



## Original Article

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# Global Trends and Hotspots in Endoscopic Discectomy: A Study Based on Bibliometric Analysis

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**Objective:** With the advancement of minimally invasive spine surgery, endoscopic discectomy (ED) has become a common technique for degenerative disease of the spine. The present study aimed to explore the knowledge structure, emerging trends, and future research hotspots in this field.

**Methods:** All relevant publications on ED from 2002 to 2021 were extracted from the Web of Science databases. Key bibliometric indicators, including countries/regions, institutions, authors, journals, references, and keywords were calculated and evaluated using VOSviewer and CiteSpace software.

**Results:** A total of 1,196 articles and reviews were included for analysis. The number of publications regarding ED increased yearly. From the quality and quantity viewpoint, China, South Korea, and the United States were the major contributors in this field. The most influential institution in the field of ED was Wooridul Spine Hospital. We identified 3,488 authors, among which Lee SH had the most significant number of papers, and Ruetten S was cocited most often. *World Neurosurgery* was the journal with the most papers, and *Spine* was the most commonly cocited journal. Keywords were stratified into 4 clusters by VOSviewer software: cluster 1 (clinical outcomes of ED in the treatment of lumbar disc herniation); cluster 2 (surgical technique of percutaneous endoscopic lumbar discectomy); cluster 3 (clinical outcomes of ED in the treatment of lumbar spinal stenosis); and cluster 4 (clinical outcomes of percutaneous endoscopic cervical discectomy). Several topics including lateral recess stenosis, spinal stenosis, and reoperation were considered as the next hotspot in ED research.

**Conclusion:** ED research has gained considerable attention over the last 2 decades. Our bibliometric findings illuminate the publication trends and research hotspots of the ED field, which may provide useful references for scholars and decision-makers interested in this field.

**Keywords:** Endoscopic discectomy, Bibliometric, VOSviewer, CiteSpace

## INTRODUCTION

Since earlier work by Kambin<sup>1</sup> to adapt arthroscopy for lumbar disc herniation (LDH), endoscopic discectomy (ED) has experienced tremendous development in the past few decades. Multiple studies<sup>2-5</sup> have suggested the ED provides equivalent clinical outcomes to conventional microdiscectomy with fewer postoperative pain, shorter hospitalizations, less local tissue in-

jury, and faster recovery. With growing experience and technological innovation, the indications of ED have been extended from lumbar degenerative diseases to degenerative diseases of the thoracic and cervical spine.<sup>6-8</sup>

Bibliometrics is a multidisciplinary discipline that involves various disciplines such as mathematics, statistics, and philology.<sup>9,10</sup> It can not only quantitatively analyze the current state of a certain research domain through data visualization, but also

identify current research hotspots and predict future research trends.<sup>11,12</sup> However, to our knowledge, there is currently no bibliometric analysis assessing the relevant status quo and trends regarding ED research have been performed.

In this study, we aimed to visually analyze publications about ED in the Web of Science (WoS) database over the past 20 years. We presented a statistical analysis of the current status of the ED field, including the annual publication, countries/regions, institutions, authors, journals, references, and keywords. We also analyzed the trends and hotspots of ED to provide a reference for scholars and decision-makers interested in this field.

## MATERIALS AND METHODS

### 1. Data Sources and Search Strategies

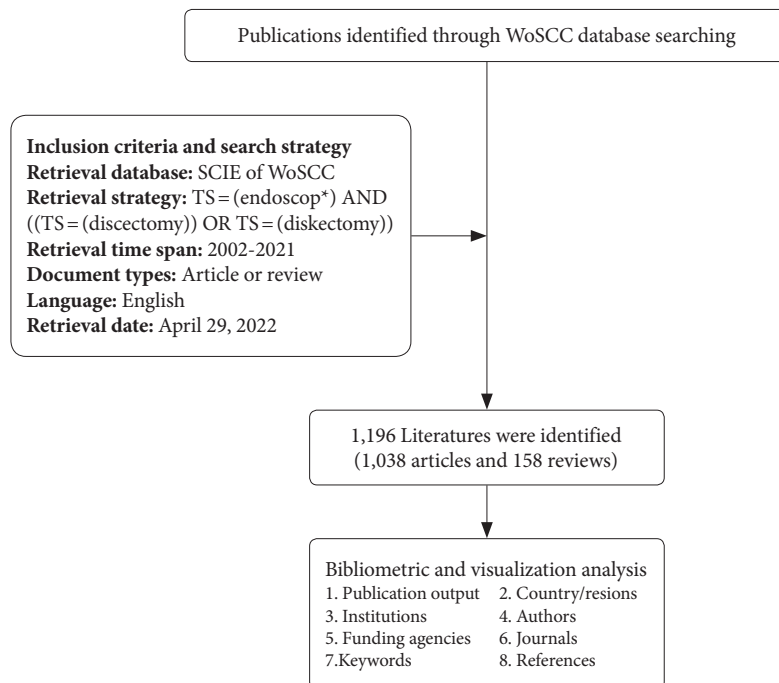
A comprehensive online search was performed using the Science Citation Index Expanded in the Web of Science Core Collection database on April 29, 2022. The search formula was “TS=(endoscop\*) AND ((TS=(discectomy)) OR TS=(diskectomy)).” The search was limited to the English language with a publication date restricted from January 1, 2002 to December 31, 2021. For literature types, only articles and reviews were included. Ultimately, 1,196 records were identified.

### 2. Data Extraction and Bibliometric Analysis

Records retrieved from WoS were extracted and downloaded in “plain text” format with “Full Record and Cited References” for subsequent bibliometric analysis.

WoS was applied to describe the characteristics of the publications, including annual publications, countries/regions, institutions, authors, journals, funding sources, citation frequency, and Hirsch index (H-index). In addition, the journal impact factor (IF) and quartile ranks were extracted from the Journal Citation Reports 2021. The information extraction process was performed by 2 researchers independently, and any discrepancies were resolved through consensus.

