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Global Research Trends in OSE Technology: A Bibliometric and Visualization Study

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Abstract: *Research on One-hole Split Endoscope (OSE) technology is garnering increasing attention. This study aims to delineate the global landscape and emerging trends within this field. Literature publications on OSE from January 1, 1992, to March 1, 2025, were retrieved from the Web of Science Core Collection's Science Citation Index Expanded. The sourced data were examined and indexed utilizing bibliometric methodologies. For the visualization analysis, VOSviewer software (version 1.6.19) was employed to conduct co-authorship, co-occurrence, bibliographic coupling, and co-citation analyses, thereby elucidating the overarching trends in OSE research in recent years.A total of 819 articles were retrieved. The volume of global OSE research and publications has demonstrated a consistent annual increase. The United States contributed the most significantly to global OSE research, attaining the highest citation counts and the highest h-index. Springer Nature and Elsevier published the highest number of relevant articles. Wooridul Spine Hospital, the University of California System, Seoul National University (SNU), and Seoul St. Mary's Hospital were identified as the four most prolific institutions. Research foci could be categorized into three primary clusters: neurosciences, surgical procedures, and orthopedics. Surgical procedures are projected to be the next prominent hotspot in the field. Based on current global research trends, the number of publications related to OSE is anticipated to continue rising. The United States currently stands as the leading contributor to this domain. The majority of future research efforts are expected to concentrate on clinical studies, particularly OSE surgical techniques, which are likely to represent the next research frontier. The findings of this study provide clinicians and researchers with a comprehensive overview of the global development of OSE technology, its core research entities, and future directions, thereby offering a bibliometric evidence base for tracking technological frontiers, selecting international collaborators, and determining priorities in clinical research.*

Keywords: *One-hole Split Endoscope; Surgical Procedures; Operative; Global Trends; Bibliometrics; Visualization Study*

1. Introduction

Spinal disorders, recognized as one of the most prevalent chronic degenerative conditions contributing to global disability rates, have consistently remained a focal point in the field of orthopedics concerning diagnostic and therapeutic advancements [1]. With the accelerating trend of population aging, the incidence of degenerative spinal pathologies, such as disc herniation and spinal stenosis, has shown a marked increase. While traditional open surgeries demonstrate established efficacy, they are inherently associated with significant limitations, including substantial tissue trauma and prolonged recovery periods [2]. Against this backdrop, One-hole Split Endoscope (OSE) technology, emblematic of the third generation of minimally invasive spine techniques, has emerged. It incorporates an innovative modular instrument design and a single-port operational approach, enabling precise neural decompression and interbody fusion. This methodology ensures therapeutic effectiveness while minimizing iatrogenic injury [3]. Nevertheless, a systematic research landscape for this technique is still lacking, and key issues such as technical standardization and indication criteria remain subjects of ongoing debate.

The OSE technique was initially proposed in 2015 by the Chinese research team led by Tengyue Zhu and was progressively refined, culminating in its formal establishment in 2019. This technique separates the surgical instruments from the endoscope within a single working channel, preserving the minimally invasive nature of single-incision coaxial spinal endoscopy while incorporating the expansive surgical

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field of view characteristic of Biportal Endoscopic Spinal Surgery (UBE). A notable constraint, however, is its reliance on arthroscopy systems for implementation. The modular design of these arthroscopy systems, which integrates the endoscope with an outer sheath, poses significant compatibility challenges in spinal surgery. Primarily, the outer sheath occupies valuable space within the surgical corridor, thereby compromising the endoscope's maneuverability. Secondly, mechanical instability at the endoscope-sheath junction may prolong intraoperative instrument adjustment times and increase the risk of fluid leakage [4]. Finally, residual nucleus pulposus represents one of the notable complications associated with OSE procedures [5]. According to literature reviews, approximately 5-13% of OSE patients require subsequent surgical intervention [6-8].

