

# Research Trends of Percutaneous Endoscopic Lumbar Discectomy in the Treatment of Lumbar Disc Herniation Over the Past Decade: A Bibliometric Analysis

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**Objective:** This study aimed to explore the research trends of percutaneous endoscopic lumbar discectomy in treating lumbar disc herniation using bibliometrics over the past ten years.

**Methods:** Relevant publications on the clinical application of percutaneous endoscopic lumbar discectomy in lumbar disc herniation were searched in the Web of Science Core Collection. Subsequently, the characteristics of all these articles were collected. Visualizing data of annual publications, journals, cited journals, authors, cited authors, countries, institutions, keywords, and cited references was performed by using CiteSpace (6.1.R6).

**Results:** A total of 642 publications were extracted between 2013 and 2022. The number of publications peaked in the year 2020. The most prolific journal was *World Neurosurgery* (81), and *Spine* (597) as the cited journal was the most popular one. China (393) was the most prolific country, followed by South Korea (100). The institution with the most productivity was Tongji University (35). Yue Zhou (20) was the most prolific author, and Sebastian Ruetten (310) was the most cited author. The keyword “interlaminar” was top of research developments with the highest citation burst (8.69). “Lumbar disc herniation”, “surgical technique”, and “complication” were popular keywords. The surgical procedures and complications of percutaneous endoscopic lumbar discectomy have been the hot topics of recent research.

**Conclusion:** This study summarized the current situation and development trends of percutaneous endoscopic lumbar discectomy clinical research in the form of visualization, and these findings may help researchers explore new directions in the future.

**Keywords:** percutaneous endoscopic lumbar discectomy, lumbar disc herniation, bibliometric analysis, complication

## Introduction

With the accelerating pace of people's work and life, the number of people suffering from lumbar disc herniation is increasing yearly. And its incidence was as high as 7.62% in China.<sup>1</sup> Percutaneous endoscopic lumbar discectomy (PELD), with less trauma and fast recovery, has been a favorable alternative to open discectomy for patients of lumbar disc herniation.<sup>2</sup> The indication for PELD has been expanded through improved techniques.<sup>3</sup> PELD, a minimally invasive spine surgery, has been a mainstream technique for lumbar disc herniation.<sup>4</sup> Some studies suggested a similar incidence of recurrence between PELD and open discectomy or microendoscopic discectomy (MED).<sup>5-7</sup> But others reported that PELD had a higher reoperation rate than open surgery.<sup>8</sup> Even so, PELD is widely used by many surgeons for patients with lumbar disc herniation.

Bibliometric is a statistical and quantitative analysis of publications. It can identify the relationship between authors, institutions, journals, references, and countries and show research trends by integrating visualization information.<sup>9</sup> CiteSpace is a commonly used software that can visualize and analyze emerging trends in publications.<sup>10</sup> To address the shortage of quantitative analysis of the research on PELD, we aimed to provide a visualization for the global scientific research on PELD by taking advantage of bibliometrics. To the best of our knowledge, there is no bibliometric analysis on PELD with CiteSpace yet. Therefore, it is necessary to analyze the articles in the last decade to reveal the current trend of PELD research. In this study, the publications in PELD research between 2013 and 2022 were selected, and the characteristics were analyzed.

## Methods

### Search Strategy

All data in this study were obtained from WoS Core Collection, including Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Conference Proceedings Citation Index - Science, Conference Proceedings Citation Index - Social Science & Humanities, Book Citation Index - Science, Book Citation Index - Social Sciences & Humanities, Emerging Sources Citation Index, Current Chemical Reactions and Index Chemicus, on January 2, 2023. Data search strategies included the topic “Percutaneous Endoscopic Lumbar Discectomy” and “lumbar disc herniation”, with a published period from 2013 to 2022. In addition, there are no restrictions on the country or language of publication. The specific search strategies and results are listed in [Table 1](#).

### Article Screening

A total of 660 results were found and sorted according to the document types. After the CiteSpace format conversion, 2 corrections, 6 editorial materials, and 10 letters were excluded. Finally, 642 publications were included in the analysis. The specific search strategy and procedure are shown in [Figure 1](#).

### Data Extraction

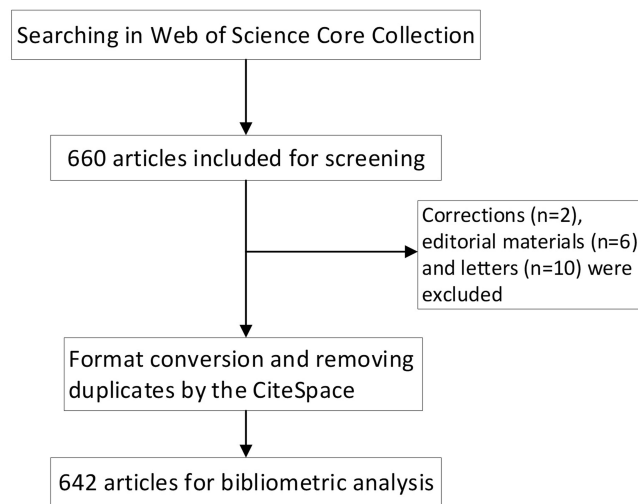
A whole of the articles was derived from the Web of Science (WoS) Core Collection and relative information was extracted. Author information could be used to clarify the prolific authors, institutions, and countries. Article information could reveal the relationship between keywords and hot topics. Meanwhile, publication and citation information could identify the publication years, cited times, prolific journals, and popular references.

