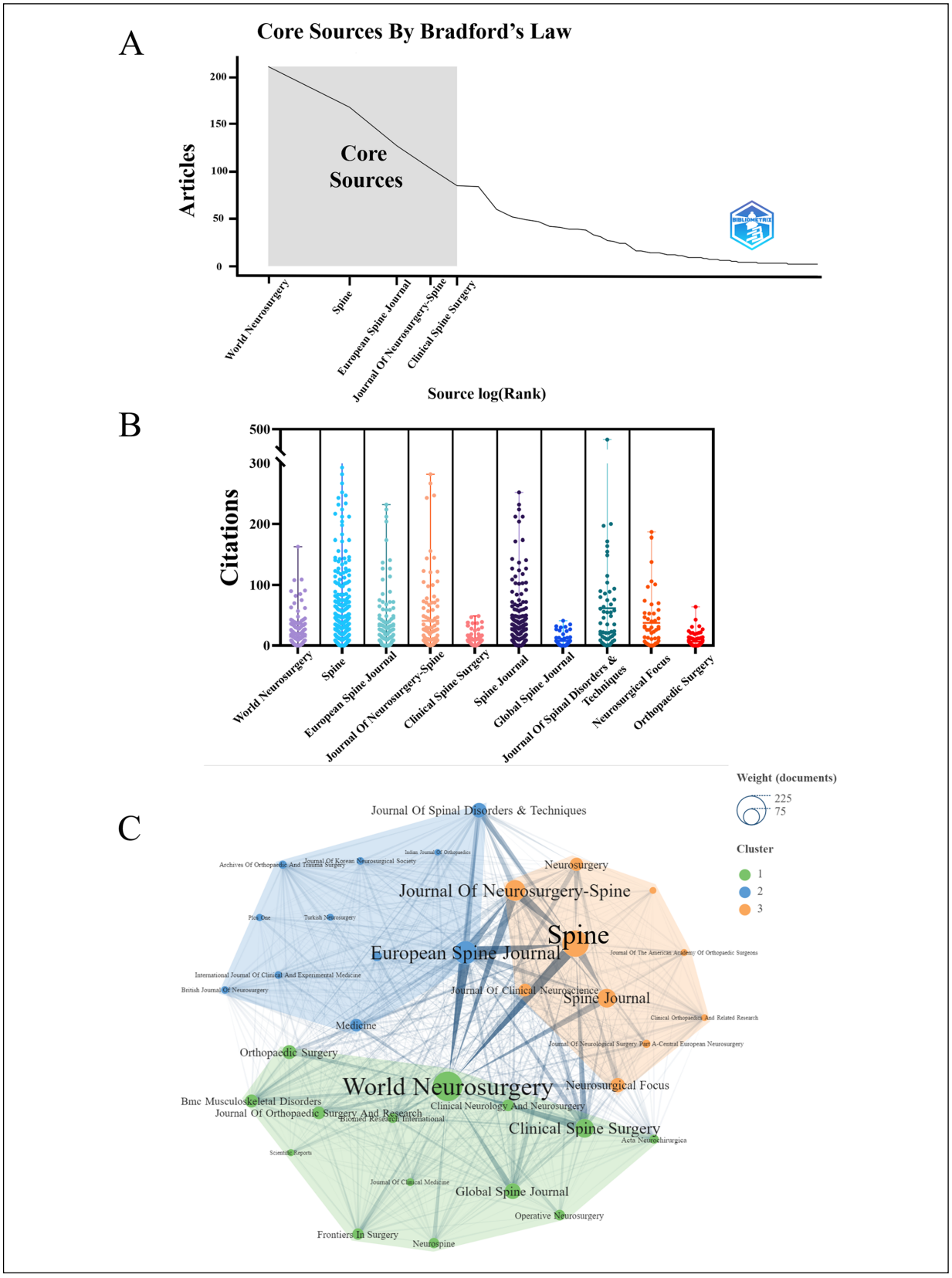
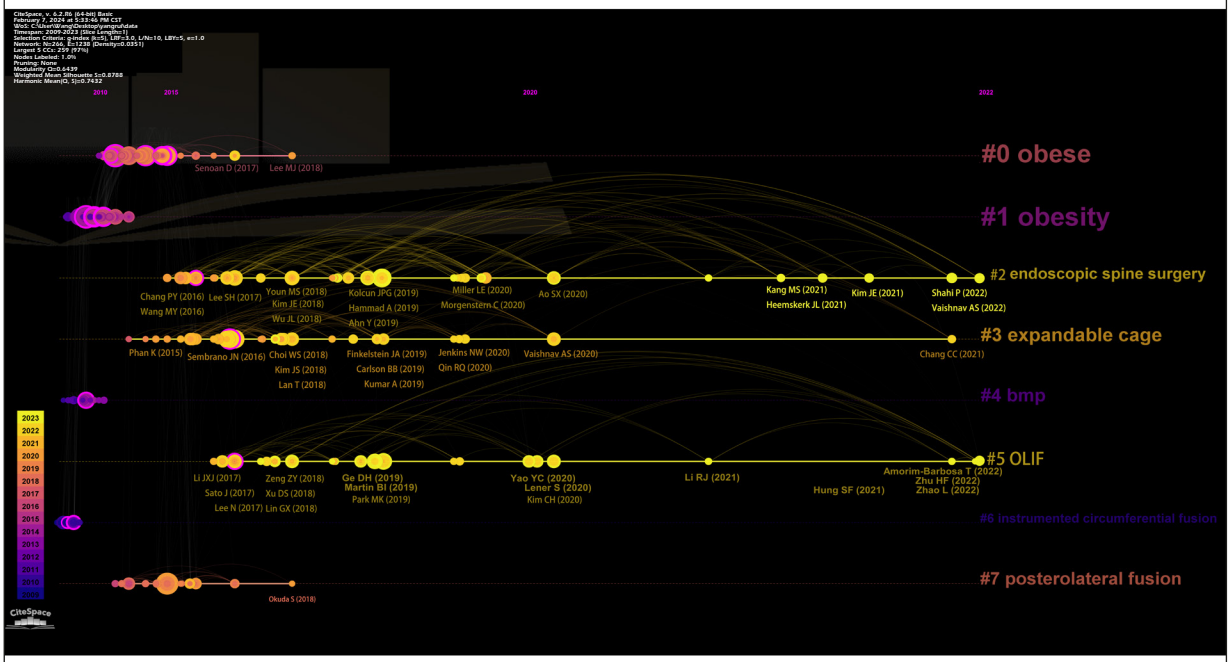


