**ORIGINAL ARTICLE**

# Bibliometric analysis and description of research trends on transforaminal full-endoscopic approach on the spine for the last two-decades

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## Abstract

**Objective** The study aims to assess the current development status of transforaminal full-endoscopic spine surgery (TFES) by exploring and analyzing the published literature to obtain an overview of this field and discover the evolution and emerging topics that are underrepresented.

**Methods** Using Bibliometrix, CiteSpace, and VOSviewer, we analyzed the bibliometric data selected from the Web of Science Core Collection between January 2002 and November 2022. The descriptive and evaluative analyses of authors, institutes, countries, journals, keywords, and references are compiled. The quantity of research productivity was measured by the number of publications that were published. A quality indicator was thought to be the number of citations. In the bibliometric analysis of authors, areas, institutes, and references, we calculated and ranked the research impact by various metrics, such as the h-index and m-index.

**Results** A total of 628 articles were identified in the field of TFES by the 18.73% annual growth rate of research on the subject from 2002 to 2022, constituting the documents are by 1961 authors affiliated with 661 institutions in 42 countries or regions and published in 117 journals. The USA ($n = 0.20$) has the highest international collaboration rate, South Korea has the highest H-index value ($h = 33$), and China is ranked as the most productive country ($n = 348$). Brown univ., Tongji univ., and Wooridul Spine represented the most productive institutes ranked by the number of publications. Wooridul Spine Hospital demonstrated the highest quality of paper publication. The Pain Physician had the highest h-index ($n = 18$), and the most cited journal with the earliest publication year in the area of FEDS is Spine ($t = 1855$).

**Conclusion** The bibliometric study showed a growing trend of research on transforaminal full-endoscopic spine surgery over the past 20 years. It has shown a significant increase in the number of authors, institutions, and international collaborating countries. South Korea, the United States, and China dominate the related areas. A growing body of evidence has revealed that TFES has leapfrogged from its infancy stage and gradually entered a mature development stage.

**Keywords** Full endoscopy · Transforaminal · Citation analysis · Spine · VOSviewer · Bibliometrix · CiteSpace

## Introduction

Widespread acceptance of reducing surgical invasiveness has gradually changed the paradigm of spine surgery and scientific publishing [1, 2]. Undoubtedly, there will be those who benefit from the microscopy widely implementing minimally invasive spine surgery techniques in the current practice of spine surgery, such as endoscopic techniques [3, 4]. For nearly two-decades, surgical techniques and endoscopic technology have dramatically developed. With the advent of higher-resolution cameras, ingenious instruments, and large channel endoscopic systems, the indications for the full-endoscopic technique for treating spine diseases are becoming more widely and clearly understood. More importantly, the success of those pioneering studies brings confidence to the clinical application of this technique [5].

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The introduction of Kambin's triangle as a safe surgical trajectory into the neuroforamen to access the intervertebral disc is the key to implementing the technical feasibility of transforaminal full-endoscopic surgery (TFES) [6]. The technical advantage of TFES is not only associated with paraspinal muscle dissection and shorter length of stay but also its application in awake and aware states under local anesthesia. [7, 8] This would greatly benefit the community of degenerative lumbar spine disease that is characterized by older age. Moreover, it also is an effective surgical technique to avoid adhesions left by the previous surgery to cope with nonextensive, noninstability revisions, such as disc reherniation [9, 10].

To our knowledge, this research is the first bibliometric work to quantitatively examine TFES research over a 20-year period. Previous articles have presented research on full-endoscopic spine surgery; however, we believe it is not enough to describe the worldwide research productivity trend of TFES [11] Our study provides the current development status of TFES by exploring and analyzing the published literature to obtain an overview of this field. By discovering the evolution of TFES research and emerging topics that are underrepresented, it can illustrate to readers a full picture via a bibliometric network map and then, make them benefit from decomposition of the network map within its main components. Identifying the trends and evolutionary trajectories can assist spine surgeons and help decide the future course of TFES research. However, no bibliometric research papers have been published so far on the application of TFES in spine surgery. Given the foregoing purpose, the aim of our research is to assist clinicians in discovering the emerging topics from published articles and illustrate an overview of the bibliometric analysis of the current state of research on TFES.

## Method

Bibliometric analysis was conducted in this study to perform quantitative statistical measurements for currently published research on the clinical application of full-endoscopic spine surgery via the transforaminal approach. This paper covers the two separate bibliometric approaches, descriptive analysis, and evaluative analysis, which also are named top-down and bottom-up analysis, respectively. This integrated bibliometric methodology not only describes the publication performance of individuals and sources but also focuses on the evaluation of the safeguarding of scientific quality aspects of scientific performance. Different software packages were used to build the networks. In our study, we used Bibliometrix 4.0.0, an open-source R-package tool for quantitative research in scientometrics and bibliometrics, which was created using the R language for statistical computing and graphics, following a logical bibliometric methodology [12]; CiteSpace 6.1.R3 Advanced, a professional Java application for exploring the critical points in the development of a field or a domain, intuitive illustrate the structural and temporal analyses results of collaboration, author co-citation, and paper co-citation networks derived from scientific publications [13]; and VOSviewer 1.6.18, a specialized software used to create bibliometric networks with graphical representations, which was used to create a keyword co-occurrence network by the clustering methodology [14].

To consider the quality of the citation reference items, our study collected data from the Web of Science Core Collection, which includes a multidisciplinary database made up of a science citation index, social science citation index and arts, and humanities citation index [15]. According to the updated evidence-based Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a twenty-year period of literature searching was conducted with the following search formula: (endoscop* or arthroscop* or full-endoscop* or uniportal) And (transforaminal OR posterolateral) And (spine or spinal or lumbar or cervical or thoracic) [16]. All research uses of the data are publicly available and did not require institutional review board approval.

In this research, we included studies published over twenty years, from 2002 to 2022. Articles had to meet the following criteria for inclusion. Only English language studies were included, and conferences, editorials, reviews, letters, and corrections were excluded. Meanwhile, a strict restriction on the full-endoscopic spine technique excluded biportal endoscopy, epiduroscopy, microendoscopy, neuroendoscopy, laryngoscopy, and thoracoscopy. Cross-checking was performed by two independent reviewers to confirm the quality of the bibliometric results, and the data were processed on three separate bibliometric software packages for thorough analysis. If a consensus could not be reached, any differences were settled through debate, including with a third senior author.

The data in this study were described using a variety of measures. The quantity of research productivity was measured by the number of publications that were published. A quality indicator was thought to be the quantity of citations. We calculated and ranked the research impact by various metrics, such as the h-index and m-index, in the bibliometric analysis of authors, areas, institutes, and references.

## Results

### Main information of bibliometric analysis

The descriptive and evaluative analysis of the retrieved data is shown in Table 1, including basic descriptions,

**Table 1** Basic information about the bibliometric dataset

| Description | Results |
| --- | --- |
| Timespan | 2002–2022 |
| Journals | 117 |
| Average years from publication | 3.65 |
| Documents | 628 |
| Annual Growth Rate % | 18.73 |
| Countries/regions | 42 |
| Affiliations | 665 |
| publishers | 56 |
| Average citations per doc | 16.38 |
| References | 7156 |
| Authors | 1961 |
| Authors of multi-authored documents | 613 |
| Co-Authors per Doc | 5.55 |
| Collaboration index | 10.69 |
| Total citation times | 10,128 |
| H-index | 47 |
| Citing articles | 2796 |

institutions, nations, and author publications. The figures and tables illustrate a wealth of useful bibliometric information on the characteristics of the current applications related to the full-endoscopic transforaminal approach. A total of 628 articles constituting the documents are by 1961 authors affiliated with 661 institutions in 42 countries or regions (Fig. 1). All of the included studies could be found in supplement. Figure 2 shows the annual number distribution and citations of the published studies in the analysis. The growth pattern shows three stages based on the chronological distribution. The infancy stage of publications about the transforaminal FE technique was from 2002 to 2009. Since 2010, the number of countries that joined the endoscopic group grew exponentially, and then, the exponential growth of article publication began in 2016. According to our analysis, the full-endoscopic technique via the transforaminal approach is becoming a more popular topic, as seen by the 18.73% annual growth rate of research on the subject from inception to 2022. The year of publication for the primary reports ranged from 2016 to 2022, with the most frequent publication year being 2020. Regarding the average number of article citations, those publications in 2008 earned higher citation numbers, with 16.05 citations per year, followed by 11.22 citations in 2002.

## Most relevant and influential journals

The study identified 628 published in 117 journals. As shown in Table 2, the most impactful journals in terms of citations and the Eigenfactor score, such as the h-index and g-index, were reported. The h-index of an included journal

is calculated as a measurement tool to discover the most influential journals in a selected area, and it is a measure of the citations of publications based on the total number of publications to reflect the productivity of individuals or organizations [17]. On the other hand, we introduced the g-index to balance the situation where the total number of published articles is low but the impact is high. A total of 20 journals were identified as the most relevant and influential sources in the TFES technique. Pain Physician had the highest h-index of 18, with 1016 total citations, 44 publications, and its first publication in 2013, followed by the second-highest of 16 by World Neurosurgery, and the third-highest of 11 in European Spine Journal. World Neurosurgery had the highest publication number of 102, and Spine had the earliest year of publication of its first article. Among the more than ten publications, Spine, European Spine Journal, and Clinical Neurology and Neurosurgery demonstrated high-journal quality based on the composite index.