### Visualized Analysis

Files that involved the above-mentioned information of the articles were exported from the WoS website and imported into CiteSpace 6.1.R6 and Microsoft Excel. CiteSpace parameters were set as followed: (1) time slicing: from 2013 January to 2022 December, and per slice chose 1 year. (2) term source: all options were ticked, including “title, abstract, author keywords, keywords plus”. (3) selection criteria: factor  $k = 25$ . (4) pruning: pathfinder, pruning sliced networks, and pruning merged networks were selected. Every item, like author, journal, keyword, and so on, was shown

**Table 1** The Topic Search Query

Set	Search Query	Results
#1	(((TS=(Percutaneous Endoscopic Lumbar Discectomy)) OR TS=(Percutaneous Transforaminal Endoscopic Discectomy)) OR TS=(Percutaneous Endoscopic Interlaminar Discectomy)) OR TS=(Transforaminal Endoscopic Lumbar Discectomy)) OR TS=(Full Endoscopic Lumbar Discectomy)) OR TS=(Percutaneous Endoscopic Discectomy), Indexes=WoS Core Collection, Time span=2013.01.01–2022.12.31	837
#2	((((TS= (lumbar disc herniation)) OR TS=(lumbar disk herniation)) OR TS=(herniated lumbar disc)) OR TS=(herniated lumbar disk)) OR TS=(lumbar disc herniations)) OR TS=(lumbar disk herniations)) OR TS=(lumbar disc prolapse)) OR TS=(lumbar disk prolapse), Indexes=WoS Core Collection, Time span=2013.01.01–2022.12.31	5269
#3	#1 AND #2	660



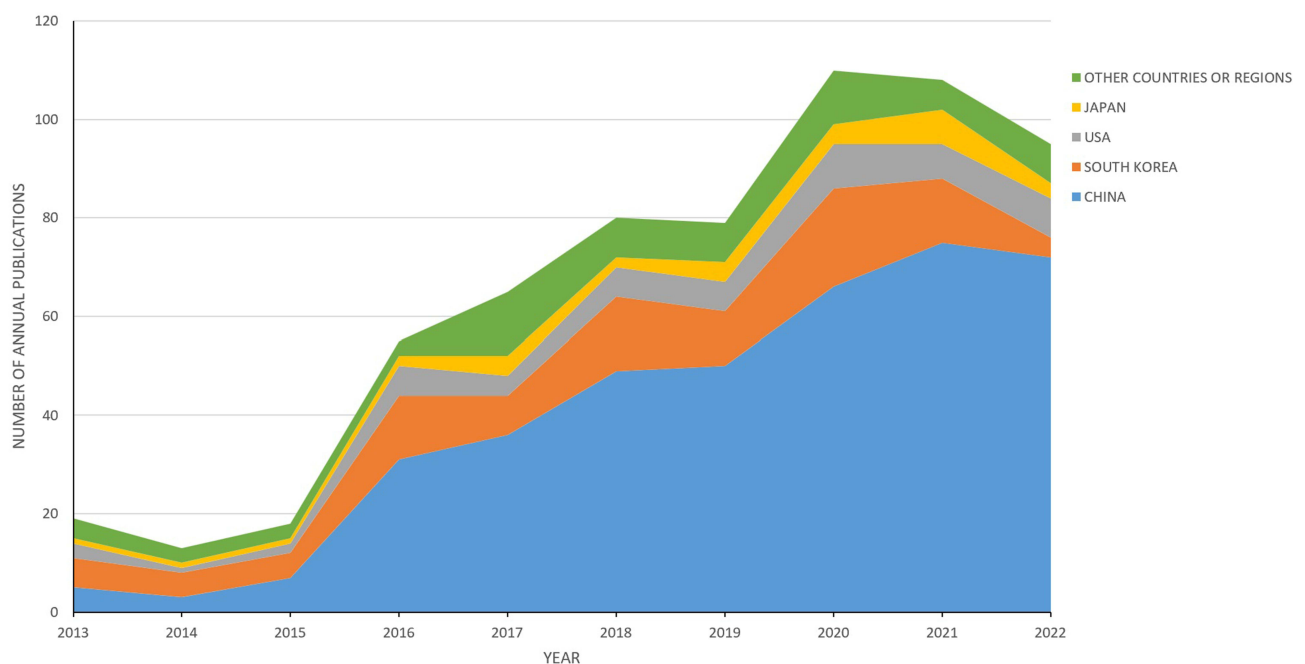
**Figure 1** Flowchart of the searching and screening of articles.

on the map as a node. The size of the node reflected the frequency of every element. The diverse colors of the node meant different years. The purple circle meant centrality, and nodes with high centrality were usually regarded as critical points in a specific field. Besides, links between the nodes suggested the relationships of co-occurrence or co-citation.

## Results

### Annual Publications

A total of 642 articles were selected after searching and screening in WoS. The exact number of annual publications is shown in [Figure 2](#). The graph indicates that the number of publications on PELD in treating lumbar disc herniation reveals a general trend of rapid increase over the past 10 years. From 2015 to 2016, there was a sharp increase from 18 publications to 55 publications. The number of publications was stable from 2018 to 2019. And the number of publications peaked in 2020,