Figure 4. Analysis of journals. **A**, Bibliometric coupling within journals. Three clusters were identified based on journals that had published more than five articles. **B**, Total citations to each Journal. **C**, Journal clustering.

A



B

Top 25 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2001 - 2023
Humphreys SC, 2001, SPINE, V26, P567	2001	15.35	2002	2006	
Lowe TG, 2002, J SPINAL DISORD TECH, V15, P31, DOI 10.1097/00024720-200202000-00005, DOI	2002	14.51	2003	2007	
Salehi SA, 2004, NEUROSURGERY, V54, P368, DOI 10.1227/01.NEU.0000103493.25162.18, DOI	2004	15.47	2004	2009	
Schwender JD, 2005, J SPINAL DISORD TECH, V18, PS1, DOI 10.1097/01.bsd.0000132291.50455.d0, DOI	2005	21.65	2005	2010	
Hackenberg L, 2005, EUR SPINE J, V14, P551, DOI 10.1007/s00586-004-0830-1, DOI	2005	15.33	2006	2010	
Peng Chan Wearn Benedict, 2009, SPINE (PHILA PA 1976), V34, P1385, DOI 10.1097/BRS.0b013e3181a4e3be, DOI	2009	27.23	2010	2014	
Dhall SS, 2008, J NEUROSURG-SPINE, V9, P560, DOI 10.3171/SPI.2008.9.08142, DOI	2008	22.16	2010	2013	
Schizas C, 2009, INT ORTHOP, V33, P1683, DOI 10.1007/s00264-008-0687-8, DOI	2009	22.14	2010	2014	
Park P, 2008, NEUROSURG FOCUS, V25, P0, DOI 10.3171/FOC/2008/25/8/E16, DOI	2008	13.25	2010	2013	
Fan SW, 2010, SPINE, V35, P1615, DOI 10.1097/BRS.0b013e3181c70fe3, DOI	2010	18.36	2011	2015	
Wang JA, 2010, EUR SPINE J, V19, P1780, DOI 10.1007/s00586-010-1404-z, DOI	2010	15.92	2011	2015	
Villavicencio Alan T, 2010, SURG NEUROL INT, V1, P12, DOI 10.4103/2152-7806.63905, DOI	2010	15.44	2011	2015	
Adogwa O, 2011, J SPINAL DISORD TECH, V24, P479, DOI 10.1097/BSD.0b013e3182055cac, DOI	2011	15.76	2012	2016	
Wu RH, 2010, SPINE, V35, P2273, DOI 10.1097/BRS.0b013e3181cd42cc, DOI	2010	14.88	2012	2015	
Lee KH, 2012, EUR SPINE J, V21, P2265, DOI 10.1007/s00586-012-2281-4, DOI	2012	24.57	2013	2017	
Lau D, 2011, J CLIN NEUROSCI, V18, P624, DOI 10.1016/j.jocn.2010.09.004, DOI	2011	15.19	2013	2016	
Xue HM, 2012, SPINE J, V12, P209, DOI 10.1016/j.spinee.2012.01.010, DOI	2012	15.02	2013	2017	
Lee JC, 2012, SPINE, V37, P1548, DOI 10.1097/BRS.0b013e318252d44b, DOI	2012	13.3	2013	2017	
Seng CS, 2013, SPINE, V38, P2049, DOI 10.1097/BRS.0b013e3182a8212d, DOI	2013	18.94	2014	2018	
Parker SL, 2014, WORLD NEUROSURG, V82, P230, DOI 10.1016/j.wneu.2013.01.041, DOI	2014	18.36	2015	2019	
Gu GF, 2014, INT ORTHOP, V38, P817, DOI 10.1007/s00264-013-2169-x, DOI	2014	13.43	2015	2019	
Khan NR, 2015, NEUROSURGERY, V77, P847, DOI 10.1227/NEU.0000000000000913, DOI	2015	16.42	2016	2020	
Phan K, 2015, EUR SPINE J, V24, P1017, DOI 10.1007/s00586-015-3903-4, DOI	2015	13.34	2016	2020	
Mobbs Ralph J, 2015, J SPINE SURG, V1, P2, DOI 10.3978/j.issn.2414-469X.2015.10.05, DOI	2015	26.96	2018	2020	