To further explore the "core journal" in the scientific publication of TFES, a reference journal co-citation network map shows 693 nodes and 3899 links using CiteSpace and Bibliometrix software. (Fig. 3) The top 10 most impactful journals account for 262 of the total number of publications and 6099 citations, or 60.22% of the total citation count. Among them, World Neurosurgery and Clinical Neurology and Neurosurgery were the emerging journals that were interested in the area of TFES after 2014. In addition, the intellectual structure network showed two different sources of knowledge camps: One was from Spine, and the other was from the European Spine Journal. It also reflects the wide recognition of the high quality of literature published by these two major journals.

## Most impactful institutes and authors

A total of 1963 authors with 665 affiliations were identified in the 628 articles. The top three rankings in terms of the number of publications on TFES are listed in Fig. 4: Brown University (*h*-index of 11,373 total citations), Tongji University (*h*-index of 11, 338 total citations), and Capital Medical University (*h*-index of 18,1431 total citations). Wooridul Spine Hospital represented the most productive institutes ranked by the number of publications. Brown University, Tongji University, and Wooridul Spine Hospital have made great contributions to the development of TFES research. Among them, Wooridul Spine Hospital demonstrated the highest quality of paper publication (1431 citations, H-index 18).

Moreover, the top 10 authors contributed 197 of the included papers, with 7753 citations, accounting for 76.55% of the total citation count. Author Telfeian AE has the highest contribution with 28 studies, followed by Kim HS with 26 studies and Wang Y with 25 studies.

**Identification of studies via databases**
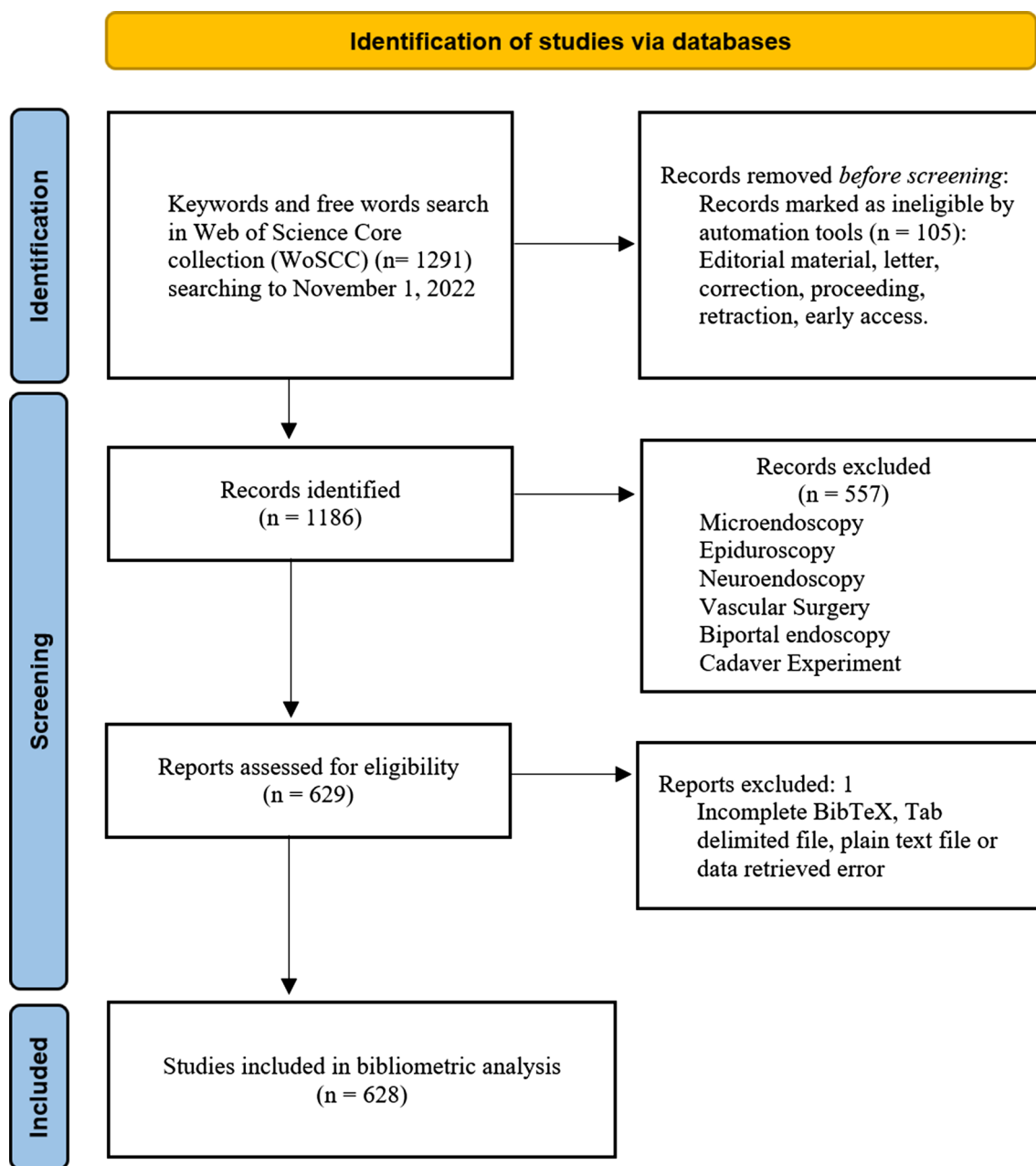


**Fig. 1** Flowchart of article inclusion for bibliometric analysis

Meanwhile, the research impact of authors was measured and illustrated in Table 3, ranked by the h-index. In terms of the h-index, Ahn Y and Rutten S are the first- and second-ranked authors. Rutten has the highest total number of citations, with 1735, followed by Komp M, with 1708; they came from the same institute, St Anna Hospital Herne. Similarly, He S and Fan G also were two impactful authors from the same institute, Shanghai Peoples Hospital 9. In the author rankings, Ahn Y, Rutten S, Komp S, Lee SH, Kim JS, and Choi G calculated the same metrics in

G-index and NP, which reflected that their papers can be used as a reliable source or were due to their reputation or popularity in the world. Furthermore, Fig. 5 shows the authors' productions over time from their first publication. The volume of the sphere is proportionate to the publication number per year, and the depth of the color of a sphere is proportionate to the total citations per year. We found that Ahn Y, Lee SH, and Rutten S are the earliest and longest-period authors, from 2004 until 2022, in the TFES publication list.
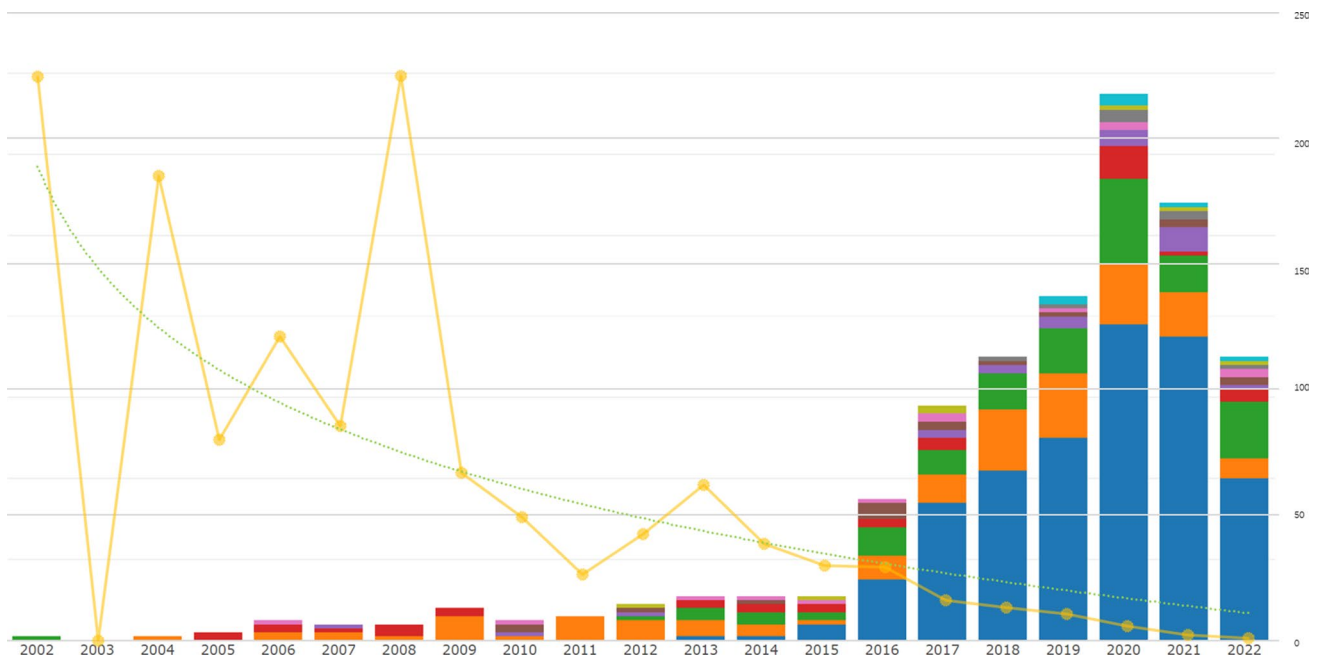
**Fig. 2** Annual publication distribution and citation trends (bar & line graphs)