**Figure 2** The number of annual publications from 2013 to 2022.

**Table 2** Top 10 Journals Related to PELD for Lumbar Disc Herniation

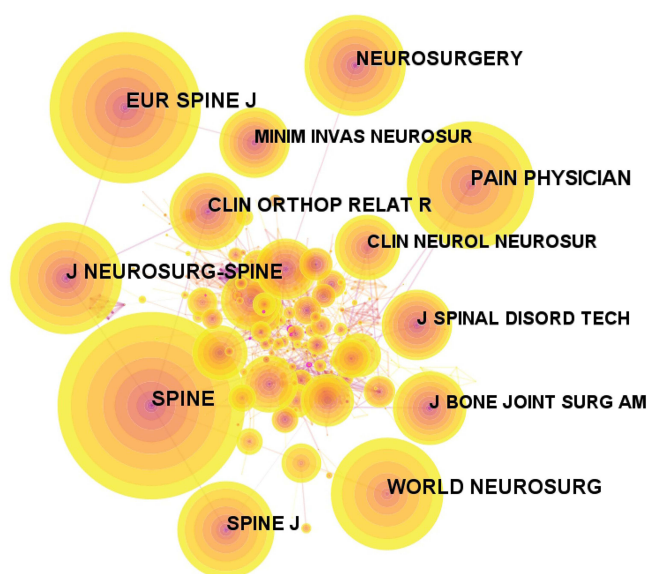
Rank	Publications	Journal	IF (2022)	Country
1	81	World Neurosurgery	2.0	United States
2	65	Pain Physician	3.7	United States
3	39	Medicine	1.6	United States
4	24	Orthopaedic Surgery	2.1	China
5	20	BMC Musculoskeletal Disorders	2.3	England
6	19	Journal of Orthopaedic Surgery and Research	2.6	England
7	18	Biomed Research international	N/A	United States
8	15	Frontiers in Surgery	1.8	Switzerland
9	15	Journal Of Neurosurgery-spine	2.8	United States
10	15	Neurospine	3.2	South Korea

with 110 publications. From 2021 to 2022, there was a mild reduction from 108 publications to 95 publications. The number of publications in productive countries, like China and South Korea, fluctuated and showed an overall upward trend.

## Journals and Cited Journal

These articles were published in 132 journals, of which the top 10 were shown in Table 2. *World Neurosurgery* was the most prolific journal, with 81 articles, followed by *Pain Physician* with 65. Their impact factors (IF) were 2.0 and 3.7 in 2022, respectively. The map of cited journals (Figure 3) was generated by CiteSpace software, and *Spine* had the highest number of citations with 597. The circle size showed the number of cited times, while the links between the circles represented the relationship between cited journals. And the line thickness represents the relationship strength. Among the top 10 cited journals (Table 3), the *Journal of Bone and Joint Surgery-American Volume* has the highest IF in 2022 (5.3), followed by *Neurosurgery* (4.8) and *Spine Journal* (4.5).

A dual-map overlay with citing and cited matrices of journals was generated by using CiteSpace 6.1.R6 software (Figure 4). Citing journals are displayed on the left of the dual-map, while the right side means cited journals. And there are 3 citation paths in this illustration. These 3 paths indicate that articles published in “neurology, sports, ophthalmology” journals tended to cite journals mainly in the domains of “health, nursing, medicine”, “sports, rehabilitation, sport” and “psychology, education, social”.



**Figure 3** Cited journal map related to PELD for lumbar disc herniation from 2013 to 2022.

**Table 3** Top 10 Cited Journals Related to PELD for Lumbar Disc Herniation

Rank	Frequency	Cited Journal	IF (2022)	Country
1	597	Spine	3.0	United States
2	482	European Spine Journal	2.8	United States
3	406	Pain Physician	3.7	United States
4	358	World Neurosurgery	2.0	United States
5	354	Journal Of Neurosurgery-spine	2.8	United States
6	322	Neurosurgery	4.8	Netherlands
7	310	Spine Journal	4.5	United States
8	246	Clinical Orthopaedics and Related Research	4.2	United States
9	236	Journal of Bone and Joint Surgery-American Volume	5.3	United States
10	229	Minimally Invasive Neurosurgery	N/A	Germany