Therefore, this study aims to conduct a comprehensive assessment of the global research status of OSE technology through bibliometric and visualization analysis, thereby elucidating its developmental trajectory and research hotspots. Bibliometrics, as a quantitative method for analyzing scientific research activity, has been extensively applied to investigate trends across various disciplines [9]. By quantifying and analyzing metrics such as publication volume, citation frequency, research institutions, and author distribution, it can objectively reflect the research vitality and academic impact within a specific field. Concurrently, visualization analysis techniques provide an intuitive representation of research findings, assisting researchers in more clearly identifying focal points and frontier dynamics.

Within this context, the present study retrieved literature on OSE technology published between January 1, 1992, and March 1, 2025, from the Web of Science Core Collection's Science Citation Index Expanded database. Utilizing bibliometric methods and VOSviewer software, a systematic analysis and visual presentation were conducted [10]. This research aims to delineate global trends in OSE technology, analyze major contributing countries, institutions, and individuals, and explore research directions and hotspots, thereby providing a reference and foundation for future investigations in this field.

2. Materials and Methods

2.1 Data Source

The data for this bibliometric analysis were sourced from the Web of Science -Science Citation Index Expanded(WOS), which is widely regarded as a premier database for such studies due to its rigorous journal selection and comprehensive citation data [11].

2.2 Search Strategy

The search strategy was constructed using the following query: Topic = (Open Spine Endoscope OR Oblique Spinal Endoscopic OR Open Spine Endoscopic OR Oblique Spinal Endoscope) AND Publication Year = (1992-01-01 to 2025-03-01) AND Language = (English) AND Document Type = (Article).

2.3 Data Collection

Complete records and cited references from the Web of Science database were downloaded and analyzed. The comprehensive dataset, including titles, publication years, author names, countries, source journals, affiliations, keywords, and abstracts, was imported into Microsoft Office 2016. Two investigators (H.F.Z. and W.T.) independently screened and extracted the literature data to ensure accuracy. Data management and initial analysis were performed using Microsoft Office 2016 and GraphPad Prism 9.

2.4 Bibliometric Analysis

Bibliometric analysis has emerged as a pivotal methodology for global analysis and investigation across diverse scientific disciplines, employing mathematical and statistical approaches to analyze large volumes of literature and identify research trends [12]. The analytical functions provided by the Web of Science platform were utilized to characterize the fundamental attributes of the included publications [13].

The h-index, serving as a robust alternative to existing metrics, represents a well-established method for quantifying the impact of scientific research. An h-index of h indicates that a scientist or country has published h papers, each of which has been cited at least h times [14].

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A logistic growth model, expressed as f(x)=a/(1+eb-cx), was employed due to its demonstrated reliability in modeling saturation dynamics and its capability for forecasting future trends [15]. The temporal evolution of publication counts was graphically represented using GraphPad Prism 9 [16]. In this model:1.f(x): Represents the dependent variable, typically the predicted cumulative number of publications or another metric of growth.2.x: Denotes the independent variable, which in this study corresponds to the publication year, serving as the temporal axis.3.a: Signifies the growth ceiling or the maximum value that f(x) approaches as x tends toward infinity, representing the theoretical saturation point for publication volume.4.b and c: These are model parameters that determine the shape and position of the sigmoidal curve. Their values were derived through fitting the model to the historical data to accurately capture the observed growth trajectory. Key metrics, including the annual publication count, the top 20 contributing countries globally, leading authors, institutions, funding agencies, research areas, total citation frequencies, source journals, average citation rates, and h-indices, were examined using Microsoft office mondo 2016 [17].For the visualization of publication networks, VOSviewer software was utilized. This tool was applied to perform analyses of bibliographic coupling, co-citation, co-occurrence, and co-authorship, thereby mapping the intellectual structure and collaborative patterns within the research landscape [18].