**Table 2** Top journals in TFES research ranked by H-index, G-index, and Eigenfactor score

| Journal | h-index | g-index | m-index | TC | NP | PY | IF | JCR |
|---|---|---|---|---|---|---|---|---|
| Pain Physician | 18 | 30 | 1.8 | 1016 | 44 | 2013 | 4.396 | Q1 |
| Spine | 16 | 17 | 0.842 | 1855 | 17 | 2004 | 3.241 | Q1 |
| World Neurosurgery | 16 | 26 | 1.778 | 1055 | 102 | 2014 | 2.210 | Q2 |
| European Spine Journal | 11 | 15 | 0.786 | 610 | 15 | 2009 | 2.721 | Q1 |
| Clinical Neurology and Neurosurgery | 10 | 16 | 1 | 290 | 16 | 2013 | 1.885 | Q2 |
| Biomed Research International | 8 | 13 | 1.143 | 174 | 14 | 2016 | 3.246 | Q2 |
| Journal of Orthopedic Surgery and Research | 8 | 12 | 0.8 | 150 | 13 | 2013 | 2.677 | Q2 |
| Medicine | 8 | 11 | 1 | 175 | 24 | 2015 | 1.817 | Q3 |
| International Orthopedics | 7 | 8 | 0.7 | 222 | 8 | 2013 | 3.479 | Q1 |
| Journal of Neurosurgery-Spine | 7 | 9 | 0.438 | 552 | 9 | 2007 | 3.467 | Q1 |

*TC* represents total citations, *NP* represents the number of publications, *PY*-start represents the year of the first publication, *IF* impact factor, *JCR* journal citation reports

## Most influential citations and historical citation network

In our research, we choose the global citation score (GCS) and local citation score (LCS) to explore the seminal or breakthrough studies in the body of intellectual structure. Figure 6 illustrates the historical citation network that describes the landmark articles, ranked based on their GCS and LCS. It is feasible to explore influential works that earned a relatively small number of citations within the local citation network but a sizable number of citations across the global citation network. We found that combination in only one paper. In the comparison of these two rankings, only one article focuses on the learning curve of the full-endoscopic

technique that appears in the LCS ranking [18]. Meanwhile, it is obvious that in the top 10 cited papers, seven studies belong to the Spine journal, published from 2002 to 2008. Meanwhile, those studies are indeed seminal works in the TFES field, from the early preliminary clinical trials of TFES and high evidence of a randomized controlled study to the standard microsurgical technique and modified technique for expanded indication to the more recent investigation of the learning curve and radiation exposure [10, 19–26].

To discover a possible future sentinel paper representing a potentially impactful and promising scientific contribution to the TFES research, which still has a lower GCS in recent times (Table 4). Our team also ranked the newest published papers according to the total GSC in the most recent five
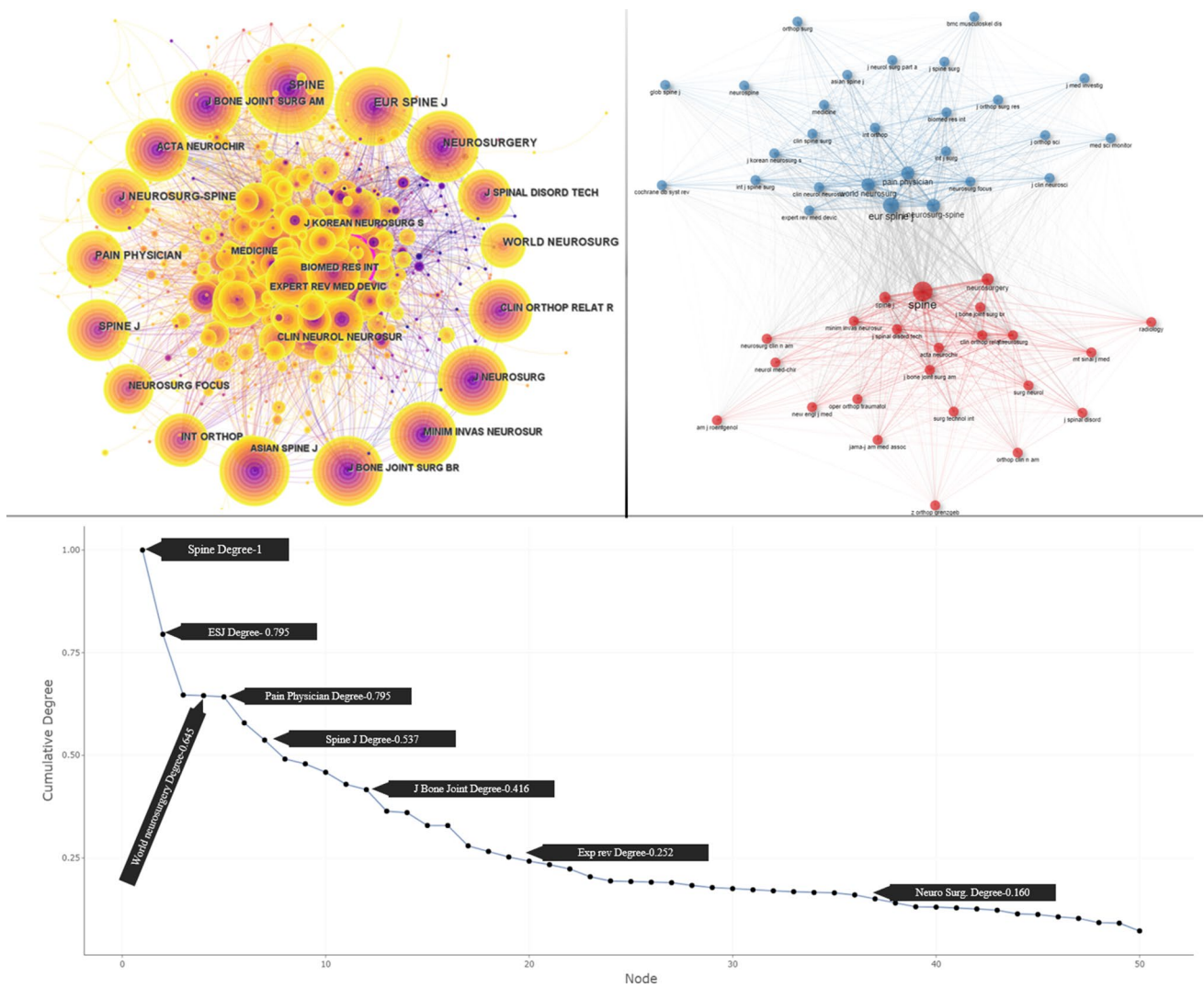
**Fig. 3** Journal co-occurrence network and intellectual structure network