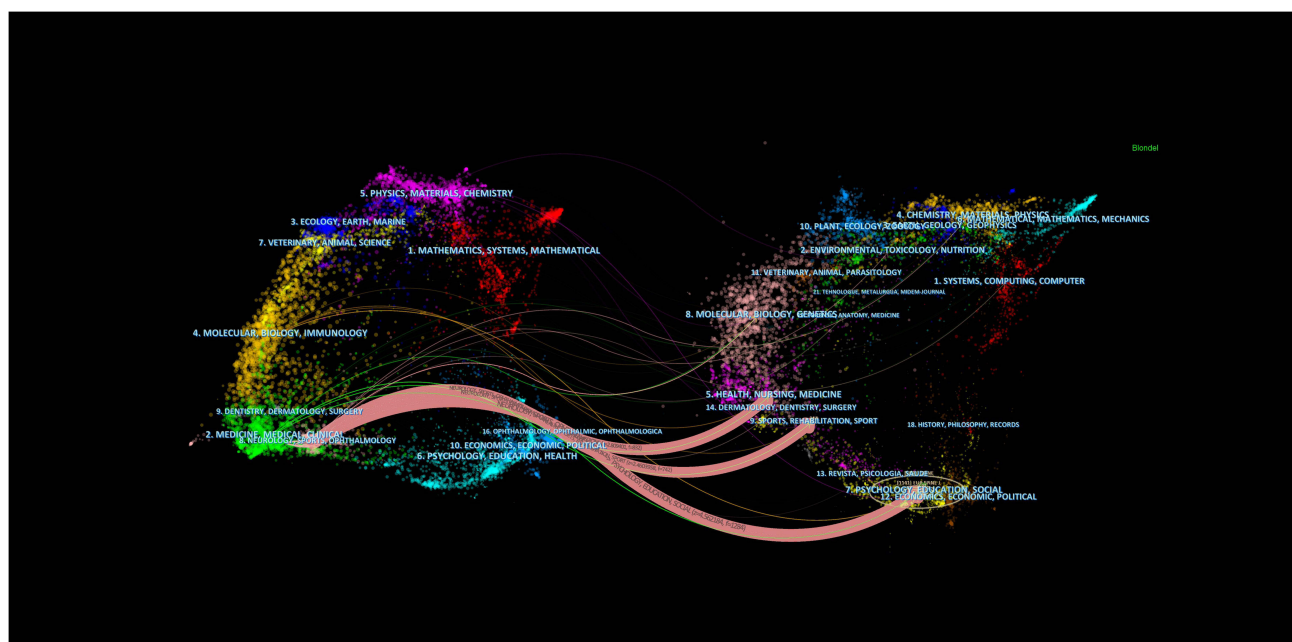
## Authors and Cited Authors

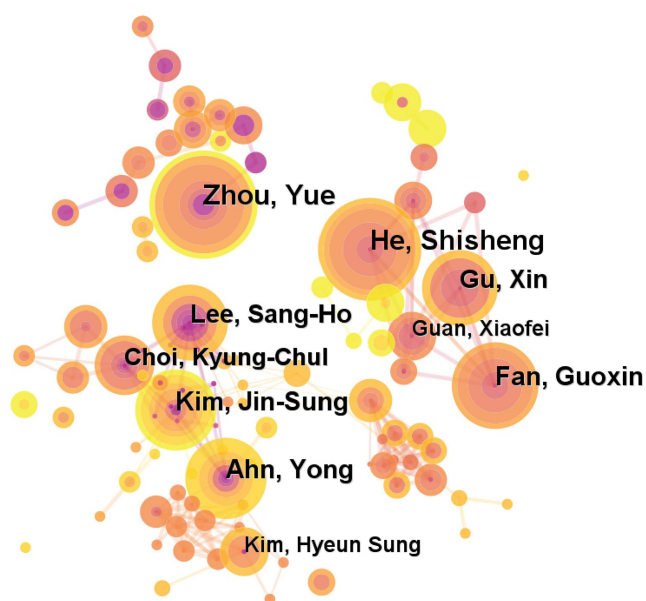
The authors of the publications were analyzed and resulted in 387 nodes and 782 links (Figure 5). The most prolific authors were Yue Zhou, from the Affiliated Xinqiao Hospital of the Third Military Medical University, with 20 articles. Shisheng He and Guoxin Fan followed, with 19 and 16 articles, respectively. The top 10 prolific authors were presented in Table 4. Half of them come from China, while another half come from South Korea.

The cited author's map consisted of 520 nodes and 1662 connecting lines. The most cited author is Sebastian Ruetten, with 310 cited times. The other highly cited authors were Yong Ahn (293), Kyung-Chul Choi (247), Gun Choi (233), and Anthony Tung Yeung (225) (Figure 6). The top 5 centrality of cited authors were Marco Teli (0.32), Yunus Aydin (0.21), Frank U. Hermantin (0.20), Jeong-Mok Kim (0.20) and Martin Barth (0.16) (Table 5).

## Distribution of Countries and Institutions

There were 45 nodes and 88 links on the distribution of countries or regions map (Figure 7). China had the highest contribution with 393 articles, followed by South Korea (100) and the United States (52). The top 10 publications of countries or regions were shown in Table 6.

**Figure 4** A dual map overlay of journals related to PELD for lumbar disc herniation from 2013 to 2022.



**Figure 5** Map of authors related to PELD for lumbar disc herniation from 2013 to 2022. The various colors in the nodes mean the different years, and links between the nodes represent cooperative relationships.

There were 263 nodes and 261 links on the distribution of institutions map (Figure 8). The research institution with the highest contribution was Tongji University, with 35 articles. Capital Medical University and Catholic University of Korea had 20 and 17 articles, respectively. The top 5 centrality of institutions were Tongji University (0.18), Artificial Intelligence Innovation Center (0.18), Sun Yat-sen University (0.16), Dayeh University (0.16) and Army Medical University (0.15). And the top 10 publications of institutions were displayed in Table 7.

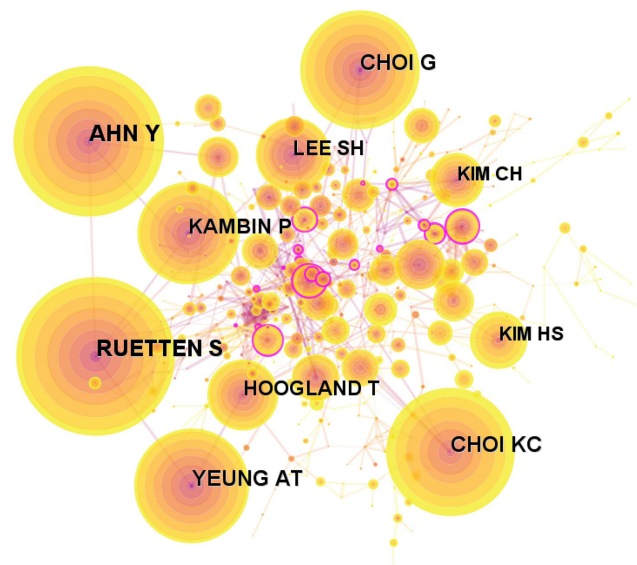
## Keywords

370 keywords appeared in the analysis, which were shown in the keyword map with 1316 links (Figure 9). Combining frequency with centrality, it showed that mainstream keywords were “lumbar disc herniation”, “surgical technique”, “microdiscectomy”, “interlaminar approach”, “pain”, “complication”, “foraminal stenosis”, and “classification” (Table 8). The top 20 keywords with the strongest citation bursts between 2013 and 2022 were shown in Figure 10. The most recent burst Keywords were “lateral recess stenosis”, “instability”, “percutaneous endoscopic transforaminal