Then, the VOSviewer 1.6.18 (Leiden University, Leiden, The Netherlands) and CiteSpace 5.8.R3 (Drexel University, Philadelphia, PA, USA) were applied to perform the bibliometric and visualization analysis. VOSviewer was applied to generate knowledge maps of the identified influential authors, contributing countries and institutions, core journals, high-quality papers, co-occurring keywords and cocited references. CiteSpace was used to extract keywords and references from publications with high-citation bursts and generate a dual-map overlay for journals. The flow diagram of literature search and analysis are presented in Fig. 1.



**Fig. 1.** The flow diagram of literature search and analysis. WoSCC, Web of Science Core Collection; SCIE, Science Citation Index Expanded.

## RESULTS

### 1. The Publication and Citation Trends

A total of 1,196 publications were identified from WoS, including 1,038 articles and 158 reviews. Fig. 2 shows the publications and citations in the field of ED between 2002 and 2021. In general, the annual number of publications and citations showed an overall increasing trend over the years. The evolution of the annual number of publications in the ED field can be separated into 2 stages: a slow and steady growth phase from 2002–2015, followed by a rapid and high-yield growth phase from 2016–2021. As of the search date, these publications received 20,633 citations, an average of 17.25 citations per publication, and an H-index of 66.

### 2. Countries/Regions, Institutions, and Funding Agencies

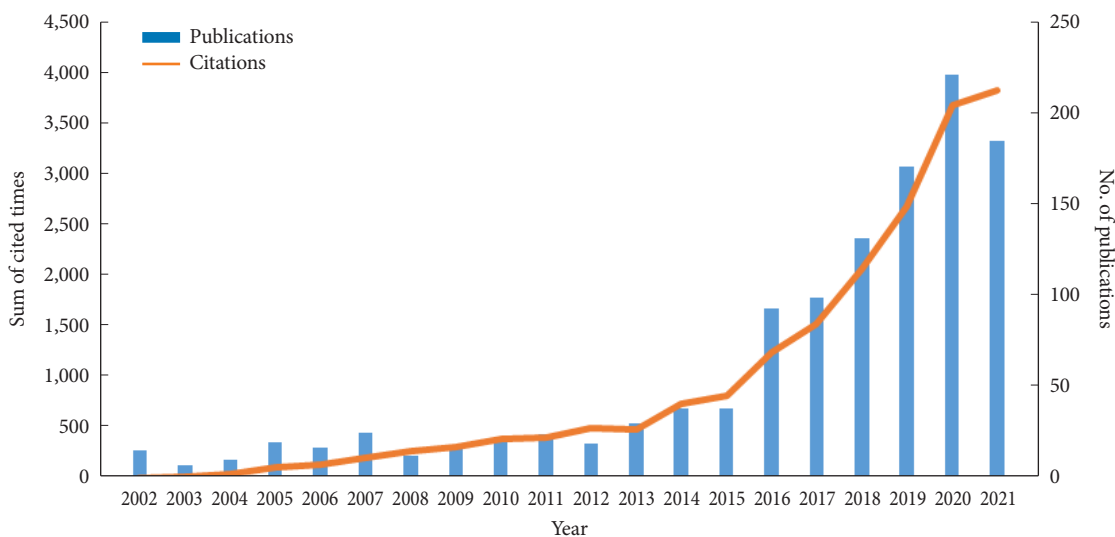
The ED is a research hotspot worldwide, with a total of 53 countries/regions contributed to this field. The top 10 most productive countries/regions in ED are shown in Table 1 and Fig. 3A. China published the largest number of papers (521), followed by South Korea (241), and the United States (181). South Korea accounted for 5,409 citations with an H-index of 40, which both ranked first among all involved countries/regions. The number of citations of publications from the United States was 5,013 with an H-index of 37, which both ranked second. Notably, though the number of citations and H-index from China both ranked third, the average number of citations ranked last in the top 10 countries/regions. The VOSviewer was

employed to analyze the network visualization of coauthorship between countries/regions. The United States and China occupied the central place of the network, and there were active collaborations among these countries/regions (Fig. 3B).

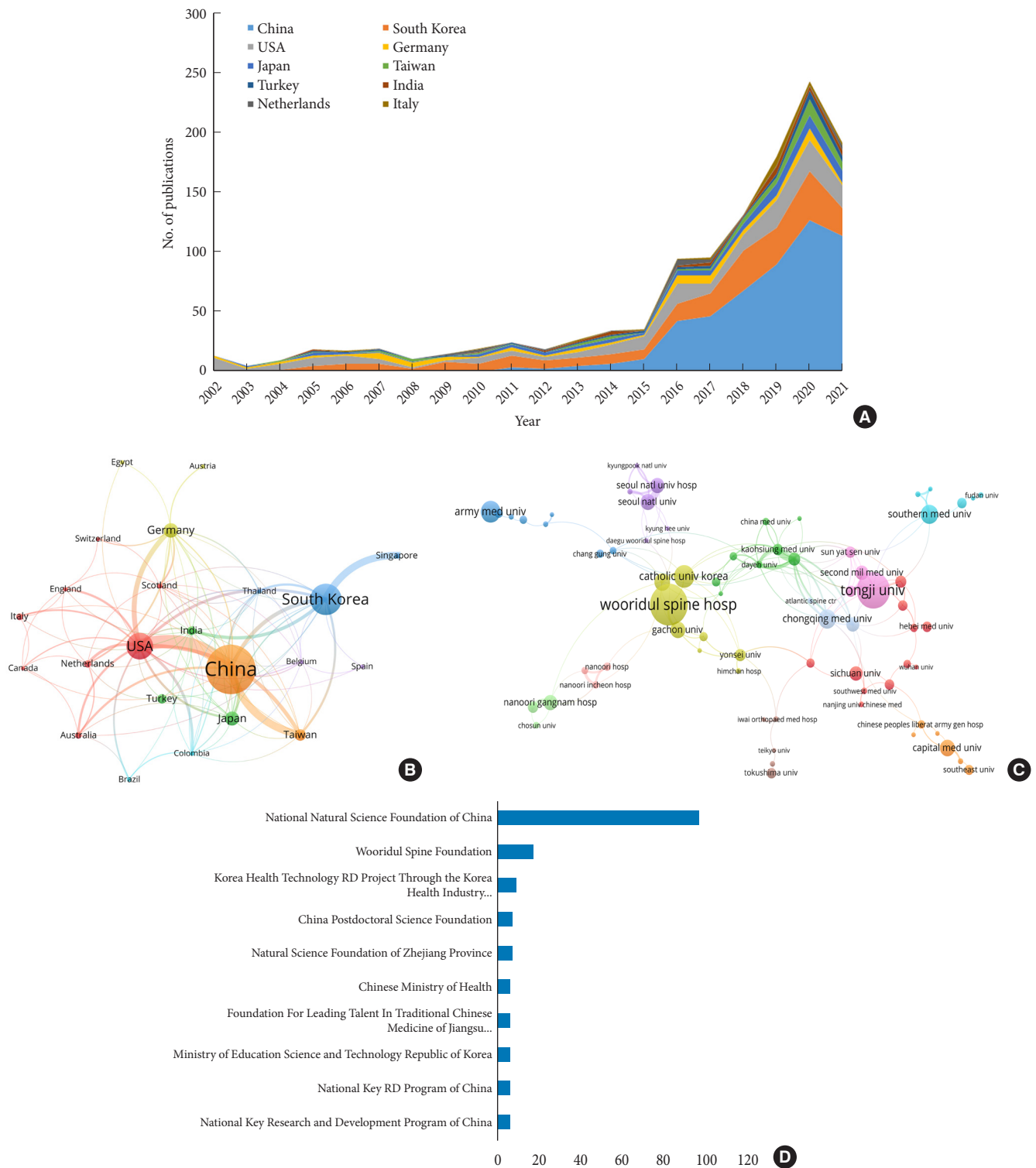
As for institutions, the top 10 most productive institutions are listed in Table 2. Among the top 10 most productive institutions, 5 were from China, 4 from South Korea, and 1 from the United States. Wooridul Spine Hospital contributed the most publications with 57 papers published, followed by the Tongji University (48 publications), and The Catholic University of Korea (31 publications). In terms of other parameters, the H-index of Wooridul Spine Hospital ranked first (32), followed by that of Army Medical University (15) and Tongji University