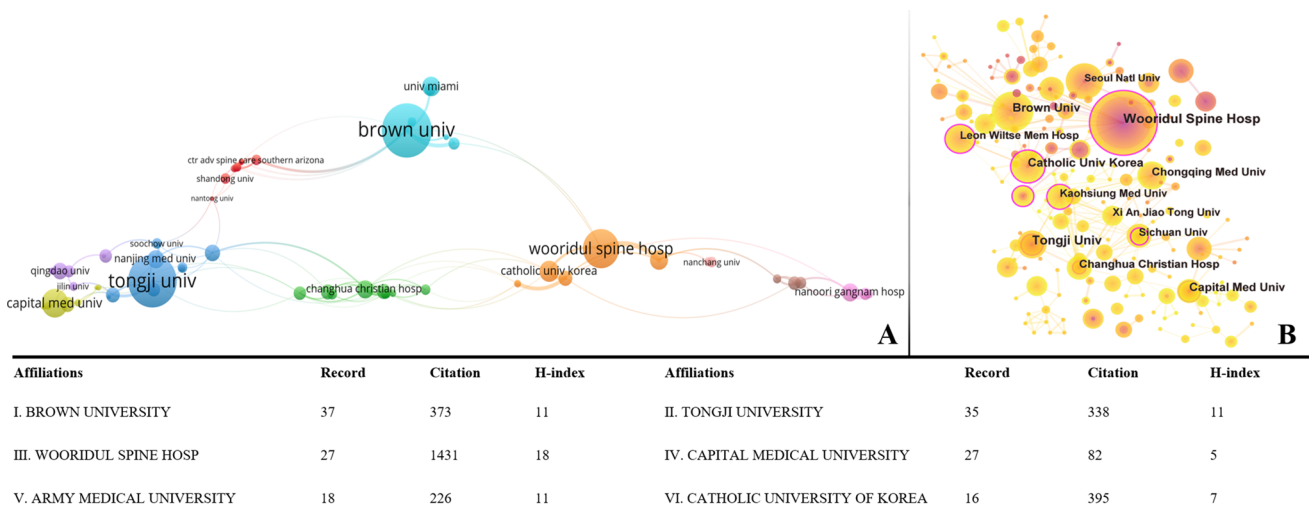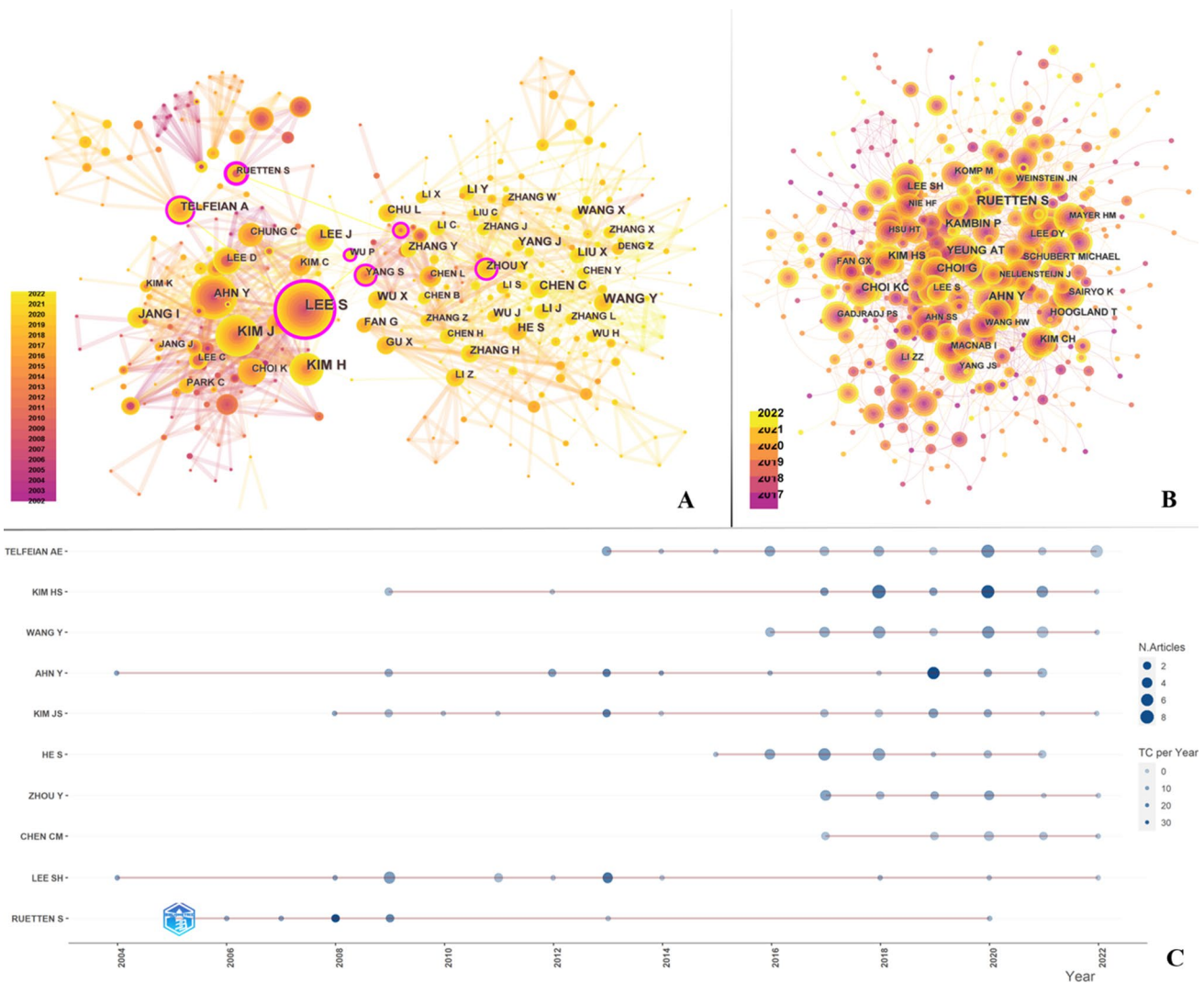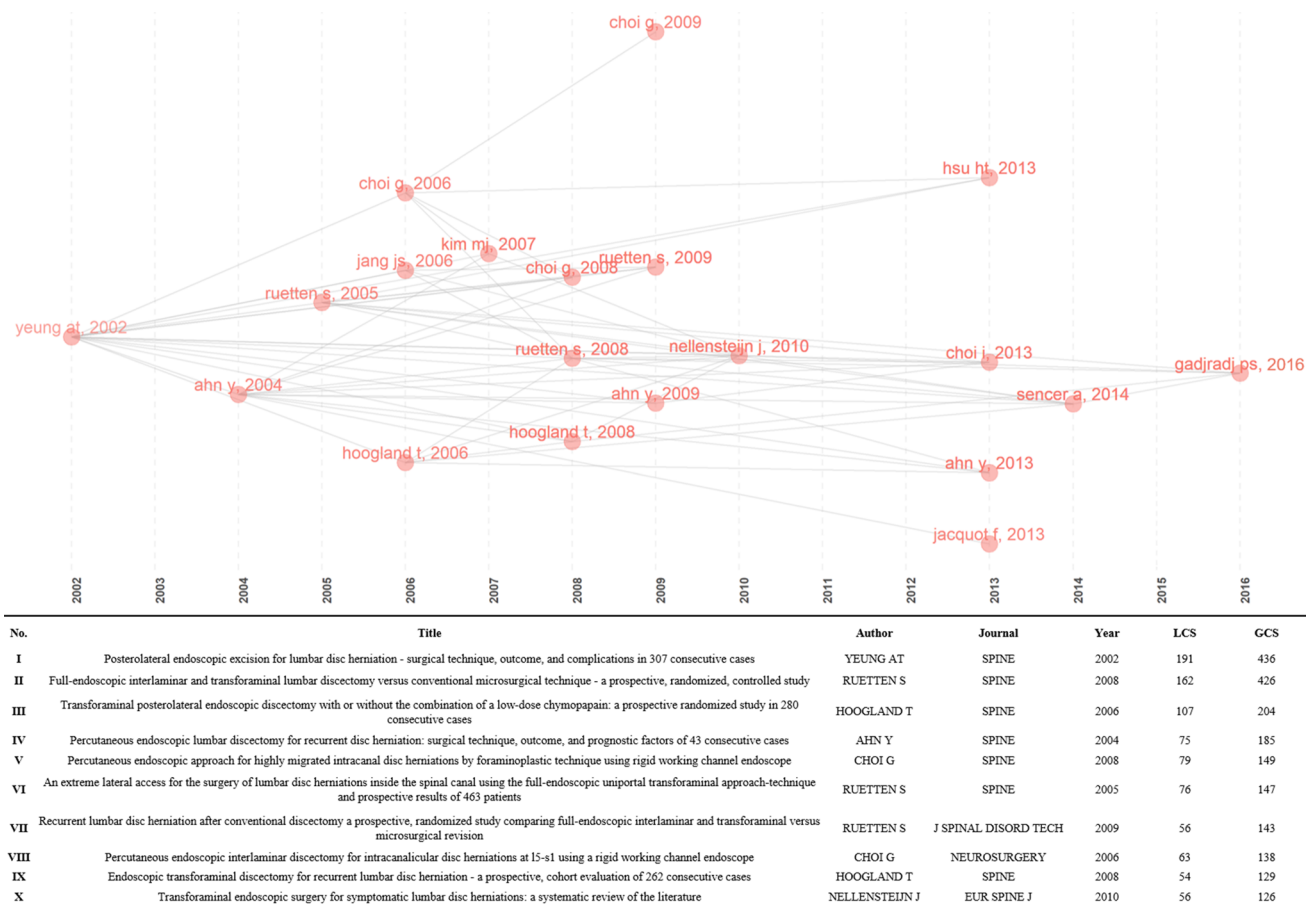| Affiliations | Record | Citation | H-index | Affiliations | Record | Citation | H-index |
|---|---|---|---|---|---|---|---|
| I. BROWN UNIVERSITY | 37 | 373 | 11 | II. TONGJI UNIVERSITY | 35 | 338 | 11 |
| III. WOORIDUL SPINE HOSP | 27 | 1431 | 18 | IV. CAPITAL MEDICAL UNIVERSITY | 27 | 82 | 5 |
| V. ARMY MEDICAL UNIVERSITY | 18 | 226 | 11 | VI. CATHOLIC UNIVERSITY OF KOREA | 16 | 395 | 7 |

**Fig. 4** Institute collaboration co-occurrence network

**Table 3** Bibliometric summary of author impact metrics in transforaminal full-endoscopic spine surgery

| Author | H-index | G-index | NP | M-index | TC | PSY | Organizations |
|---|---|---|---|---|---|---|---|
| Ahn Y | 14 | 20 | 20 | 0.737 | 988 | 2004 | Gachon University Gil Medical Ctr |
| Ruetten S | 13 | 14 | 14 | 0.722 | 1735 | 2005 | St Anna Hosp Herne |
| Kim HS | 12 | 21 | 26 | 0.857 | 454 | 2009 | Nanoori Gangnam Hosp |
| Komp M | 12 | 12 | 12 | 0.667 | 1708 | 2005 | St Anna Hosp Herne |
| Lee SH | 12 | 14 | 14 | 0.800 | 678 | 2008 | Woori Spine Hosp |
| He S | 11 | 15 | 21 | 1.375 | 257 | 2015 | Shanghai Peoples Hosp 9 |
| Telfeian AE | 11 | 17 | 28 | 1.1 | 344 | 2013 | Rhode Isl Hosp |
| Zhou Y | 11 | 14 | 18 | 1.833 | 228 | 2017 | Xinqiao Hosp |
| Fan G | 10 | 14 | 16 | 1.25 | 216 | 2015 | Shanghai Peoples Hosp 9 |
| Kim JS | 10 | 18 | 18 | 0.667 | 603 | 2008 | Seoul St. Mary's Hospital |
| Choi G | 9 | 10 | 10 | 0.529 | 542 | 2006 | Pohang Woori Spine Hosp |