**Table 4** The Top 10 Authors Related to PELD for Lumbar Disc Herniation

Rank	Author	Publications
1	Yue Zhou	20
2	Shisheng He	19
3	Guoxin Fan	16
4	Jin-Sung Kim	15
5	Yong Ahn	15
6	Sang-Ho Lee	14
7	Xin Gu	14
8	Kyung-Chul Choi	11
9	Xiaofei Guan	9
10	Hyeun Sung Kim	9





**Figure 6** Map of cited authors related to PELD for lumbar disc herniation from 2013 to 2022.

discectomy” and “percutaneous endoscopic interlaminar discectomy”. The keyword “interlaminar” had a strength citation burst of 8.69, followed by “surgical technique” (4.93), and “percutaneous endoscopic transforaminal discectomy” (3.81).

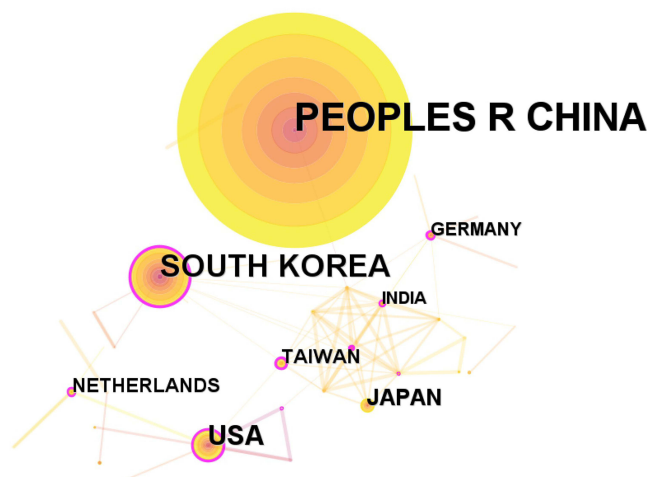
## Cited References

When two articles were cited by another article at the same time, they have a relationship of co-citation. The relationships between cited references were shown in Figure 11. The top 5 frequency and centrality of cited references were listed in Table 9 and Table 10. A retrospective study published by Choi KC in 2016 got the highest co-citation times, followed by his other study in 2015 and a study of Liu XY in 2018. Choi KC compared the outcomes of large lumbar disc herniation treated with percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy, and believed that PELD could be as effective as open lumbar microdiscectomy.<sup>11</sup> And he concluded that main causes of unsuccessful PELD were incomplete removal of herniated discs, recurrence, persistent pain even after complete removal and approach-related pain, by performing a review on 10,228 patients.<sup>5</sup> The article with the highest centrality was published by Du JW in 2016, illustrating that PELD via a translaminar approach could be safe and effective for the treatment of soft, highly down-migrated lumbar disc herniation.

In this study, CiteSpace 6.1.R6 software was used to perform cluster analysis on cited references, to acquire pivotal information and explore research trends from cited references. The logarithmic likelihood ratio (LLR) algorithm was applied to assess nominal terms extracted from the keywords. A map of 20 clusters was made with a modularity value of 0.8094, which meant the results were quite reliable. The top 7 clusters were “migrated disc herniation”, “sciatica”, “radiation”, “microendoscopic discectomy”, “percutaneous endoscopic lumbar discectomy”, “early recurrence”, “percutaneous lumbar disc decompression” (Figure 12).

**Table 5** Top 5 Frequency and Centrality of Cited Authors Related to PELD for Lumbar Disc Herniation

Rank	Frequency	Cited Author	Rank	Centrality	Cited Author
1	310	Sebastian Ruetten	1	0.32	Marco Teli
2	293	Yong Ahn	2	0.21	Yunus Aydin
3	297	Kyung-Chul Choi	3	0.20	Frank U. Hermantin
4	233	Gun Choi	4	0.20	Jeong-Mok Kim
5	225	Anthony Tung Yeung	5	0.16	Martin Barth



**Figure 7** Map of countries or regions researching PELD for lumbar disc herniation from 2013 to 2022.

## Discussion

In the present study, we extracted 642 related articles from the WOS core collection database between 2013 and 2022. Bibliometric analysis was utilized to probe the characteristics of the PELD in lumbar disc herniation from various perspectives in this field by using CiteSpace 6.1.R6 software. All these findings may have impacts on the research in the following studies.

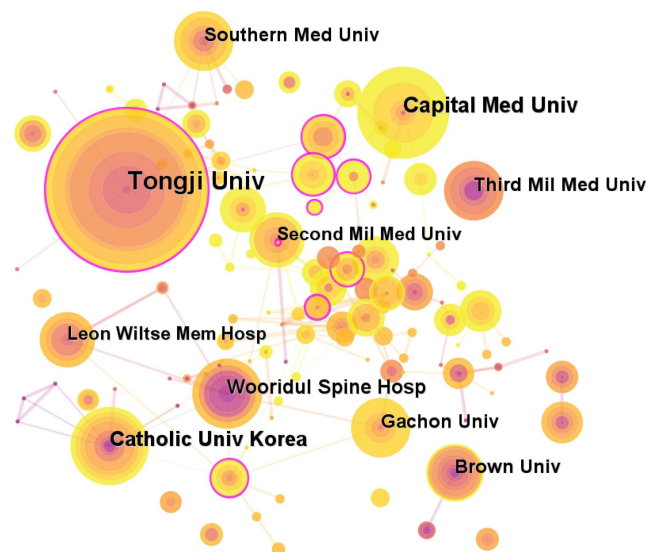
PELD provides equivalent curative effects for treating lumbar disc herniation compared with open lumbar microdiscectomy.<sup>14,20,21</sup> PELD shows advantages in less tissue damage, less intraoperative blood loss, and fast post-operative recovery.<sup>20,22</sup> Besides, PELD can be performed under local anesthesia.<sup>23,24</sup> Because of these unique advantages, PELD has been a burgeoning technology in the recent decade, especially in China and South Korea. In terms of this study, the number of articles has increased dramatically since 2016. The publications of China have made up over half every year since 2016. Consequently, this technique has developed rapidly and has been widely applied by surgeons around China since 2016.