**Table 1.** Top 10 largest contributing countries/regions in the field of endoscopic discectomy research

Rank	Country/region	No.	Citations	Average article citations	H-index
1	China	521	3,985	7.65	28
2	South Korea	241	5,409	22.44	40
3	USA	181	5,013	27.7	37
4	Germany	65	2,408	37.05	22
5	Japan	63	721	11.44	14
6	Taiwan	44	623	14.16	12
7	Turkey	31	316	10.19	10
8	India	26	271	10.42	10
9	Netherlands	20	671	33.55	13
10	Italy	19	264	13.89	8



**Fig. 2.** The global trend of annual publications and citations related to endoscopic discectomy research from 2002 to 2021.



**Fig. 3.** (A) The annual number of publications in the top 10 countries/regions from 2002 to 2021. (B) The coauthorship map of countries/regions involved in percutaneous endoscopic discectomy research (generated by VOSviewer). (C) The coauthorship map of institutions involved in endoscopic discectomy research (generated by VOSviewer); The size of the node indicates the number of documents in the countries/regions or institutions, and the thickness of the line between the nodes indicates the collaborative intensity between countries/regions or institutions. (D) The top 10 most active funding agencies involved in endoscopic discectomy research.

**Table 2.** Top 10 most productive institutions in the field of endoscopic discectomy research

Rank	Institutions	Country	No.	Citations	Average no. of citations	H-index
1	Wooridul Spine Hospital	South Korea	57	2,895	50.79	32
2	Tongji University	China	48	461	9.6	13
3	The Catholic University of Korea	South Korea	31	673	21.71	12
4	Army Medical University	China	30	526	17.53	15
5	Brown University	USA	27	408	15.11	12
6	Southern Medical University	China	24	101	4.21	6
7	Chongqing Medical University	China	23	244	10.61	9
8	Leon Wiltse Memorial Hospital	South Korea	22	503	22.86	12
9	Capital Medical University	China	21	54	2.57	4
10	Gachon University	South Korea	21	206	9.81	8

**Table 3.** Top 10 most active funding agencies in the field of endoscopic discectomy research

Rank	Funding Source	Country	No.	% of 1,196
1	National Natural Science Foundation of China	China	96	8.027
2	Wooridul Spine Foundation	South Korea	16	1.338
3	Korea Health Technology R D Project Through The Korea Health Industry Development Institute Khidi Ministry of Health Welfare Republic of Korea	South Korea	8	0.669
4	China Postdoctoral Science Foundation	China	6	0.502
5	Natural Science Foundation of Zhejiang Province	China	6	0.502
6	Chinese Ministry of Health	China	5	0.418
7	Foundation for Leading Talent in Traditional Chinese Medicine of Jiangsu Province	China	5	0.418
8	Ministry of Education Science and Technology Republic of Korea	South Korea	5	0.418
9	National Key R D Program of China	China	5	0.418
10	National Key Research and Development Program of China	China	5	0.418

(13). The citation frequency of papers from Wooridul Spine Hospital ranked first (2,895 times), followed by that from The Catholic University of Korea (673 times) and Army Medical University (526 times). The Wooridul Spine Hospital had the highest average citations of 50.79 per paper, followed by Leon Wiltse Memorial Hospital (22.86) and The Catholic University of Korea (21.71). The institutional coauthorship network map was conducted by VOSviewer and illustrated in Fig. 3C. There was an active collaboration among leading institutions.