3. Results

3.1 Global Publication Trends

3.1.1 Volume of Global Publications

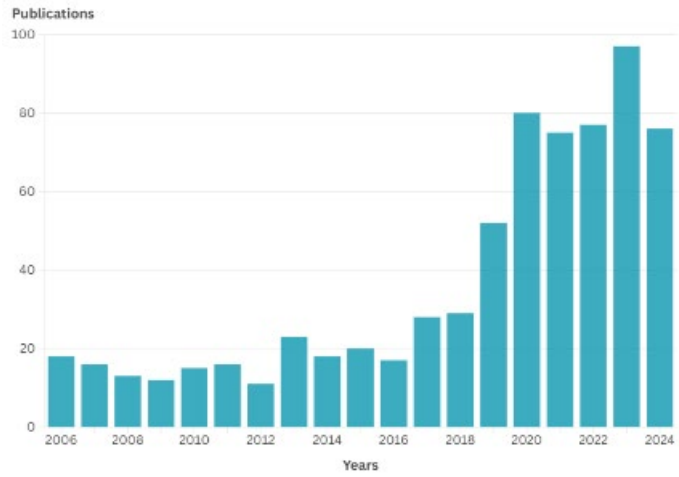
A total of 819 articles met the search criteria for the period from January 1, 1992, to March 1, 2025. Analysis of the annual publication output indicates that the majority of these studies (415 articles, 50.67%) were published between 2020 and 2025. Examination of the temporal trend from 2006 to 2024 reveals a marked and consistent increase in the annual number of global publications concerning OSE technology. Furthermore, the relative research interest in this field has demonstrated a distinct upward trajectory in recent years (Figure 1a).

3.1.2 Contributions by Country

A total of 63 countries and regions contributed to this research domain. Among these, the United States emerged as the most prolific contributor, publishing 267 articles (32.60%), followed by China with 160 publications (19.54%), South Korea with 147 (17.95%), Germany with 84 (10.26%), and Italy with 40 (4.88%) (Figure 1b, c).

3.1.3 Global Publication Trends

A logistic growth model was applied to the temporal profile of publication volume to project future trajectories. Figure 1d presents the resulting model fitting curve, demonstrating the projected growth trend in the global number of publications in the forthcoming years [19].



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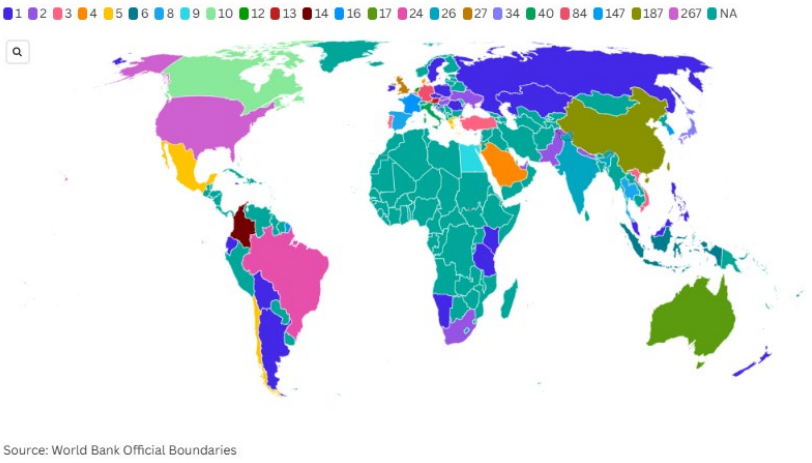