The visualized analysis clearly presented a network of relationships between the high-impact institutions and authors. Most of the top ten prolific authors stemmed from the top five institutions with the most contributions, and they were all from China and South Korea. Tongji University ranked first in both the publications and the centrality, which occupied an important position in the clinical application of PELD. As seen from [Figure 8](#), there were few connections between large

**Table 6** Top 10 Publications of Countries or Regions Related to PELD for Lumbar Disc Herniation

Rank	Publications	Country or Region
1	393	China
2	100	South Korea
3	52	United States
4	29	Japan
5	18	Taiwan
6	15	Netherlands
7	13	Germany
8	12	India
9	10	Greece
10	9	Turkey





**Figure 8** Map of institutions researching PELD for lumbar disc herniation from 2013 to 2022.

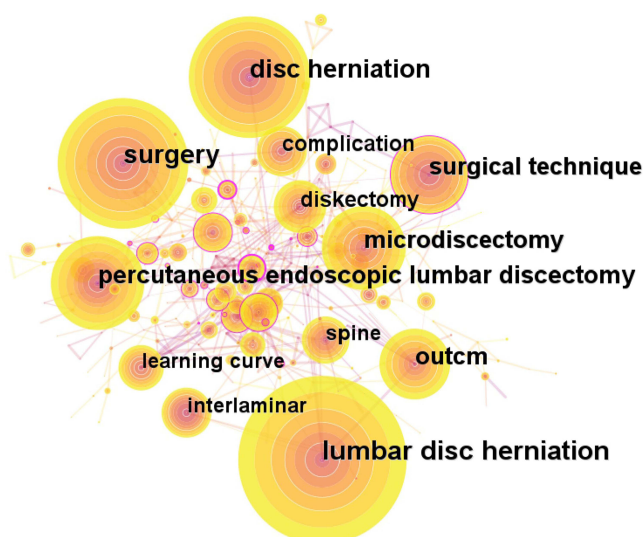
nodes representing prolific institutions, which meant that studies between high-impact institutions were relatively independent. More multicenter studies will be published if these prolific institutions cooperate, which are of higher value.

In this study, most of the top 10 journals were orthopedic and neurosurgery specialty journals, with at least 15 publications (Table 2). The impact factor of these journals was between 1.6 and 3.7. Thus, these results suggested that most articles on PELD were published in specialty journals. At the same time, there was a lack of highly scholarly impact journals in this field. As an essential indicator, citations can evaluate the academic impact of publications. The highly cited journals were also more likely to be orthopedic and neurosurgery specialty journals, such as *Spine*, *Journal of Bone and Joint Surgery*, *Neurosurgery*, and *Spine Journal*. It is obvious that American journals were dominating in cited journals of research about PELD. The dual map (Figure 4) showed that citing journals focus on the field of “Neurology, sports, ophthalmology”. And cited journals are mainly in the domains of “health, nursing, medicine”, “sports, rehabilitation, sport” and “psychology, education, social”, which is in accord with the results in Table 3.

We analyzed co-occurrence and burst of keywords to explore the research trends of PELD. Keywords are commonly used to catch the hot topics of publications in recent years. Besides, cited references were clustered according to keywords to find the major topics. The main keywords of these articles were presented in the visualized analysis (Figure 9). As we expected, “lumbar disc herniation” was mentioned most often. And keywords about surgical procedures, like “microdiscectomy”, “surgical technique”, “interlaminar”, and “decompression”, gained a lot of interest. In addition to keywords related to the surgery, the terms “complication”, “instability”, “outcome”, and “learning curve”

**Table 7** Top 10 Publications and Centrality of Institutions Related to PELD for Lumbar Disc Herniation

Rank	Publications	Institution	Rank	Centrality	Institution
1	35	Tongji University	1	0.18	Tongji Univ
2	20	Capital Med Univ	2	0.18	Artificial Intelligence Innovat Ctr
3	17	Catholic Univ Korea	3	0.16	Sun Yat Sen Univ
4	15	Wooridul Spine Hosp	4	0.16	Dayeh Univ
5	13	Brown Univ	5	0.15	Army Med Univ
6	13	Southern Med Univ	6	0.14	Nanjing Med Univ
7	13	Gachon Univ	7	0.13	Tianjin Med Univ
8	13	Third Mil Med Univ	8	0.12	Chinese Peoples Liberat Army Gen Hosp
9	12	Second Mil Med Univ	9	0.11	Tianjin Univ
10	12	Leon Wiltse Mem Hosp	10	0.09	Gachon Univ



**Figure 9** Map of keywords researching PELD for lumbar disc herniation from 2013 to 2022.

pointed to the focus of PELD for lumbar disc herniation (Figures 9 and 10). The top 7 clusters of cited references reflected that topics of surgical technique (“radiation”, “microendoscopic discectomy”, “percutaneous endoscopic lumbar discectomy”, and “percutaneous lumbar disc decompression”), pathological characteristics (“migrated disc herniation” and “sciatica”) and complication (“early recurrence”) were given a lot of attention.