The top 10 most active funding agencies are shown in Table 3 and Fig. 3D, 7 were from China, and the other 3 were from South Korea. The National Natural Science Foundation of China financed 96 studies in the ED field (ranked first, 8.027%), followed by the Wooridul Spine Foundation (16 studies, 1.338%) and the Korea Health Technology R D Project through the Korea Health Industry Development Institute Khidi Ministry of

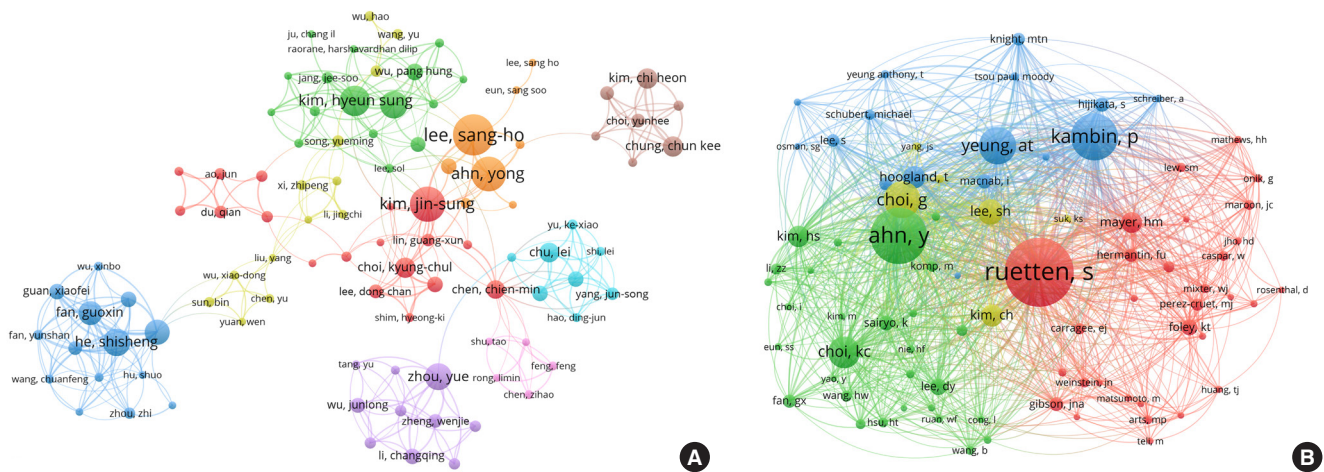
Health Welfare Republic of Korea (8 studies, 0.669%).

### 3. Authors and Cocited Authors

A total of 3,488 authors contributed to the publications on ED research. The top 10 most productive authors and the top 10 cocited authors are presented in Table 4. Among the top 10 authors, 5 were from South Korea, 4 from China, and 1 from the United States. Lee SH published the most papers (66) and ranked first, followed by Ahn Y (43) and Kim HS (41). The co-authorship network of authors was performed by VOSviewer and illustrated in Fig. 4A. In this network, different colors represent different clusters. It found that authors in the same cluster have relatively close cooperation. Nevertheless, the collaboration between authors from different clusters was weak, indicating little cooperation between different research teams. Additionally, we also use VOSviewer to perform author cocitation

**Table 4.** Top10 most productive authors and the top 10 cocited authors in the field of endoscopic discectomy research

Rank	Author	Country	No.	Total citations	H-index	Cocited author	Country	Citations
1	Lee SH	South Korea	66	2,916	32	Ruetten S	Germany	1,113
2	Ahn Y	South Korea	43	1,816	24	Ahn Y	South Korea	850
3	Kim HS	South Korea	41	459	14	Kambin P	USA	675
4	Kim JS	South Korea	38	948	15	Yeung AT	USA	494
5	He SS	China	31	302	11	Choi G	South Korea	485
6	Zhou Y	China	27	520	15	Choi KC	South Korea	407
7	Jang IT	South Korea	26	286	8	Lee SH	South Korea	294
8	Telfeian AE	USA	25	397	12	Hoogland T	Germany	256
9	Gu X	China	23	242	10	Kim CH	South Korea	247
10	Fan GX	China	23	235	10	Kim HS	South Korea	240



**Fig. 4.** The network visualization map of authors' coauthorship (A) and cocitation (B). In the authors' coauthorship map, the node's size represents the number of papers published by the author, and the thickness of the line between the nodes indicates the collaborative intensity between authors. In authors' cocitation map, the size of the node represents the citation frequency, and the line between 2 nodes means that both were cited by one author.

analysis. In cocited author network analysis (Fig. 4B), Ruetten S (1,113 times) had the highest citation frequency and ranked first, followed by Ahn Y (850 times) and Kambin P (675 times).

**4. Journals and Cocited Journals**

A total of 174 journals published papers on ED research. The top 10 journals with the greatest number of publications are listed in Table 5 and Fig. 5A. Among the top 10 journals, 7 were from the United States, and the other 3 were from Germany, England, and South Korea. World Neurosurgery published the most papers (179), followed by Pain Physician (75) and Medicine (53). Spine has the largest number of total citations (3,406 times) and highest value of H-index (27), and Pain Physician has the highest IF (2021 IF, 4.396). The journal cocitation analysis was conducted via VOSviewer. As shown in Fig. 5B, the top

5 cocited journals were *Spine* (6,326 times), *European Spine Journal* (2,097 times), *Neurosurgery* (1,528 times), *World Neurosurgery* (1,336 times), and *Journal of Neurosurgery-Spine* (1,269 times).

A dual-map overlay of journals was generated using CiteSpace (Fig. 5C). We found that there were 3 main citation paths. The published articles were mainly focused on journals in the field of neurology, sports, and ophthalmology, whereas most of the cited articles were published in journals in the field of health, nursing, medicine, sports, rehabilitation, sport, psychology, education, and social.