de Kunder SL, 2017, SPINE J, V17, P1712, DOI 10.1016/j.spinee.2017.06.018, DOI	2017	15.68	2019	2023	

Figure 5. Analysis of citations and references. **A**, Timeline of co-cited references related to TLIF. **B**, Reference burst detection of the top 25 references with the strongest emergent strength.

Table V. The top 10 most cited literatures.

Rank	First author	Title	Journal	Type	Year of publication	Total citations
1	Schwender et al[12]	Minimally invasive transforaminal lumbar interbody fusion (TLIF) - Technical feasibility and initial results	Journal of Spinal Disorders and Techniques	Article	2005	449
2	Rodgers et al[13]	Intraoperative and Early Postoperative Complications in Extreme Lateral Interbody Fusion an Analysis of 600 Cases	Spine	Article	2011	365
3	Humphreys et al[14]	Comparison of posterior and transforaminal approaches to lumbar interbody fusion	Spine	Article	2001	356
4	Smith et al[15]	Rates of Infection After Spine Surgery Based on 108,419 Procedures A Report from the Scoliosis Research Society y Morbiditand Mortality Committee	Spine	Article	2011	293
5	Dhall et al[16]	Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up	Journal of Neurosurgery-Spine	Article	2008	282
6	Wong et al[17]	Neurologic impairment from ectopic bone in the lumbar canal: a potential complication of off-label PLIF/TLIF use of bone morphogenetic protein-2 (BMP-2)	Spine Journal	Article	2008	272
7	Hsieh et al[18]	Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: implications for the restoration of foraminal height, local disc angle, lumbar lordosis, and sagittal balance	Journal of Neurosurgery-Spine	Article	2007	267
8	Parker et al[19]	Utility of minimum clinically important difference in assessing pain, disability, and health state after transforaminal lumbar interbody fusion for degenerative lumbar spondylolisthesis	Journal of Neurosurgery-Spine	Article	2011	249
9	Isaacs et al[20]	Minimally invasive microendoscopy-assisted transforaminal lumbar interbody usion with instrumentation	Journal of Neurosurgery-Spine	Article	2005	247
10	Ong et al[21]	Off-Label Use of Bone Morphogenetic Proteins in the United States Using Administrative Data	Spine	Article	2010	217

of intervertebral space height, and enhancement of lumbar stability. As a result, TLIF has gained widespread utilization in clinical practice[23,24]. Therefore, a comprehensive analysis was undertaken on a total of 1,907 publications obtained from 181 journals, encompassing the contributions of 7,232 authors affiliated with 1,775 institutes spanning 57 countries/regions. Notably, the USA exhibited the highest number of publications, with 763 (40.03%) articles on TLIF. The