As we know, the selection and establishment of the surgical approach are crucial for PELD.<sup>25,26</sup> In two articles by Sebastian Ruetten, the most cited author, there were two commonly used approaches of PELD surgery for lumbar disc herniation or recurrent lumbar disc herniation after conventional discectomy, percutaneous endoscopic interlaminar discectomy (PEID) and percutaneous endoscopic transforaminal discectomy (PETD).<sup>27,28</sup> PEID is better to deal with disc herniation of L5/ S1 than PETD. Highly migrated and calcified disc herniation are also indications of PEID. However, PETD is much safer than PEID, which may lead to dural laceration and other complications.<sup>29</sup> With the development of this technology, it was emphasized that PELD had some limitations. Apart from common complications, Zhou reported that unique complications of PELD contained passage of the working channel through the spinal canal, super-elastic nerve hook caught by exiting nerve root, epidural hematoma, radicular artery injury, and intraoperative seizure.<sup>30</sup> Yin concluded that the rate of PELD recurrence was 3.6%, and it usually occurred within 6 months post-operatively. Older age, obesity, upper lumbar disc and central disc herniation were independent risk factors for recurrence after PELD recurrent herniation.<sup>31</sup> Consequently, reasonable indications, proficiency improvement, and selection of appropriate surgical approach are the keys to reducing complications and recurrence rates.

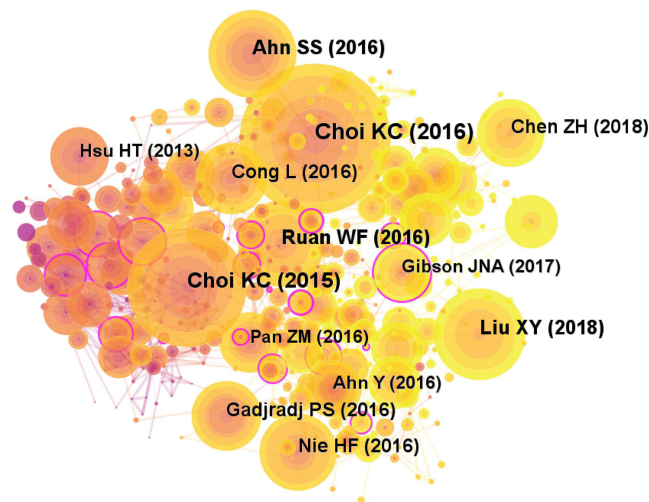
**Table 8** The Top 10 Keywords with the Highest Frequency and Centrality Related to PELD for Lumbar Disc Herniation

Rank	Frequency	Keywords	Rank	Centrality	Keywords
1	237	Lumbar disc herniation	1	0.37	Arthroscopic microdiscectomy
2	187	Surgery	2	0.36	Pain
3	172	Disc herniation	3	0.26	Foraminal stenosis
4	131	Percutaneous endoscopic lumbar discectomy	4	0.23	Discectomy
5	120	Microdiscectomy	5	0.21	Interlaminar approach
6	111	Surgical technique	6	0.20	Annulus fibrosus
7	103	Outcomes	7	0.19	Prevalence
8	77	Diskectomy	8	0.18	Decompression
9	74	Complication	9	0.18	Microendoscopic diskectomy
10	73	Interlaminar	10	0.17	Classification

### Top 20 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2013 - 2022
interlaminar	2013	8.69	2015	2016	
surgical technique	2013	4.93	2016	2016	
percutaneous endoscopic transforaminal discectomy	2018	3.81	2021	2022	
surgeon	2019	3.42	2019	2019	
follow up	2013	3.38	2013	2018	
percutaneous discectomy	2014	3.3	2014	2016	
percutaneous endoscopic discectomy	2014	3.14	2014	2016	
working channel endoscope	2017	3.03	2017	2018	
spine surgery	2015	2.86	2015	2018	
minimally invasive	2013	2.86	2015	2016	
lateral recess stenosis	2019	2.82	2019	2020	
spinal stenosis	2017	2.81	2019	2020	
endoscopic discectomy	2013	2.77	2013	2013	
experience	2014	2.7	2017	2019	
failure	2014	2.56	2014	2015	
instability	2020	2.53	2020	2022	
conventional microsurgical technique	2013	2.44	2013	2015	
fusion	2014	2.44	2018	2018	
percutaneous endoscopic interlaminar discectomy	2018	2.4	2021	2022	
removal	2015	2.35	2015	2018	

**Figure 10** Top 20 keywords with the strongest citation bursts. The red bar shows the keyword was highly cited, while the green bar represents the keyword was in low frequency.