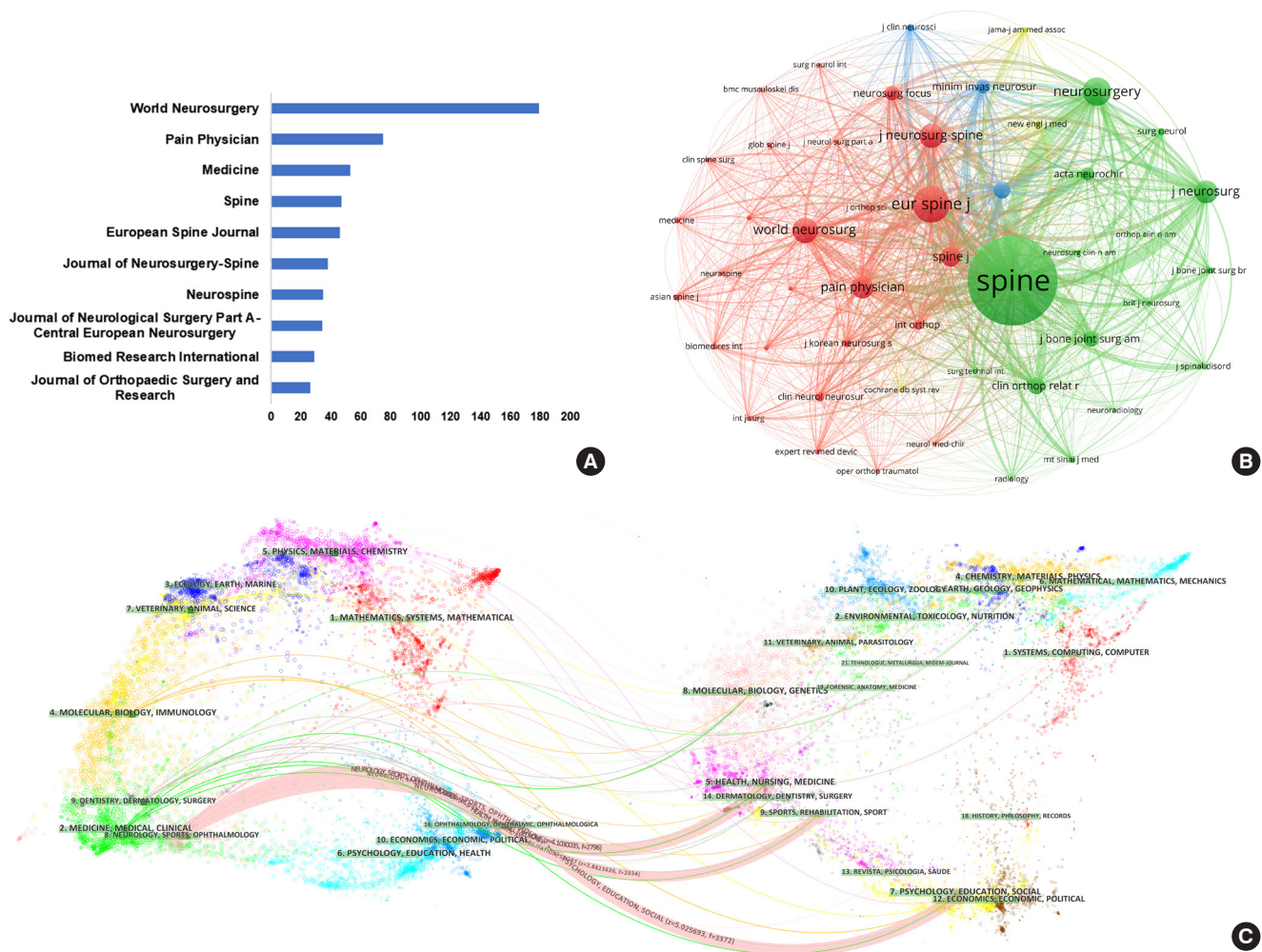
**5. Cocited Reference and Reference Burst**

We used VOSviewer to analyze the cocited references and create a network map (Fig. 6A). The top 10 most cocited refer-

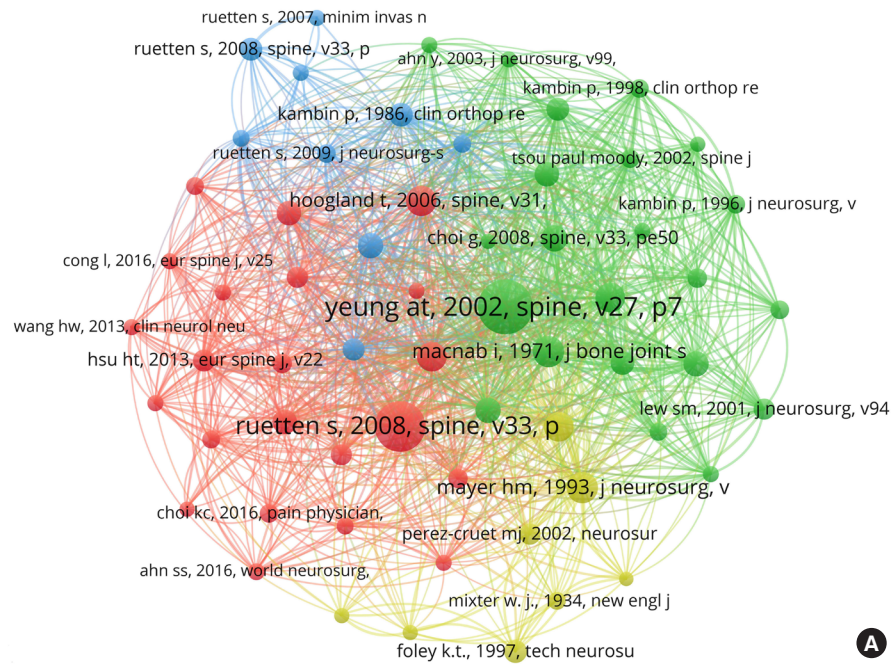
**Table 5.** Top 10 journals with the greatest number of publications in the field of endoscopic discectomy research

Rank	Journal title	No.	Country	Citations	H-index	IF (2021)	JCR (2021)
1	<i>World Neurosurgery</i>	179	USA	1,578	18	2.210	Q3/Q4
2	<i>Pain Physician</i>	75	USA	1,293	21	4.396	Q2
3	<i>Medicine</i>	53	USA	187	7	1.817	Q3
4	<i>Spine</i>	47	USA	3,406	27	3.241	Q2/Q3
5	<i>European Spine Journal</i>	46	Germany	1,511	22	2.721	Q2/Q3
6	<i>Journal of Neurosurgery-Spine</i>	38	USA	1,143	18	3.467	Q1/Q2
7	<i>Neurospine</i>	35	South Korea	259	9	3.374	Q2/Q3
8	<i>Journal of Neurological Surgery Part A-Central European Neurosurgery</i>	34	USA	180	8	0.984	Q4
9	<i>Biomed Research International</i>	29	USA	260	10	3.246	Q3
10	<i>Journal of Orthopaedic Surgery and Research</i>	26	UK	177	9	2.677	Q2

IF, impact factor; JCR, Journal Citation Report; Q, quartile.