**Fig. 5** Author co-occurrence network in TFES research: publications and citations over time

| No. | Title | Author | Journal | Year | LCS | GCS |
|---|---|---|---|---|---|---|
| I | Posterolateral endoscopic excision for lumbar disc herniation - surgical technique, outcome, and complications in 307 consecutive cases | YEUNG AT | SPINE | 2002 | 191 | 436 |
| II | Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique - a prospective, randomized, controlled study | RUETTEN S | SPINE | 2008 | 162 | 426 |
| III | Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases | HOOGLAND T | SPINE | 2006 | 107 | 204 |
| IV | Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases | AHN Y | SPINE | 2004 | 75 | 185 |
| V | Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope | CHOI G | SPINE | 2008 | 79 | 149 |
| VI | An extreme lateral access for the surgery of lumbar disc herniations inside the spinal canal using the full-endoscopic uniportal transforaminal approach-technique and prospective results of 463 patients | RUETTEN S | SPINE | 2005 | 76 | 147 |
| VII | Recurrent lumbar disc herniation after conventional discectomy a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision | RUETTEN S | J SPINAL DISORD TECH | 2009 | 56 | 143 |
| VIII | Percutaneous endoscopic interlaminar discectomy for intracanalicular disc herniations at l5-s1 using a rigid working channel endoscope | CHOI G | NEUROSURGERY | 2006 | 63 | 138 |
| IX | Endoscopic transforaminal discectomy for recurrent lumbar disc herniation - a prospective, cohort evaluation of 262 consecutive cases | HOOGLAND T | SPINE | 2008 | 54 | 129 |
| X | Transforaminal endoscopic surgery for symptomatic lumbar disc herniations: a systematic review of the literature | NELLENSTEIJN J | EUR SPINE J | 2010 | 56 | 126 |

**Fig. 6** Historical direct citation network of most impacted journal. Global citation score (GCS): the citation frequency based on the online WOS database count which represent the fundamental devel-opment of selected field; Local citation score (LCS)., it is the number of citation times cited by researches within the included papers, indicating the impact of scope of this research

years, showing the average per year number of citations. We found that all of the recently published papers were not included in the previous GCS ranking. These additional papers pursue higher-level clinical evidence to demonstrate the effectiveness of TFES, such as long-term follow-up-controlled trials or systematic reviews and meta-analyses. [27–29] Meanwhile, some papers seem to move toward cutting-edge topics such as endoscopic transforaminal lumbar interbody fusion without general anesthesia [30].

## Co-occurrence analysis of keywords and reference

From the 628 published records, a total of 1674 keywords were extracted. The co-occurrence keyword network map was clustered, and the overlay visualization is shown in Fig. 7. The algorithm automatically generated five different clusters, and the largest nodes were "herniation" and "discectomy". Cluster 1 was structured with the largest node, "herniation", representing the technique indication, such as the diagnosis, classification of herniation and instability of spine alignment, which is the key point to determine

the postoperative clinical outcome of TFES. Cluster 2 was constructed by the various surgical technique strategies to address the various spinal disorders, such as foraminoplasty, foraminotomy, foraminal stenosis, lateral recess stenosis, and spinal stenosis. Cluster 3 represented the surgical evidence and technique issues, including meta-analysis, radiation exposure, and learning curve. Cluster 4 indicated the technique prototype at the earlier application of TFES, including arthroscopic microdiscectomy and percutaneous nucleotomy. In addition, the overlay visualization of the keyword network map shows that recent research trends are clustered by the words "efficacy", "TLIF", and "risk factors". Furthermore, the data showed that the top 20 keywords with the strongest citation burst first appeared in 2002. The timeline of keyword co-occurrence analysis was illustrated in Fig. 8.

In our study, our team also used CiteSpace to visualize the co-occurrence network of cited references. (Fig. 7). The primary clusters were illustrated and calculated by Silhouette Coefficient (The best value is 1, values near 0 indicate overlapping clusters and the worst value is: 1) from 2002 to 2020 with the following: "clinical outcome" (Cluster 0,

**Table 4** Top emerging TFES papers ranked by recent gcs and average annual citations

| No | Title | Author | Journal | Year | Average per year | GCS |
|---|---|---|---|---|---|---|
| I | Comparison of percutaneous endoscopic transfo-raminal discectomy, microendoscopic discectomy, and microdiscectomy for symptomatic lumbar disc herniation: minimum 2-year follow-up results | Liu XY | Journal of Neurosurgery | 2018 | 15.2 | 76 |
| II | Endoscopic transforaminal lumbar interbody fusion without general anesthesia: operative and clinical outcomes in 100 consecutive patients with a mini-mum 1-year follow-up | Kolcun JPG | Neurosurgrical Focus | 2019 | 16.75 | 67 |
| III | Percutaneous transforaminal endoscopic discectomy compared with microendoscopic discectomy for lumbar disc herniation: 1-year results of an ongoing randomized controlled trial | Chen ZH | Journal of Neurosurgery | 2018 | 10.8 | 54 |
| IV | Percutaneous Endoscopic Lumbar Discectomy for All Types of Lumbar Disc Herniations (LDH Includ-ing Severely Difficult and Extremely Difficult LDH Cases | Kim HS | Pain Physician | 2018 | 10.6 | 53 |
| V | Reduced Acute Care Costs With the ERAS (R) Mini-mally Invasive Transforaminal Lumbar Interbody Fusion Compared With Conventional Minimally Invasive Transforaminal Lumbar Interbody Fusion | Wang MY | Neurosurgery | 2018 | 10.4 | 52 |
| VI | Endoscopic transforaminal lumbar interbody fusion: a comprehensive review | Ahn Y | Expert Review of Medical Devices | 2019 | 11.75 | 47 |
| VII | Evolution of Spinal Endoscopic Surgery | Kim M | Neurospine | 2019 | 11.5 | 46 |
| VIII | Percutaneous Endoscopic Lumbar Discectomy: Indica-tions and Complications | Pan MM | Pain Physician | 2020 | 14.67 | 44 |
| IX | Endoscopic spine discectomy: indications and out-comes | Ahn Y | International Orthopedics | 2018 | 9.5 | 38 |
| X | Percutaneous Endoscopic Lumbar Discectomy for L5S1 Lumbar Disc Herniation Using a Transforami-nal Approach Versus an Interlaminar Approach: A Systematic Review and Meta-Analysis | Chen JG | World Neurosurgery | 2018 | 7.2 | 36 |
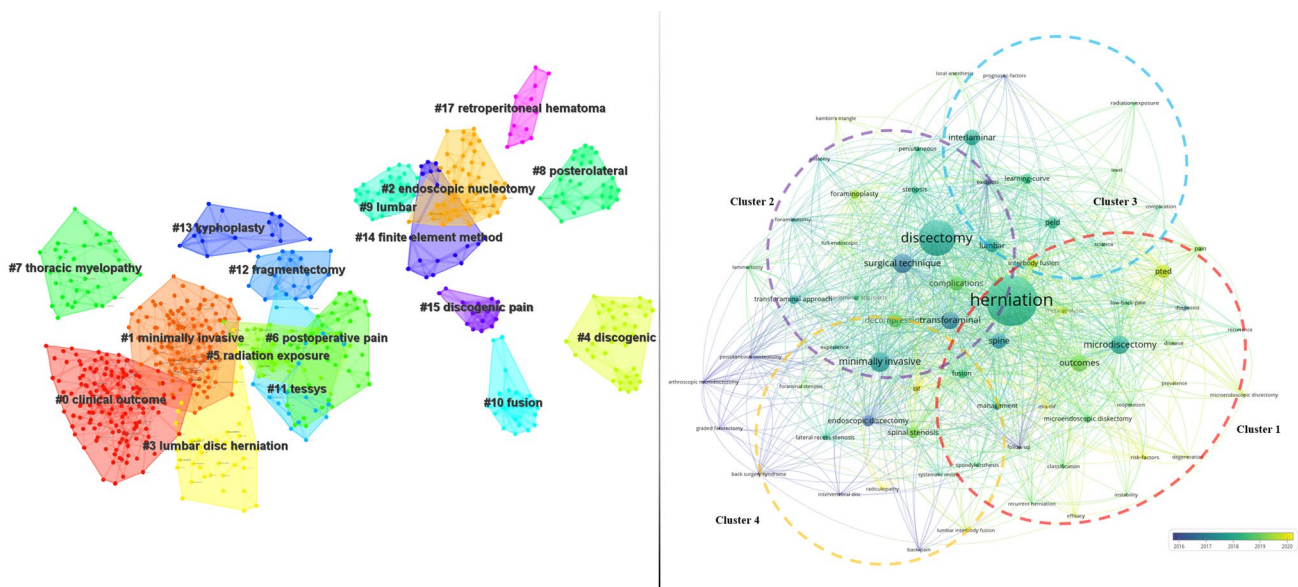