**Figure 11** Map of cited references related to PELD for lumbar disc herniation from 2013 to 2022.

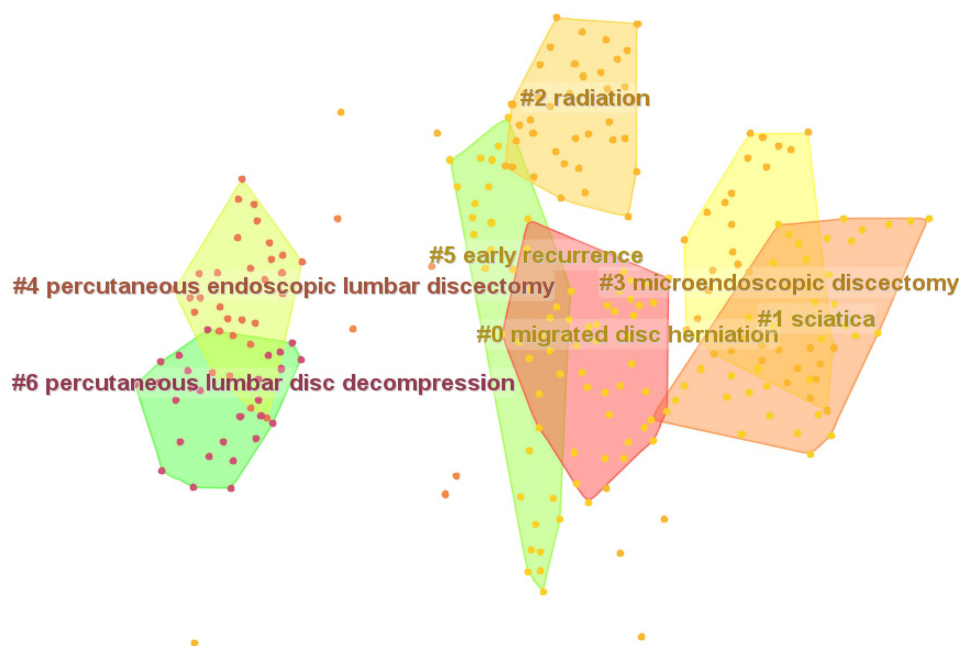
**Table 9** The Top 5 Frequency of Cited References Related to PELD for Lumbar Disc Herniation

Rank	Frequency	Reference	Author (Publication Year)
1	82	Percutaneous Endoscopic Lumbar Discectomy as an Alternative to Open Lumbar Microdiscectomy for Large Lumbar Disc Herniation <sup>11</sup>	Choi K.C. (2016)
2	65	Unsuccessful percutaneous endoscopic lumbar discectomy: a single-center experience of 10,228 cases <sup>5</sup>	Choi K.C. (2015)
3	50	Comparison of percutaneous endoscopic transforaminal discectomy, microendoscopic discectomy, and microdiscectomy for symptomatic lumbar disc herniation: minimum 2-year follow-up results <sup>12</sup>	Liu XY (2018)
4	48	Comparison of Outcomes of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Young Adults: A Retrospective Matched Cohort Study <sup>13</sup>	Ahn SS (2016)
5	40	Comparison of percutaneous endoscopic lumbar discectomy versus open lumbar microdiscectomy for lumbar disc herniation: A meta-analysis <sup>14</sup>	Ruan WF (2016)

**Table 10** The Top 5 Centrality of Cited References Related to PELD for Lumbar Disc Herniation

Rank	Centrality	Reference	Author (Publication Year)
1	0.40	Outcomes of percutaneous endoscopic lumbar discectomy via a translaminar approach, especially for soft, highly down-migrated lumbar disc herniation <sup>15</sup>	Du JW (2016)
2	0.24	Percutaneous Transforaminal Endoscopic Discectomy for Lumbar Disk Herniation <sup>16</sup>	Gadjradj PS (2016)
3	0.18	Percutaneous endoscopic decompression for lumbar spinal stenosis <sup>17</sup>	Ahn Y (2014)
4	0.18	Risk of Developing Seizure After Percutaneous Endoscopic Lumbar Discectomy <sup>18</sup>	Choi G (2011)
5	0.16	Evaluation of transforaminal endoscopic lumbar discectomy in the treatment of lumbar disc herniation <sup>19</sup>	Wang K (2015)

To some extent, proficiency in minimally invasive procedures can reduce postoperative complications in PELD. However, PELD has a rather long learning curve, which was also a high-frequency keyword in this study. The learning curve is a process of meeting a predefined level of performance with increasing experience and training. The surgical technique of PELD has a steep



**Figure 12** Top 7 clusters of cited references related to PELD for lumbar disc herniation from 2013 to 2022.

learning curve, especially for complex cases.<sup>32</sup> Wu compared the learning curves of the transforaminal approach of PELD at different levels (L4/5 and L5/S1) and suggested the technique of transforaminal approach at the L4/5 level may be easier to be mastered.<sup>33</sup> To research the learning curve of PELD, some professors conducted comparative studies. Sun concluded that prior experience with selective nerve root block could help novice surgeons shorten operation time and reduce the complication rate.<sup>34</sup> With the assistance of an O-arm-based navigation system, Ao found that it reshaped the learning curve of PELD, increased the accuracy of puncture, and minimized radiation exposure.<sup>35</sup> The accumulation of surgeons' experience, the update of equipment, and the innovation of techniques are significant in reducing the complications of PELD. Therefore, the surgical procedures and complications of PELD have been the hot topics of recent research and still will be the trends in the future.

## Limitations

The selected articles in this study were only from the WoS Core Collection. Some articles of high value about PELD may be omitted from other databases. Time sequence and self-citation may impact citation times to a certain degree. Nevertheless, we believe these articles could reflect the general state and trend of PELD research.

## Conclusion

The PELD in treating lumbar disc herniation is a relatively developed technique, with a notable increase in the 2010s. In this study, scholars from hospitals or universities in China, South Korea, and the United States made great contributions to this technique. *World Neurosurgery* was the most prolific journal, and *Spine* was the most influential journal in the field of PELD. Most articles focused on the surgical procedures and complications of PELD, which also will get more attention in the future.

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## Disclosure

The authors declare that there is no conflict of interest regarding the publication of this paper.

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