**Fig. 5.** (A) The top 10 journals with the greatest number of publications. (B) The network visualization map of journal cocitation analysis using VOSviewer. The size of the node represents the citation frequency, and the line between 2 nodes means that both were cited by 1 journal. (C) A dual-map overlay of journals on endoscopic discectomy research was generated by CiteSpace. The labels represent different disciplines covered by the journals. The citing journals are on the left half, the cited journals are on the right half, and the colored path represents the citation relationship.



### Top 25 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2002 - 2021
Yeung AT, 2002, SPINE, V27, P722, DOI 10.1097/00007632-200204010-00009, DOI	2002	13.25	2003	2007	
Perez-Cruet MJ, 2002, NEUROSURGERY, V51, P0, DOI 10.1227/01.NEU.0000031004.69814.2D, DOI	2002	10.19	2004	2007	
Ahn Y, 2004, SPINE, V29, P0, DOI 10.1097/01.BRS.0000134591.32462.98, DOI	2004	10	2006	2009	
Choi G, 2006, NEUROSURGERY, V58, P59, DOI 10.1227/01.NEU.0000192713.95921.4A, DOI	2006	9.07	2007	2011	
Ruetten S, 2007, J NEUROSURG-SPINE, V6, P521, DOI 10.3171/spi.2007.6.6.521, DOI	2007	10.28	2008	2012	
Lee S, 2007, EUR SPINE J, V16, P431, DOI 10.1007/s00586-006-0219-4, DOI	2007	9.06	2008	2012	
Ruetten S, 2008, SPINE, V33, P931, DOI 10.1097/BRS.0b013e31816c8af7, DOI	2008	19.2	2010	2013	
Choi G, 2008, SPINE, V33, P0, DOI 10.1097/BRS.0b013e31817bfa1a, DOI	2008	9.25	2010	2013	
Nellensteijn J, 2010, EUR SPINE J, V19, P181, DOI 10.1007/s00586-009-1155-x, DOI	2010	11.75	2012	2015	
Wang B, 2011, SPINE J, V11, P122, DOI 10.1016/j.spinee.2010.12.006, DOI	2011	9.99	2012	2016	
Teli M, 2010, EUR SPINE J, V19, P443, DOI 10.1007/s00586-010-1290-4, DOI	2010	9.39	2012	2015	
Ruetten S, 2009, J SPINAL DISORD TECH, V22, P122, DOI 10.1097/BSD.0b013e318175ddb4, DOI	2009	9.37	2012	2014	
Ahn Y, 2012, EXPERT REV MED DEVIC, V9, P361	2012	13.52	2013	2017	
Ahn Y, 2013, SPINE, V38, P617, DOI 10.1097/BRS.0b013e318275ca58, DOI	2013	11.44	2014	2018	
Birkenmaier C, 2013, PAIN PHYSICIAN, V16, P335	2013	11.08	2014	2018	
Gibson JNA, 2012, SURG-J R COLL SURG E, V10, P290, DOI 10.1016/j.surge.2012.05.001, DOI	2012	9.72	2014	2017	
Hsu HT, 2013, EUR SPINE J, V22, P727, DOI 10.1007/s00586-012-2540-4, DOI	2013	14.94	2015	2018	
Choi KC, 2013, PAIN PHYSICIAN, V16, P547	2013	12.23	2015	2018	
Wang HW, 2013, CLIN NEUROL NEUROSUR, V115, P1987, DOI 10.1016/j.clineuro.2013.06.008, DOI	2013	11.46	2015	2018	
Sencer A, 2014, WORLD NEUROSURG, V82, P884, DOI 10.1016/j.wneu.2014.05.032, DOI	2014	9.58	2015	2018	
Choi I, 2013, EUR SPINE J, V22, P2481, DOI 10.1007/s00586-013-2849-7, DOI	2013	9.54	2015	2018	
Ahn Y, 2014, NEUROSURGERY, V75, P124, DOI 10.1227/NEU.0000000000000361, DOI	2014	9.99	2016	2019	
Ahn Y, 2014, EXPERT REV MED DEVIC, V11, P605, DOI 10.1586/17434440.2014.940314, DOI	2014	9.77	2017	2019	
Liu XY, 2018, J NEUROSURG-SPINE, V28, P317, DOI 10.3171/2017.6.SPINE172, DOI	2018	10.97	2019	2021	
Komp M, 2015, PAIN PHYSICIAN, V18, P61	2015	8.79	2019	2021	

**Fig. 6.** (A) The cocitation network map of references on endoscopic discectomy. The size of the node represents the citation frequency, and the line between 2 nodes means that both were cited by 1 paper. (B) The top 25 references with the highest burst value (generated by CiteSpace). The blue bars indicate the time interval, and the red bars indicate the active time.



**Table 6.** Top 10 cocited references in the field of endoscopic discectomy research

Rank	First author	Title	Year	Source	Citations
1	Yeung AT	Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases	2002	<i>Spine</i>	308
2	Ruetten S	Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study	2008	<i>Spine</i>	274
3	Mayer HM	Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy	1993	<i>Journal of Neurosurgery</i>	143
4	Macnab I	Negative disc exploration: an analysis of the causes of nerve-root involvement in sixty-eight patients	1971	<i>The Journal of Bone and Joint Surgery</i>	139
5	Hoogland T	Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases	2006	<i>Spine</i>	137
6	Ahn Y	Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases	2004	<i>Spine</i>	133
7	Ruetten S	Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach	2007	<i>Journal of Neurosurgery-Spine</i>	132
8	Hermantin FU	A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy	1999	<i>The Journal of Bone and Joint Surgery</i>	129
9	Choi G	Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplasty using rigid working channel endoscope	2008	<i>Spine</i>	110
10	Ruetten S	A new full-endoscopic technique for the interlaminar operation of lumbar disc herniations using 6-mm endoscopes: prospective 2-year results of 331 patients	2006	<i>Minimally Invasive Neurosurgery</i>	108

ences are presented in Table 6. The most cocited reference was an article published in *Spine* by Yeung and Tsou<sup>13</sup> with 308 citations in 2002, entitled “Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases.” Among the top 10 references, 9 articles focused on the surgical technique and outcome of ED.