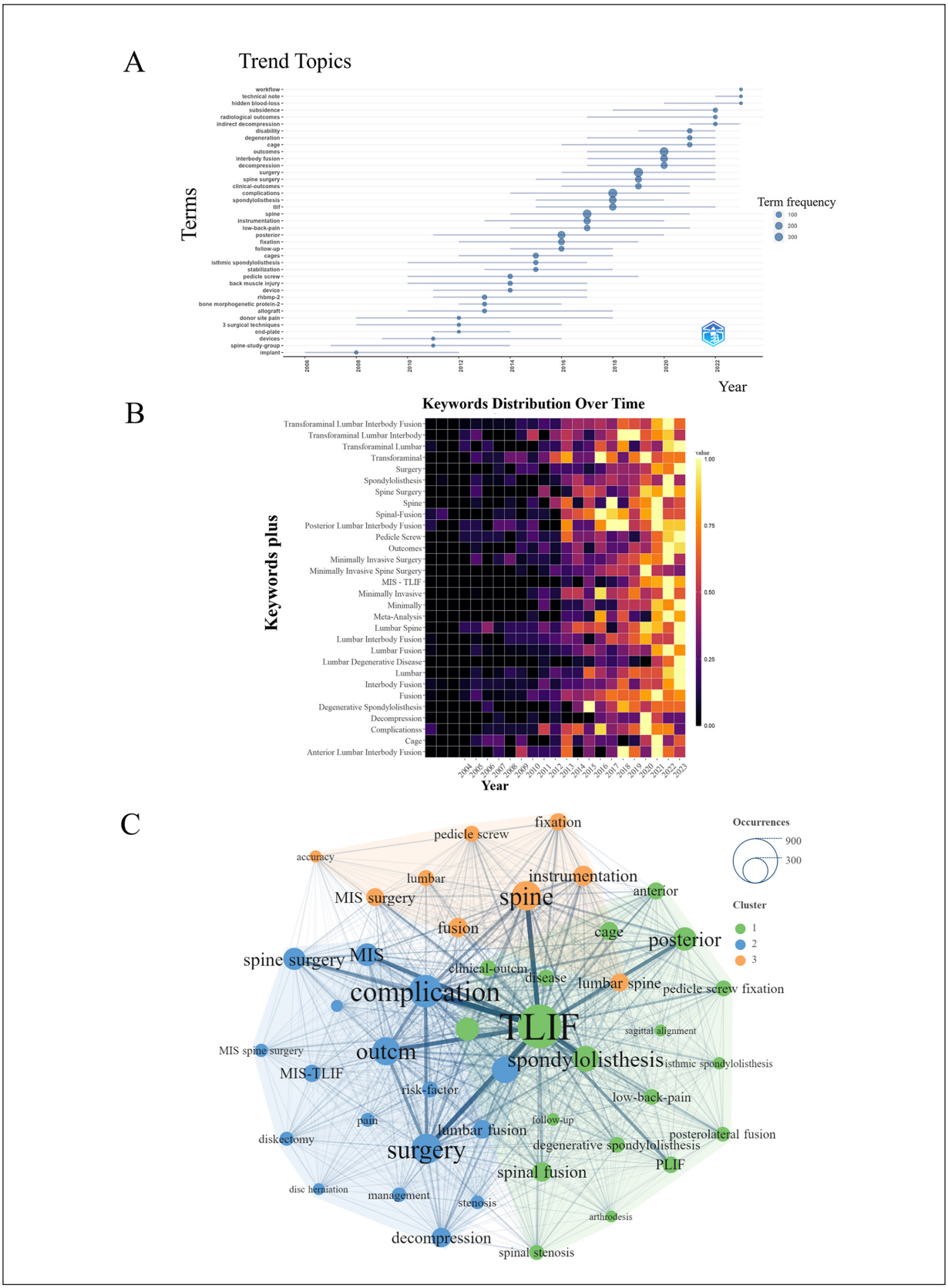


Figure 6. Analysis of keywords. **A**, Trend topics from 2000 to 2023. **B**, Heat map of 30 keywords. **C**, Keywords clustering.