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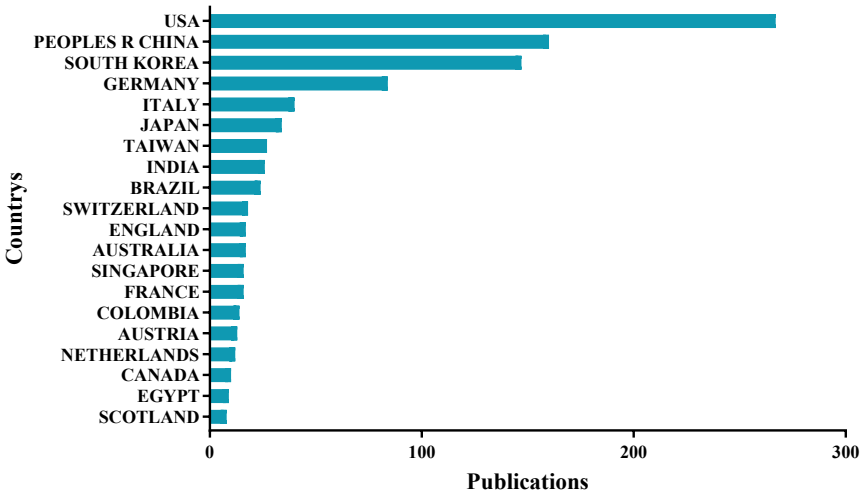

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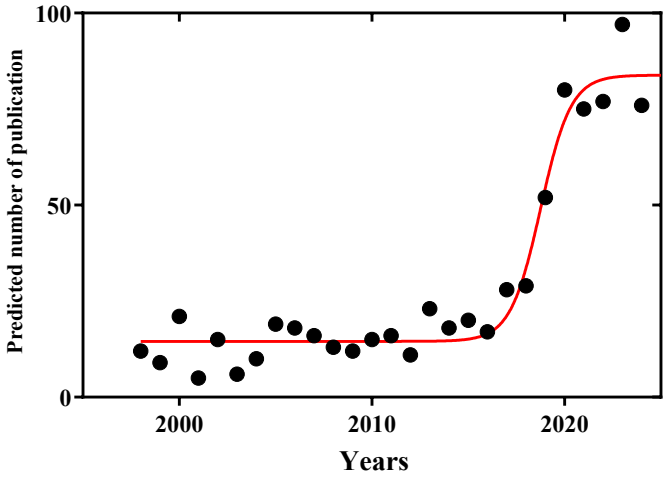

(d)

(a) Cumulative publication output and relative research interest in OSE. (b) World distribution map of OSE-related publications. (c) Total number of OSE-associated publications from the top 20 contributing countries. (d) Fitted curve projecting the growth trend in global publication volume over the coming years.

Figure 1: Global publication trends in OSE and related research.

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3.2 Publication Quality by Country

3.2.1 Total Citation Frequency

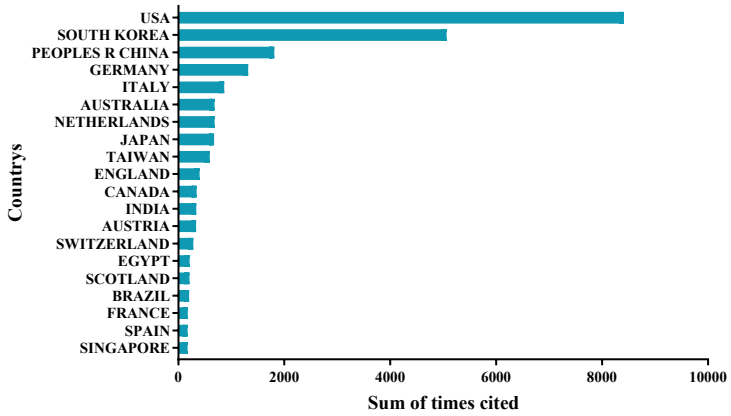
An analysis of total citation frequencies reveals distinct national contributions to the field's scholarly impact. Publications from the United States garnered the highest aggregate citation count (8,412), underscoring their substantial influence. South Korea ranked second in total citation frequency (5,063), followed by China (1,810) (Figure 2a).