The ‘Burstness’ tool of the Citespace software was used to identify the publications that received widespread attention from related researchers during a certain period of time.<sup>14,15</sup> Fig. 6B presents the top 25 references with the strongest citation bursts. The strongest burst reference was an article published in *Spine* by Ruetten et al.<sup>16</sup> (2010–2013, strength 19.2), entitled “Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study.” In addition, the articles of Liu et al.<sup>17</sup> and Komp et al.<sup>18</sup> were the most recent high-citation reference with a citation burst.

## 6. Keywords Analysis of Research Hotspots

Research hotspots and frontiers of the ED field can be revealed through keyword co-occurrence analysis and burst detection. In this study, VOSviewer was applied to present the keyword co-occurrence and cluster analysis (Fig. 7A). We merged some keywords with the same meaning to get a better perspective. According to the criteria that the co-occurrence of the keywords was at least 15 times, we totally introduced 84 keywords into the analysis. The top 5 keywords identified were “discectomy,” “surgery,” “disc herniation,” “lumbar disc herniation,” and “endoscopy,” which is consistent with our research topic. In addition, the inclusion keywords could be classified into 4 clusters: (1) clinical outcomes of ED in the treatment of LDH, green frames; (2) clinical outcomes of ED in the treatment of LDH, blue frames; (3) clinical outcomes of ED in the treatment of lumbar spinal stenosis (LSS), yellow frames; (4) clinical outcomes of percutaneous endoscopic cervical discectomy (PECD), red frames.



**Top 22 Keywords with the Strongest Citation Bursts**

Keywords	Year	Strength	Begin	End	2002 - 2021
lumbar	2002	5.38	2002	2012	
arthroscopic microdiscectomy	2002	4.87	2002	2011	
chemonucleolysis	2002	4.28	2002	2012	
discectomy	2002	4.23	2002	2007	
nucleotomy	2002	3.45	2002	2009	
experience	2002	3.19	2002	2006	
excision	2002	6.03	2004	2014	
endoscopic discectomy	2002	5	2006	2015	
arthroscopicmicrodiscectomy	2002	3.1	2006	2014	
fragment excision	2002	3.32	2007	2008	
surgical technique	2002	7.49	2008	2012	
technical note	2002	4.22	2012	2018	
conventional microsurgical technique	2002	3.48	2012	2015	
interlaminar	2002	6.8	2015	2016	
minimally invasive	2002	6.75	2015	2016	
percutaneous endoscopic lumbar discectomy	2002	4.47	2015	2017	
clinical outcomes	2002	3.15	2015	2016	
spinal surgery	2002	3.65	2016	2017	
transforaminal approach	2002	3.34	2016	2018	
lateral recess stenosis	2002	3.2	2018	2021	
spinal stenosis	2002	4.56	2019	2021	
reoperation	2002	3.3	2019	2021	

**Fig. 7.** (A) Keyword co-occurrence analysis on endoscopic discectomy research using the VOSviewer. The size of the node represents the occurrence times of keywords, the line between 2 nodes represents the co-occurrence of keywords, and different colors represent different clusters. (B) The top 25 keywords with the highest burst value (generated by CiteSpace). The blue bars indicate the time interval, and the red bars indicate the active time.

We also used CiteSpace to detect burst keywords (Fig. 7B). Among these words, “surgical technique” (2008–2012, strength 7.49) was the strongest burst keyword. Notably, the citation burst time of keywords including “lateral recess stenosis” (2018–2021), “spinal stenosis” (2019–2021), and “reoperation” (2019–2021) has continued to 2021, and the bursts are still ongoing, indicating that these research directions have received great attention recently.

## DISCUSSION

In the past 20 years, ED has been extensively researched, and the overall number of publications has also increased yearly. From 2002 to 2015, the relatively small amount of paper in this period suggests that the study of ED is in its infancy. From 2016 to 2021, the number of papers showed rapid growth, demonstrating that the ED has been attracting increasing interest from scholars in the last years. Therefore, the topic of ED possibly remains a research hotspot in the field of spinal surgery, and the number of publications on ED may increase in the upcoming years.

From the current study, China had the largest number of publications in the ED field, followed by South Korea. Of course, this is closely associated with the local funding agencies, and the top ten funding agencies were all from China and South Korea. South Korea, the United States, and China ranked in the top three regarding the total number of citations and H-index. Of note, China ranked first for the number of publications, while it ranked third for the total number of citations and H-index. This suggests that although China has an advantage in the number of publications, the quality of the publication is relatively low, resulting in a low average article citation. The possible reasons might be (1) The research on ED started late in China, with only 32 papers published from 2002–2015 (South Korea, 79 papers; United States, 75 papers). It is only since 2016 that China has gradually become a leading country in terms of the annual number of publications. (2) The type of studies published in China is primarily case-control studies and case series, while there are relatively few high-quality randomized control trials. (3) There may be certain language barriers, and China has less cooperation with top countries such as South Korea and the United States. Thus, it is urgent to promote the quality of papers for Chinese scholars in the future. Among the top 10 productive institutions, 5 were from China, and 4 were from South Korea. This may be the reason why China and South Korea have published most papers on the ED

field. It is noteworthy that Wooridul Spine Hospital ranks first regarding the number of publications, the total number of citations, and H-index. This indicates that Wooridul Spine Hospital might be the top research institution in this field, and scholars interested in ED may cooperate with this institution.

According to the authors and cocited authors in Table 4, the top 3 most prolific authors were all from South Korea (Lee SH, Ahn Y, and Kim HS). This indicates that scholars from South Korea is leading in the field of ED, and there will be more papers on this field to be published on these scholars and their teams in the future. As for cocited authors, the publications of 3 authors were cocited more than 500 times, with Ruetten S having the highest citation frequency, followed by Ahn Y, and Kambin P. Notably, Ahn Y was ranked second in both the number of publications and cocitation frequency, indicating that the papers published by him and his team are excellent in both quantity and quality. The chief contribution of Ruetten S was first proposing the use of percutaneous endoscopic interlaminar discectomy for the treatment of LDH, and his team subsequently had done a lot of investigations for clinical promotion and application of this technique.<sup>16,19-21</sup>

Professor Kambin P is one of the top experts in the ED field from the United States. Through extensive clinical and cadaver studies, he proposed “safe working zone” for the transforaminal approach, which has been robustly cited and widely utilized in percutaneous transforaminal endoscopic discectomy (PTED).<sup>22,23</sup>

As for journal analysis, the journals with the most papers about ED were *World Neurosurgery*, followed by *Pain Physician, Medicine*. Thus, it suggests that more studies on this field would also be preferentially published in the listed journals. From the perspective of cocited journals, *Spine* was the journal with the highest citations, followed by the *European Spine Journal, Neurosurgery*, indicating the important influence of these journals in this field. Subsequently, researchers interested in ED should pay more attention to these journals as mentioned above.