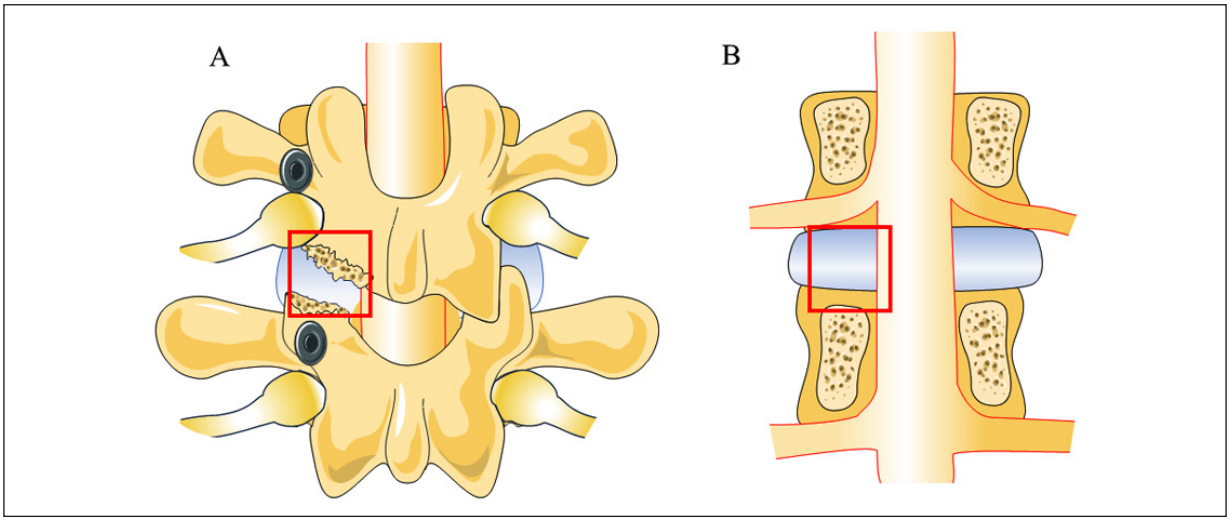


Figure 7. Anatomical diagram of the TLIF surgical approach. **A**, After exposing the bony structure, the facet of the approach side, including the inferior and superior facets, is removed; after removing the ipsilateral ligamentum flavum, the dural sac and nerve roots are exposed, the intervertebral disc is exposed from the intervertebral foramen region, and the TLIF procedure is completed for exposure. **B**, After removing the posterior bony structure, the extent of exposure of the TLIF procedure was schematically depicted. Red line: TLIF surgical exposure range.

most productive institution was Rush University, with 96 (5.03%) publications. The author with the highest publication output was Singh, Kern with 75 (3.93%) publications. World Neurosurgery demonstrated the highest level of productivity, having published a total of 211 (11.06%) articles. The most frequently used keywords were "TLIF", "spondylolisthesis" and "complication". Meanwhile, "workflow", "technical note" and "hidden blood loss" have been identified as the research frontiers for the forthcoming years.

Minimally Invasive Transforaminal Lumbar Interbody Fusion (MIS-TLIF)

In 2002, Foley and Lefkowitz[9] initially introduced the concept of MIS-TLIF. They postulated that MIS-TLIF could effectively minimize intraoperative bleeding and soft tissue trauma, expedite postoperative recovery, and yield comparable clinical outcomes to conventional TLIF procedures. With advancements and refinements in MIS-TLIF technology, the surgical indications for its use have expanded considerably. It is now employed in the treatment of various conditions, including primary and recurrent lumbar disc herniation, lumbar spinal stenosis, lumbar spondylolisthesis, lumbar instability, lumbar pseudoarthrosis formation, degenerative scoliosis, and painful discogenic disorders[25-27]. However, there are certain contraindications to consider, such as spondylolisthesis exceeding a certain degree, severe bony spinal stenosis, and significant anatomical damage in the foraminal region following previous open surgery[28].