**Fig. 7** Keywords co-occurrence network
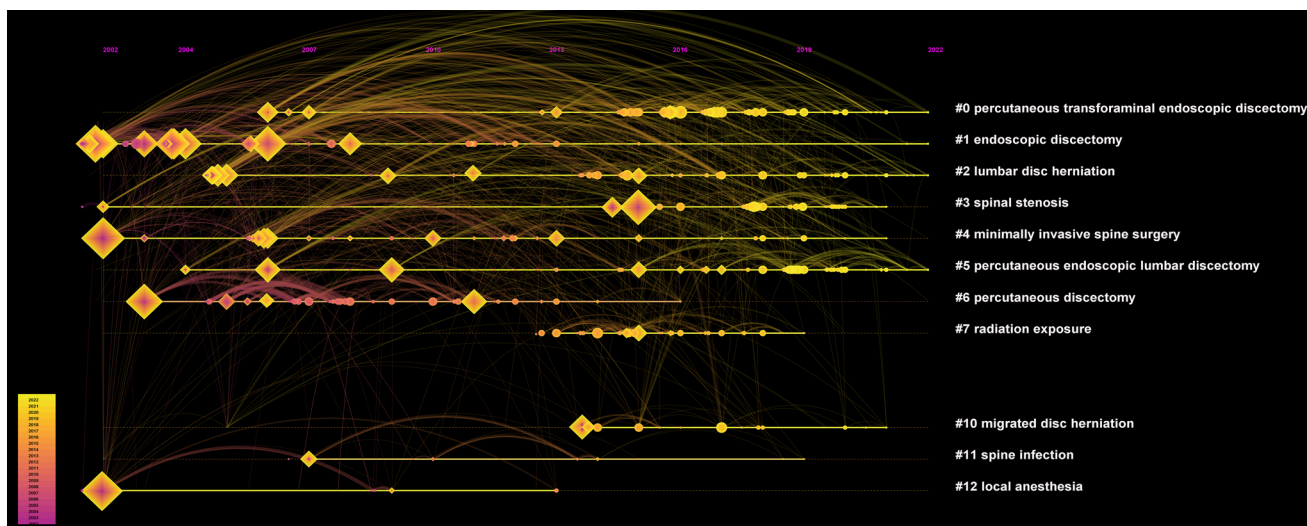
**Fig. 8** Timeline of most cited reference co-occurrence network

$n = 135$, Sihouette $= 0.814$), "minimally invasive" (Cluster 1, $n = 122$, Sihouette $= 0.748$), "endoscopic nucleotomy" (Cluster 2, $n = 49$, Sihouette $= 0.896$), "lumbar disc herniation" (Cluster 3, $n = 38$, Sihouette $= 0.884$). On the other hand, the earliest and highest reference burst occurred in 2003, only one year after Yeung published his groundbreaking article, and the burst continued until four years later. The average duration of their bursts was $3.12 \pm 0.83$, and the longest burst time was reported with Lee's paper, which demonstrated the high risk of operative failure of full-endoscopic surgery in cases with high-canal compromise or high-grade migrated herniation [31]. From the dual-map overlay visualization of journal-to-journal reference citation, we revealed that the research field of TFES is frequently cite the journal areas of neurology, sports, clinical, medical, medicine; and most cited by the area of health, nursing, sports, rehabilitation, psychology, education, economics, social, economic, and political (Fig. 9).

## International cooperation trends

According to the Worldometer, there are 195 countries in the world as of 2022. Of a total of 601 FEDS papers that were published from the top 10 most productive areas, almost all of the papers were from these countries. This indicates that the FEDS technique did not earn higher
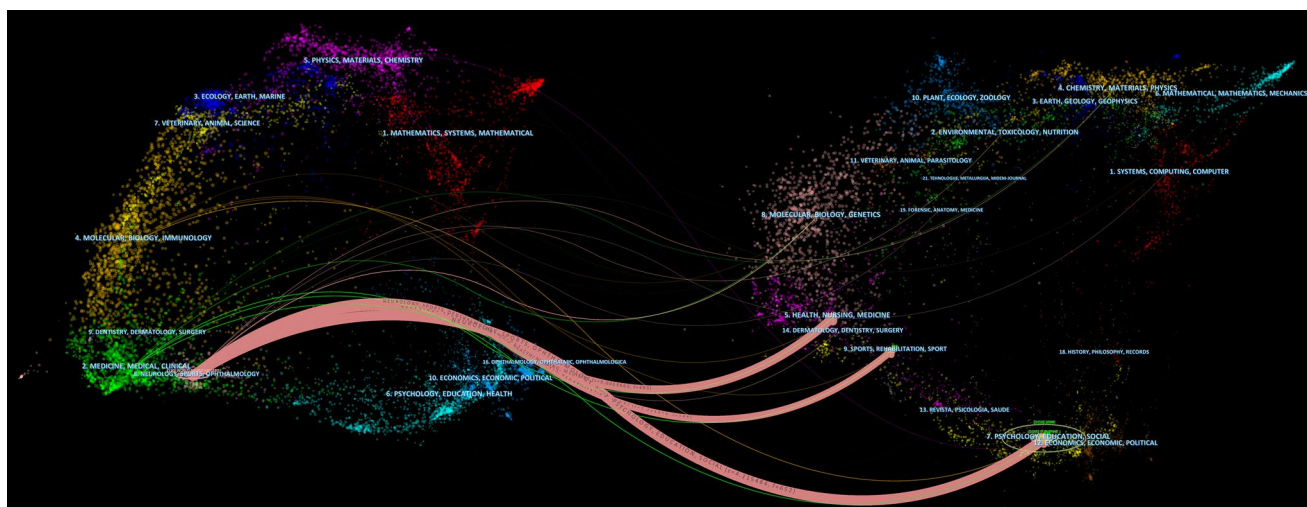


**Fig. 9** Dual-map overlay visualization of journal-to-journal citations. The arrow of a citation points from citing journals (left) to cited journals (right)

penetration rates in the world; however, with the development of the last twenty years, an increasing number of countries are starting to join, and the countries that already have the technology are cooperating more frequently. As shown in Fig. 10, China received the highest single country publication (SCP), and South Korea received the highest multiple country publication (MCP). The USA has the highest international collaboration rate (ICR), followed by the Netherlands and South Korea. Among them, South Korea rewards the highest H-index value and citations, with an average number of citations of 28.8 per year. Moreover, the world map of worldwide research productivity is illustrated, and the countries marked with the intensity of the color in the figures are the degree of productivity, and the line between them represents the frequency of international cooperation. Of the top 10 major productive countries, China was the most productive country, followed by South Korea and the United States.

## Discussion

Our paper represents the first scoping study on the cutting-edge evolution of minimally invasive spine surgery with the full-endoscopic technique via the transforaminal approach. The study results inform the full-endoscopic community about the current state of the art, and we identified the critical area in the development of the TFES field and demonstrated how the existing knowledge has evolved over the years. The clinical supervisors, decision-makers, and manufacturers can use the information here as identified research trajectories to design the standards and agendas by collecting a past overview or drawing the advanced direction in endoscopic technology, accelerating the real transition spread of TFES to one of the standard procedures covered by the health insurance system.

We described the developmental research trajectory of TFES from the analysis of the VOSviewer and CiteSpace bibliometric networks. Specifically, as endoscopic instrumentation was in its infancy in spine surgery, researchers were dedicated to publishing research on the feasibility of
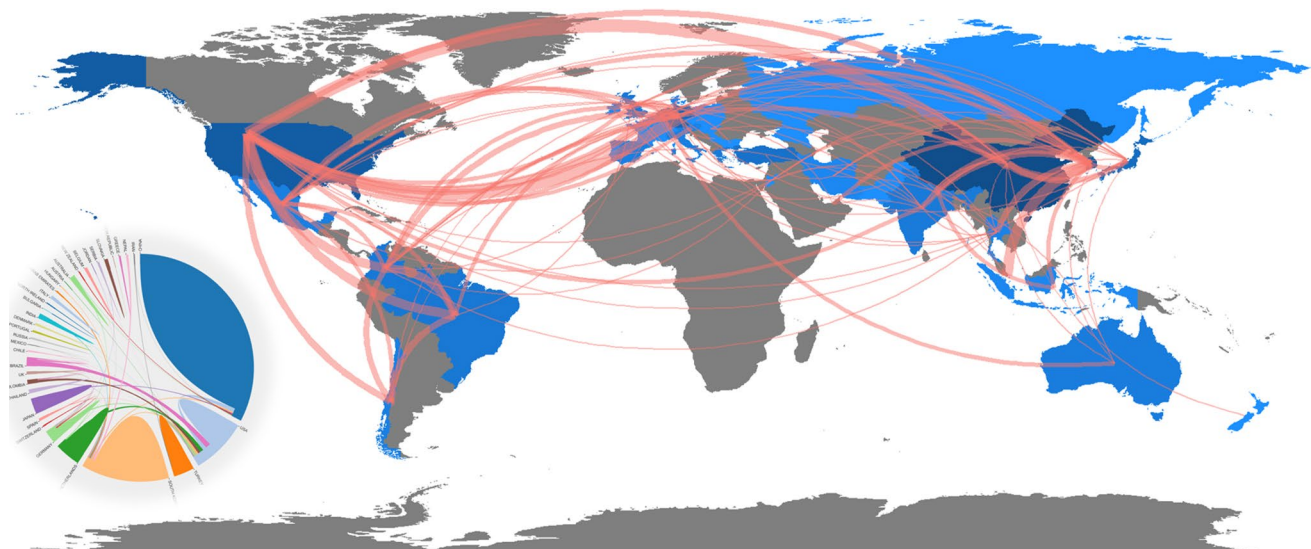