As shown in Table 6, the most cocited article in this field was Yeung and Tsou<sup>13</sup> published in 2002, which mainly introduced ‘inside-out’ technique of posterolateral endoscopic lumbar discectomy, called YESS technique. Subsequently, a substantial number of novel techniques based on the YESS technique have constantly emerged, which vastly promotes the development of PTED. Of note, a total of 3 publications within the list of top 10 cocited papers were reported by Ruetten S, which also explained why he was the author with the highest cocitation frequency. Burst references are those that are frequently cited over a period of time.<sup>14,15</sup> Among these references, the references

with the strongest citation bursts are published by Ruetten et al.<sup>21</sup> with burst duration from 2010 to 2013. In this study, Ruetten et al. used a prospective randomized controlled trial design to compare the clinical results of lumbar discectomies in full-endoscopic transforaminal and interlaminar approach with the conventional microdiscectomy. They concluded that the full-endoscopic technique is equivalent in efficacy to conventional microdiscectomy, with the advantage of operation technique and reduced traumatization. More importantly, among the top 25 references with the strongest citation burst, 2 references are still in burstness, indicating that this topic has received sustained attention in recent years.

In bibliometrics, the analysis of frequently appearing keywords is used to identify the research direction. As illustrated in the keywords clustering map in Fig. 7A, all the included keywords in the ED research could separate into 4 main clusters.

(1) Clinical outcomes of ED in the treatment of LDH: At the beginning of the development of the ED technique, most of the studies focused on exploring whether the percutaneous endoscopic lumbar discectomy (PELD) was effective. At present, many studies have shown that PELD has the same effect as conventional microdiscectomy with the advantages of minimal trauma, fast recovery, and less pain.<sup>3,24-26</sup>

(2) Surgical technique of PELD: As the PELD technique has been gradually accepted by surgeon and patient, some scholars have started to focus on improving surgical techniques. Recently, numerous attempts have been made to simplify the operation, reduce the procedure time, and shorten the learning curve.<sup>27-31</sup> For example, Ao et al.<sup>32</sup> designed a novel targeted foraminoplasty device with the specially designed double-cannulas for PELD; their results showed that this novel technique is a safe and effective procedure for LDH, and provides more advantages than the traditional TESSYS technique in reducing the difficulty of PELD learning, minimizing radiation exposure, and decreasing intraoperative pain associated with foraminoplasty.

(3) Clinical outcomes of ED in the treatment of LSS: LSS is a common spinal disorder in the elderly, which is classified into central spinal stenosis, lateral recess stenosis, and foraminal stenosis.<sup>33</sup> In the past, the indication for ED was mainly soft disc herniation, and only a few physicians could use ED to manage LSS.<sup>34,35</sup> With the rapid developments of surgical techniques and instruments, the indication of ED has expanded from soft disc herniation to LSS. Various studies have confirmed the safety and efficacy of ED in the treatment of LSS.<sup>36-39</sup> Study carried out by Li et al.<sup>40</sup> showed that ED is a safe and effective technique for the treatment of LSS in the elderly, with the advantages

of less traumatic, fewer anesthesia-related complications, and fast postoperative recovery.

(4) Clinical outcomes of PECD: Currently, PECD has been developed as an effective surgical alternative for cervical disc herniation or radiculopathy.<sup>41-44</sup> PECD can be performed using an anterior or posterior approach, which depends on the localization of pathology.<sup>45</sup> With the aid of laser and high-speed drills, PECD can complete the resection of central, paracentral, or foraminal soft disc herniations.<sup>46-48</sup> Compared with anterior cervical discectomy and fusion or posterior microdiscectomy, the most significant benefits of PECD are clearer surgical field, less tissue damage, and quicker recovery.<sup>49,50</sup>

As shown in the keyword burst detection results, lateral recess stenosis, spinal stenosis, and reoperation are the latest burst terms in recent years, which indicate that these research topics might be considered as the next hotspot in ED research. Additionally, it identifies promising directions for research, which is of interest to scholars and funding agencies. Therefore, it suggests that scientific breakthroughs regarding these research topics may be possible within the next few years.

Publications on ED research evaluated in the current study are reviewed from the WoS database. To our knowledge, this is the first-ever bibliometric study to analyze publications of ED around the world, providing a valuable reference for further exploration in this field. Despite our comprehensive and systematic analysis of ED research in this study, there are some limitations that require discussion. First of all, the bibliometric analysis was limited to English language publications, and thus we may have missed some important papers published in other languages. As far as we know, most of the non-English papers lack English abstract or references, unable to meet the requirements of bibliometric analysis.<sup>51</sup> Secondly, the data analyzed in this study originated only from the WoS database, and some papers from other databases might have been missed. However, it should be noted that the WoS database is the most commonly used tool for bibliometric analysis.<sup>52</sup> Finally, the publications in 2022 were not included in our study as the WoS database is constantly updated, and the data for this year is incomplete. Nevertheless, we believe that this study has included the vast majority of publications from 2002, and our conclusions would not be affected even with these updated data.

## CONCLUSION

In conclusion, the annual number of publications regarding ED has been constantly growing since 2002. From the quality

and quantity viewpoint, China, South Korea, and the United States were the major contributors in this field. According to keywords analysis, 4 research directions were identified: (1) clinical outcomes of ED in the treatment of LDH, (2) surgical technique of PELD, (3) clinical outcomes of ED in the treatment of LSS, (4) clinical outcomes of PECD. More focus will be placed on lateral recess stenosis, spinal stenosis, and reoperation, which may be the next hotspot in ED research.

## NOTES

**Conflict of Interest:** The authors have nothing to disclose.

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