MIS-TLIF Working Channel and Surgical Approaches

Over the course of more than a decade, MIS-TLIF technology has matured, with advancements in minimally invasive channel systems facilitating easier and faster operations. Commonly used minimally invasive channel systems include METRxTM X-tube cannula (Medtronic Inc., Minneapolis, MN, USA), Pipeline channel (DePuy Synthes Spine Inc., Raynham, MA, USA), and MASTQuadrant channel (Medtronic Inc., Minneapolis, MN, USA)[25,29,30]. Furthermore, advancements in interbody fusion cages have also contributed to improved rates of interbody fusion[31,32]. Considerable research has been dedicated to exploring the internal fixation techniques employed in MIS-TLIF. Currently, internal fixation methods can be categorized into four main types: bilateral pedicle screw fixation (BPS), unilateral pedicle screw fixation (UPS), bilateral incision unilateral pedicle screw + contralateral facet screw fixation (UPFS), and unilateral incision unilateral pedicle screw + contralateral translaminar screw fixation (UPFS + TLS). Among these options, BPS and UPS fixation, often referred to as bilateral *vs.* unilateral fixation, represent the predominant approaches used in MIS-TLIF[33-35].

MIS-TLIF in Multilevel Degenerative Diseases

The clinical application of MIS-TLIF has evolved beyond being a simple treatment for single-stage lumbar disc herniation. It has shown versatility in treating a range of complex and multistage lumbar degenerative diseases[36]. Researchers have explored the use of MIS-TLIF in the management of multilevel lumbar degenerative diseases. For instance, in a retrospective study by Fan et al[37], 60 patients with three-level lumbar spinal stenosis were evaluated. Following MIS-TLIF or posterior lumbar interbody fusion (PLIF), significant improvements were observed in measures such as visual analog scale (VAS) scores for low back pain and leg pain, Oswestry Disability Index (ODI), and SF-36 scores at a 12-month follow-up compared to preoperative assessments. However, there were no significant differences between the MIS-TLIF and PLIF groups in terms of these outcome measures. Notably, the MIS-TLIF group demonstrated reduced intraoperative blood loss, shorter hospital stays, and lower VAS scores for low back pain at the 6-month postoperative mark compared to the PLIF group.

MIS-TLIF in Thoracolumbar Degenerative Diseases

Traditional open surgery for thoracolumbar disc herniation is associated with extensive disruption of the posterior spinal structures, which can lead to significant postoperative vertebral instability and muscle denervation. Consequently, patients may experience persistent low back pain following surgery, and there is also a risk of nerve injury[38,39]. A retrospective analysis conducted by Wang et al[40] investigated the clinical outcomes of ten patients who underwent MIS-TLIF for thoracolumbar junction disc herniation. The study revealed that no significant complications were reported during the final follow-up assessment. The findings suggest that MIS-TLIF is a safe and effective surgical procedure for managing disc herniation in the thoracolumbar junction. However, it is worth noticing that the occurrence of non-union was relatively high compared to previous literature on the subject. Maruo et al[41], however, reported a case of thoracolumbar disc herniation that was treated using MIS-TLIF, but the patient developed hemothorax after the surgery. Subsequent investigations in the literature have indicated that this complication may be associated with intraoperative screw placement causing injury to the lateral cutaneous branch of the intercostal artery. Surgeons should be vigilant and take precautions to avoid such complications. It is noteworthy that surgical treatment for thoracolumbar disc herniation typically requires a larger fusion space compared to surgery for lower lumbar disc herniation.

MIS-TLIF in Deformity Correction

Minimally invasive surgery has gained increasing popularity as it utilizes smaller incisions to reduce complications associated with traditional open approaches. Traditional adult scoliosis correction surgery is often accompanied by significant risks due to factors such as advanced age and multiple comorbidities, leading to slow postoperative recovery. Various minimally invasive surgical techniques have been developed to address the limitations of open surgery for patients who may not tolerate it well. One such technique is MIS-TLIF, which is employed for correcting degenerative scoliotic deformities in the adult spine[42]. However, there is a scarcity of studies investigating MIS-TLIF in this specific patient population, particularly high-quality prospective comparative studies. The available studies[43,44] exhibit considerable variability in outcomes, particularly with regard to deformity correction and the incidence of complications.