| Country | N (%) | SCP | MCP | ICR | H-index | TC | Avg. C |
|---|---|---|---|---|---|---|---|
| CHINA | 348 (55.41) | 336 | 12 | 0.034 | 23 | 2467 | 7.09 |
| KOREA | 105 (16.72) | 85 | 20 | 0.19 | 33 | 2814 | 26.8 |
| USA | 69 (10.99) | 55 | 14 | 0.2 | 20 | 925 | 13.41 |
| GERMANY | 21 (3.34) | 20 | 1 | 0.048 | 15 | 2081 | 99.1 |
| JAPAN | 19 (3.03) | 18 | 1 | 0.053 | 7 | 215 | 11.32 |
| NETHERLANDS | 13 (2.07) | 7 | 6 | 0.462 | 10 | 427 | 32.85 |
| TURKEY | 13 (2.07) | 12 | 1 | 0.077 | 6 | 158 | 12.15 |
| GREECE | 6 (0.96) | 6 | 0 | 0 | 4 | 41 | 6.83 |
| ITALY | 4 (0.64) | 4 | 0 | 0 | 3 | 26 | 6.5 |
| INDIA | 3 (0.48) | 3 | 0 | 0 | 3 | 64 | 21.33 |

**Fig. 10** World map showing the distributions of publications. The color intensity is proportional to the number of publications, and the red line is the relationship of country collaboration. Single country publications (SCP): The list of authors in one article are all come from the same area; Multiple country publications (MCP): the list of authors belong to various countries which represents inter-country collaboration

the endoscopic technique that passed directly through the intervertebral foramen and removal of the pain generator by fragmentectomy, which we call the "inside-out" technique designed by Anthony Yeung. Subsequently, Hoogland published the "outside-in" technique, which involves positioning the working cannula outside the foramen first and then, entering the spinal canal via foraminoplasty before targeting removal of the herniated disc [32]. Moreover, the effect of TFES on the stability of the spinal sequence also was considered. The full-endoscopic technique is less intrusive on the facet joint than conventional decompression spine surgery, which eliminates the necessity for positioning the pedicle screw, thus preserving postoperative spinal mobility while reducing the risk of adjacent spine degeneration.

On the other hand, TFES allows surgery to be performed under local anesthesia (LA), which decreases the risk of intraoperative and postoperative complications associated with general anesthesia, especially in a community of degenerative spinal diseases that are considered poor candidates for general anesthesia because of advanced age or underlying diseases [33]. At the same time, LA allows for real-time feedback on nerve root interferences during intraoperative decompression and thus, circumvents associated complications, such as paresthesias in a dermatomal distribution or weakness of muscle. This feedback mechanism also compensates to some extent for the early stage of the technical defect with low resolution and high latency of the camera, reducing the risk of potential iatrogenic injury to the neural structure. With the number of reported scientific studies on this technique having increased, researchers have begun to improve the surgical technique to improve the safety of the surgical trajectory from the foramen into the spinal canal or to conduct studies on different surgical approaches, such as the interlaminar approach, to explore the difference on comparison of the posterior approach compared to the posterolateral approach on nerve decompression [34]. Furthermore, updated instruments have improved the overall efficiency of the procedure, such as high-speed diamond drills and large-diameter working channels that allow for safer and more efficient bony work with a wider and clearer surgical field. This instrumentation innovation combined with modified surgical techniques has expanded the indications for early-stage TFES, such as converting the contraindication to indication, such as mild spinal stenosis or disc migration. The evolution of clinical practice and medical devices has been positive in the development of TFES, which is a technique that is a device closely related to and in constant update with the needs of the operator.

As the surgical technique continues to mature, the need for evidence about it has increased. Particularly, in the last decade, an increasing number of clinical studies have begun to report high-quality clinical evidence, such as long-term clinical follow-up results, randomized or retrospective controlled trials, and systematic reviews with meta-analyses. In fact, TFES has achieved encouraging clinical outcomes in decompression surgery [27]. The available results suggest that the TFES technique is considered to have equivalent effectiveness compared to microscopic discectomy [35]. Recently, some innovators have attempted to transfer the technique advantage of the full-endoscopic technique to lumbar interbody fusion. Actually, investigators have identified that the full-endoscopic technique can fill the technical gap of indirect decompression, like TLIF or OLIF technique [36, 37]. Full-endoscopic interbody fusion combines the concept of indirect and direct decompression for precise removal of the pain generator while also allowing for supervision of the processing of endplate preparation under endoscopy. Customizing the fusion bed of the implant further improved postoperative patient fusion rates. This paradigm shifts to traditional disc preparation, which depends on fluoroscopic C-arm guidance without direct visualization.

The endoscopic technique differs from conventional surgical views in that the investigator extends the field of view to the lesion target through the instrument camera, and the surgical field of view depends on the instrumentation and the operator's own skill. Therefore, there is a steep learning curve for the full-endoscopic technique [18]. Beginners are more prone to intraoperative or postoperative complications in their early practice and perform multiple times intraoperative X-rays, which not only increases the total radiation exposure but also prolongs the overall endoscopic operation time. Fortunately, recent advances in image-assisted technology, such as electromagnetic or robotic navigation technologies, have all been installed with real-time intraoperative instrument tracking systems that can be achieved to maximize lesion removal while avoiding excessive X-ray exposure [38, 39]. Obviously, these assistive technologies have the potential to flatten the learning curve. However, the cost of the device may impede the step of surgeons who want to try, which also is one of the main reasons for the limited spread of FEDS.

## Limitations

There are certain limitations in our study. First, high-quality articles published recently with high citation potential in the future may not be accurately predicted and analyzed. Second, to ensure the integrity of the data information and the quality of best practice publications, we included only journal articles from the Web of Science Core Collection's social science citation index database in our bibliometric analysis in our methodological search strategy. Although Web of Science is one of the largest databases in the world, it includes only a fraction of scientific publications. Future research may expand the scope of the search strategy to

larger databases, such as Scopus; however, the causes of potential citation network analysis errors caused by confounding citation networks in non-WoS databases need to be further explored before they can be applied. The third concerns keyword omission and confusion caused by possible artificial search bias in the early technology of endoscopy. It is worth mentioning that we performed a manual secondary check of the title, abstract, and keyword fields of the included articles after analyzing the search and consulted senior researchers to exclude irrelevant articles, which may help to compensate for this limitation to some extent. Meanwhile, we cannot neglect to consider the 'Matthew effect' in our citation analysis, which means that researchers tend to cite articles written by researchers who embrace respect, reputation, and popularity in their citation selections; thus, the actual value of the citations may be exaggerated.

## Conclusion

Our research is the first attempt to illustrate the 20-year development of knowledge structure on the full-endoscopic technique via the transforaminal approach. In this study, various quantitative bibliometric results have provided the big picture of the knowledge structure on the subject under study, all of which are based on the elaborate conceptual design and advanced software algorithms. A growing body of evidence has revealed that TFES has leapfrogged from the infancy stage and has gradually entered a mature development stage.

## Declarations

**Conflict of interest** The corresponding author, Jin-Sung Kim, is a consultant of Richard Wolf, GmbH, and Elliquence, LLC. The other authors have no conflicts of interest to declare.