3.2.2 Average Citation Frequency

Analysis of average citation rates per article revealed distinct patterns of scholarly impact. Publications from the Netherlands demonstrated the highest average citation frequency (56.92 citations per article). Australia ranked second in this metric (40.24 citations per article), followed by South Korea (34.68 citations per article), Canada (34.50 citations per article), and the United States (31.98 citations per article) (Figure 2b).

3.2.3 h-index

The United States achieved the highest h-index (53), followed by South Korea (40), China (20), Germany (20), and Italy (16) (Figure 2c).



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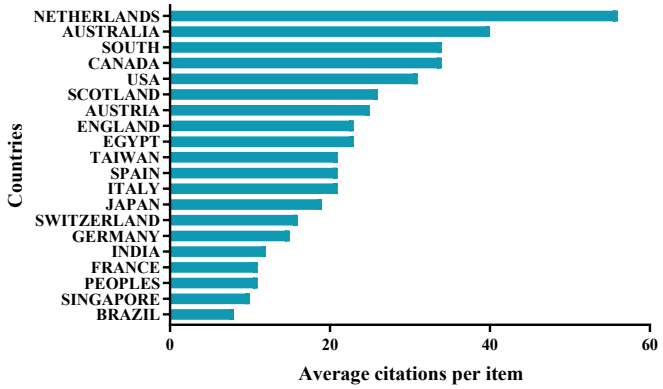

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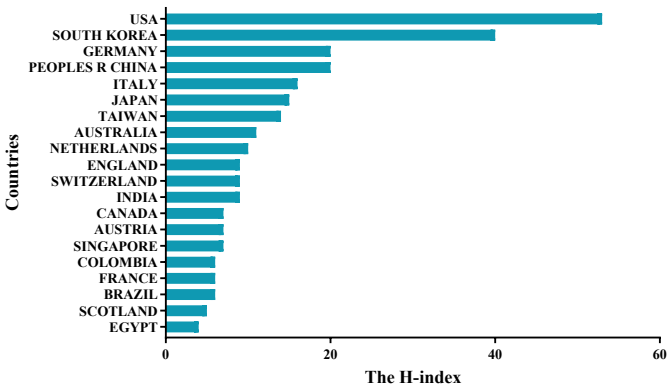

(c)

(a) Total citation frequency of country-specific publications. (b) Average citation frequency per publication by country. (c) h-index of national publication outputs.

Figure 2: Publication quality metrics by country in OSE and related research.

3.3 Global Publication Assessment

3.3.1 Journal Analysis

The top 5 journals publishing OSE-related research were Spine (64 articles), World Neurosurgery (60 articles), European Spine Journal (53 articles), Journal of Neurosurgery: Spine (32 articles), and Pain Physician (26 articles). The 20 journals with the highest number of publications are presented in Figure 3a.

3.3.2 Funding Sources

Figure 3b delineates the leading funding sources supporting OSE research. The National Natural Science Foundation of China (NSFC) funded 26 studies, ranking first, while the Wooridul Spine Foundation supported 10 studies, securing the second position.

3.3.3 Authors

The top 20 authors published a total of 277 articles, accounting for 33.82% of all publications in this field (Figure 3c). Kim, J.S. published 24 articles in the field of OSE technology, Kim, H.S. published 23, and Ahn, Y. followed with 22 articles related to OSE technology.

3.3.4 Publishing Institutions

The top 20 most productive institutions collectively contributed 338 publications, accounting for 41.27% of all articles in this field (Figure 3d). Wooridul Spine Hospital and the University of California System published 33 and 23 articles, respectively.

3.3.5 Research Areas

The distribution of research domains associated with OSE is presented in Figure 3e. Neurosciences, Surgery, Orthopedics, General Internal Medicine, and Anesthesiology represented the predominant research areas, accounting for the highest proportion of publications.