Navigation and Robotically Assisted Surgery

In a study conducted by Liu et al[27], a comparison was made between navigation-assisted transforaminal lumbar interbody fusion (N-TLIF) and navigation-assisted minimally invasive TLIF (NM-TLIF). The findings revealed that NM-TLIF, when compared to N-TLIF, offers the advantage of being a less invasive procedure while maintaining similar or improved accuracy in screw placement. Furthermore, NM-TLIF was associated with better symptom relief during the midterm postoperative recovery period. However, it is important to emphasize the need for real-time adjustments during pedicle insertion in NM-TLIF rather than solely relying on the entry point and trajectory outlined in the intraoperative plan. In a retrospective study conducted by Lin et al[45], it was observed that patients undergoing robot-guided MIS-TLIF demonstrated reduced intraoperative blood loss compared to those undergoing freehand fluoroscopy-guided procedures. Additionally, robot-guided MIS-TLIF was associated with shorter operative durations, particularly

in cases involving higher-level (>3 levels) spinal surgeries. Notably, the postoperative outcomes were comparable between the two approaches, suggesting similar efficacy in achieving desired surgical outcomes.

The extensive utilization of MIS-TLIF can be attributed to its favorable clinical effectiveness, coupled with the benefits of minimal tissue injury, cost-effectiveness, and early postoperative recovery offered by MIS techniques. Nevertheless, it is important to acknowledge the limitations of MIS-TLIF. Compared to conventional procedures, MIS-TLIF involves increased intraoperative radiation exposure and a steep learning curve. During the initial stages of training, inadequate patient selection and imperfect technical proficiency may elevate the risks of complications such as cerebrospinal fluid leakage, nerve damage, screw placement failure, and suboptimal treatment outcomes[46-48]. Consequently, the implementation of this procedure may pose challenges within primary healthcare settings. Meanwhile, it is unequivocally asserted that in the conscientious execution of a comprehensive informed consent process, medical practitioners bear an ethical obligation to disclose and initiate a substantive discourse concerning the potential hazards, advantages, and possible alternatives associated with a specific medical intervention. The comprehensive depiction and deliberation of potential alternatives constitute a pivotal element of the disclosure procedure, as patients may encounter challenges in comprehending risks in abstract terms and thus necessitate a comparative framework to enable a truly informed resolution[49-51]. Therefore, when deciding between MIS-TLIF and open surgery, surgeons should not only strictly adhere to surgical indications and contraindications but also employ a dialectical analysis based on their own technical proficiency and patient-specific factors, thereby avoiding hasty decision-making.

Strength and Limitations

This study presents a comprehensive bibliometric analysis of the field of TLIF, encompassing an assessment of its overall scope, advancements, notable contributions, and emerging trends. Researchers are advised to prioritize recent and highly cited references, as well as topics of interest within the field. However, it is important to acknowledge certain limitations inherent in this bibliometric analysis. The exclusion of recently published articles may be attributed to temporal delays in data collection. Additionally, our analysis was confined to articles sourced exclusively from the WoS Core Collection, which may have restricted the breadth of our findings. Lastly, despite the algorithm's objective execution of the analysis, we observed an inherent subjective bias in the interpretation of the data.

Conclusions

The field of TLIF has undergone significant evolution over time, revealing a notable trend. Advancements in science and technology, along with extensive research, have expanded the indications for MIS-TLIF surgery, challenging previous contraindications. Various internal fixation methods, interbody fusion cages, navigation systems, robotically assisted surgery, and artificial intelligence have emerged as well. Clinicians are suggested to use evidence-based medicine, the patient's preference, and their own expertise to make appropriate choices. However, a comprehensive evaluation of the long-term effectiveness of MIS-TLIF requires extensive prospective research across multiple centers to understand its true benefits for patients.

Conflict of Interest

The authors declare that they have no conflict of interests.

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Ethics Approval

Not applicable.

Informed Consent

Not applicable.

Data Availability

All data analyzed were included in this paper; further requests can be consulted, and data can be obtained from the corresponding author.

Authors' Contribution

Y.-X. Hu and H. W contributed to the study conception and design. Y.-X. Hu and R. Yang and S.-M. Liu collected and analyzed the clinical data and wrote the manuscript. Y.-X. Hu, R. Yang and H. W submitted and revised the manuscript. The final version of the manuscript was read and approved by all authors.

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