## References

1. Smith ZA, Fessler RG (2012) Paradigm changes in spine surgery: evolution of minimally invasive techniques. Nat Rev Neurol 8:443–450. https://doi.org/10.1038/nrneurol.2012.110

2. Hermansen E, Austevoll IM, Hellum C, Storheim K, Myklebust TÅ, Aaen J, Banitalebi H, Anvar M, Rekeland F, Brox JI, Franssen E, Weber C, Solberg TK, Furunes H, Grundnes O, Brisby H, Indrekvam K (2022) Comparison of 3 different minimally invasive surgical techniques for lumbar spinal stenosis: a randomized clinical trial. JAMA Netw Open 5:e224291–e224291. https://doi.org/10.1001/jamanetworkopen.2022.4291

3. Kim JY, Hong HJ, Lee DC, Kim TH, Hwang JS, Park CK (2022) Comparative analysis of 3 types of minimally invasive posterior cervical foraminotomy for foraminal stenosis, uniportal-, biportal endoscopy, and microsurgery: radiologic and midterm clinical outcomes. Neurospine 19:212–223. https://doi.org/10.14245/ns.2142942.471

4. Bae J, Kim J, Lee SH, Kim JS (2022) Comparative analysis of transforaminal endoscopic thoracic discectomy and microscopic discectomy for symptomatic thoracic disc herniation. Neurospine 19:555–562. https://doi.org/10.14245/ns.2244294.147

5. Mayer HM, Brock M (1993) Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. J Neurosurg 78:216–225. https://doi.org/10.3171/jns.1993.78.2.0216

6. Kambin P, Sampson S (1986) Posterolateral percutaneous suction-excision of herniated lumbar intervertebral discs. Report of interim results. Clin Orthop Relat Res 207:37–43

7. Hyun SJ, Kim YB, Kim YS, Park SW, Nam TK, Hong HJ, Kwon JT (2007) Postoperative changes in paraspinal muscle volume: comparison between paramedian interfascial and midline approaches for lumbar fusion. J Korean Med Sci 22:646–651. https://doi.org/10.3346/jkms.2007.22.4.646

8. Gadjradj PS, Harhangi BS (2022) Full-endoscopic transforaminal discectomy versus open microdiscectomy for sciatica: update of a systematic review and meta-analysis. Spine 47:E591-e594. https://doi.org/10.1097/brs.0000000000004421

9. Yagi K, Kishima K, Tezuka F, Morimoto M, Yamashita K, Takata Y, Sakai T, Maeda T, Sairyo K (2022) Advantages of revision transforaminal full-endoscopic spine surgery in patients who have previously undergone posterior spine surgery. J Neurol Surg A Cent Eur Neurosurg. https://doi.org/10.1055/a-1877-0594

10. Hoogland T, van den Brekel-Dijkstra K, Schubert M, Miklitz B (2008) Endoscopic transforaminal discectomy for recurrent lumbar disc herniation: a prospective, cohort evaluation of 262 consecutive cases. Spine 33:973–978. https://doi.org/10.1097/BRS.0b013e31816c8ade

11. Lin G-X, Zhu M-T, Kotheeranurak V, Lyu P, Chen C-M, Hu B-S (2022) Current Status and research hotspots in the field of full endoscopic spine surgery: A bibliometric analysis. Front Surg 9:989513. https://doi.org/10.3389/fsurg.2022.989513

12. Aria M, Cuccurullo C (2017) bibliometrix: An R-tool for comprehensive science mapping analysis. J Informet 11:959–975. https://doi.org/10.1016/j.joi.2017.08.007

13. Chen C (2006) CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Soc Inform Sci Technol 57:359–377. https://doi.org/10.1002/asi.20317

14. van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538. https://doi.org/10.1007/s11192-009-0146-3

15. Norris M, Oppenheim C (2007) Comparing alternatives to the web of science for coverage of the social sciences' literature. J Informetrics 1:161–169. https://doi.org/10.1016/j.joi.2006.12.001

16. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Bmj 372:n71. https://doi.org/10.1136/bmj.n71

17. Bornmann L, Daniel HD (2009) The state of h index research. Is the h index the ideal way to measure research performance? EMBO Rep 10:2–6. https://doi.org/10.1038/embor.2008.233

18. Hsu HT, Chang SJ, Yang SS, Chai CL (2013) Learning curve of full-endoscopic lumbar discectomy. Eur Spine J 22:727–733. https://doi.org/10.1007/s00586-012-2540-4

19. Yeung AT, Tsou PM (2002) Posterolateral endoscopic excision for lumbar disc herniation: Surgical technique, outcome, and complications in 307 consecutive cases. Spine 27:722–731. https://doi.org/10.1097/00007632-200204010-00009

20. Ruetten S, Komp M, Merk H, Godolias G (2008) Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. Spine 33:931–939. https://doi.org/10.1097/BRS.0b013e31816c8af7

21. Ruetten S, Komp M, Godolias G (2005) An extreme lateral access for the surgery of lumbar disc herniations inside the spinal canal using the full-endoscopic uniportal transforaminal approach-technique and prospective results of 463 patients. Spine 30:2570–2578. https://doi.org/10.1097/01.brs.0000186327.21435.cc

22. Choi G, Lee SH, Lokhande P, Kong BJ, Shim CS, Jung B, Kim JS (2008) Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope. Spine 33:E508-515. https://doi.org/10.1097/BRS.0b013e31817bfa1a

23. Ahn Y, Lee SH, Park WM, Lee HY, Shin SW, Kang HY (2004) Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases. Spine 29:E326-332. https://doi.org/10.1097/01.brs.0000134591.32462.98

24. Hoogland T, Schubert M, Miklitz B, Ramirez A (2006) Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases. Spine 31:E890-897. https://doi.org/10.1097/01.brs.0000245955.22358.3a

25. Ruetten S, Komp M, Merk H, Godolias G (2009) Recurrent lumbar disc herniation after conventional discectomy: a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision. J Spinal Disord Tech 22:122–129. https://doi.org/10.1097/BSD.0b013e318175ddb4

26. Choi G, Lee SH, Raiturker PP, Lee S, Chae YS (2006) Percutaneous endoscopic interlaminar discectomy for intracanalicular disc herniations at L5-S1 using a rigid working channel endoscope. Neurosurgery 58:ONS59-68. https://doi.org/10.1227/01.neu.0000192713.95921.4a

27. Liu X, Yuan S, Tian Y, Wang L, Gong L, Zheng Y, Li J (2018) Comparison of percutaneous endoscopic transforaminal discectomy, microendoscopic discectomy, and microdiscectomy for symptomatic lumbar disc herniation: minimum 2-year follow-up results. J Neurosurg Spine 28:317–325. https://doi.org/10.3171/2017.6.Spine172

28. Chen J, Jing X, Li C, Jiang Y, Cheng S, Ma J (2018) Percutaneous endoscopic lumbar discectomy for L5S1 lumbar disc herniation using a transforaminal approach versus an interlaminar approach: a systematic review and meta-analysis. World Neurosurg 116:412-420.e412. https://doi.org/10.1016/j.wneu.2018.05.075

29. Chen Z, Zhang L, Dong J, Xie P, Liu B, Wang Q, Chen R, Feng F, Yang B, Shu T, Li S, Yang Y, He L, Pang M, Rong L (2018) Percutaneous transforaminal endoscopic discectomy compared with microendoscopic discectomy for lumbar disc herniation: 1-year results of an ongoing randomized controlled trial. J Neurosurg Spine 28:300–310. https://doi.org/10.3171/2017.7.Spine161434

30. Kolcun JPG, Brusko GD, Basil GW, Epstein R, Wang MY (2019) Endoscopic transforaminal lumbar interbody fusion without general anesthesia: operative and clinical outcomes in 100 consecutive patients with a minimum 1-year follow-up. Neurosurg Focus 46:E14. https://doi.org/10.3171/2018.12.Focus18701

31. Lee SH, Kang BU, Ahn Y, Choi G, Choi YG, Ahn KU, Shin SW, Kang HY (2006) Operative failure of percutaneous endoscopic lumbar discectomy: a radiologic analysis of 55 cases. Spine 31:E285-290

32. Schubert M, Hoogland T (2005) Endoscopic transforaminal nucleotomy with foraminoplasty for lumbar disk herniation. Oper Orthop Traumatol 17:641–661. https://doi.org/10.1007/s00064-005-1156-9

33. Kerimbayev T, Kenzhegulov Y, Tuigynov Z, Aleinikov V, Urunbayev Y, Makhambetov Y, Pan A, Abishev N, Oshayev M, Baiskhanova D, Solodovnikov M, Akshulakov S (2022) Transforaminal endoscopic discectomy under general and local anesthesia: a single-center study. Front Surg 9:873954. https://doi.org/10.3389/fsurg.2022.873954

34. Ruetten S, Komp M, Merk H, Godolias G (2007) Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach. J Neurosurg-Spine 6:521–530. https://doi.org/10.3171/spi.2007.6.6.521

35. Gadjradj PS, Harhangi BS (2022) Full-endoscopic transforaminal discectomy versus open microdiscectomy for sciatica: update of a systematic review and meta-analysis. Spine 47:E591–E594. https://doi.org/10.1097/brs.0000000000004421

36. Kim J-S, Lokanath Y (2020) Endoscope-assisted oblique lumbar interbody fusion. In: Kim HS, Mayer M, Heo DH, Park CW (eds) Advanced techniques of endoscopic Lumbar Spine Surgery. Springer, Singapore

37. Zhang H, Xu DR, Wang C, Zhu K, Guo JW, Zhao C, Han JL, Liu HC, Ma XX, Zhou CL (2022) Application of electromagnetic navigation in endoscopic transforaminal lumbar interbody fusion: a cohort study. Eur Spine J 31:2597–2606. https://doi.org/10.1007/s00586-022-07280-1

38. Wu J, Ao S, Liu H, Wang W, Zheng W, Li C, Zhang C, Zhou Y (2020) Novel electromagnetic-based navigation for percutaneous transforaminal endoscopic lumbar decompression in patients with lumbar spinal stenosis reduces radiation exposure and enhances surgical efficiency compared to fluoroscopy: a randomized controlled trial. Ann Transl Med 8:1215. https://doi.org/10.21037/atm-20-1877

39. Fan N, Yuan S, Du P, Zhu W, Li L, Hai Y, Ding H, Wang G, Zang L (2020) Design of a robot-assisted system for transforaminal percutaneous endoscopic lumbar surgeries: study protocol. J Orthop Surg Res 15:479. https://doi.org/10.1186/s13018-020-02003-y

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