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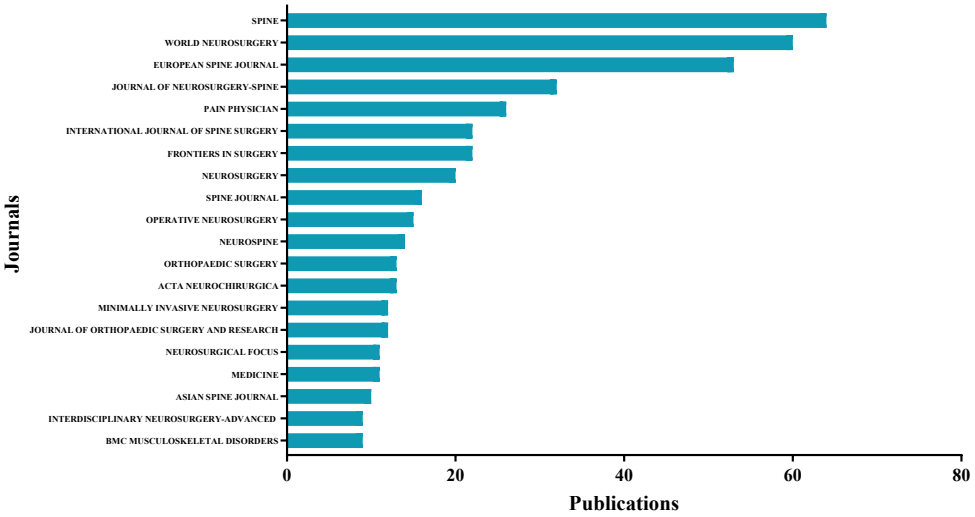

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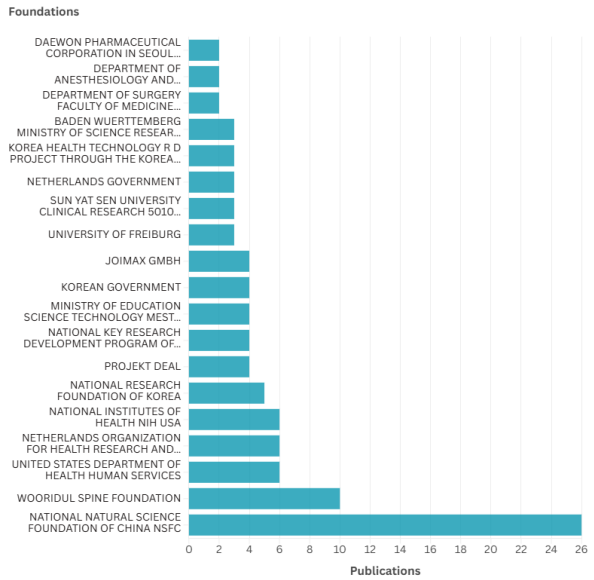

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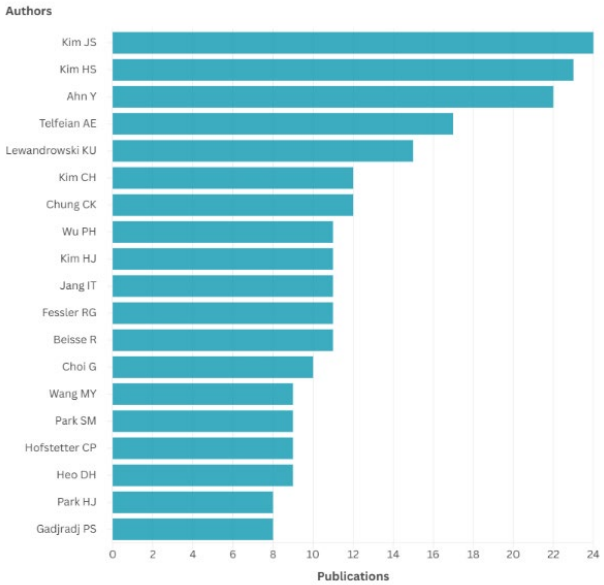

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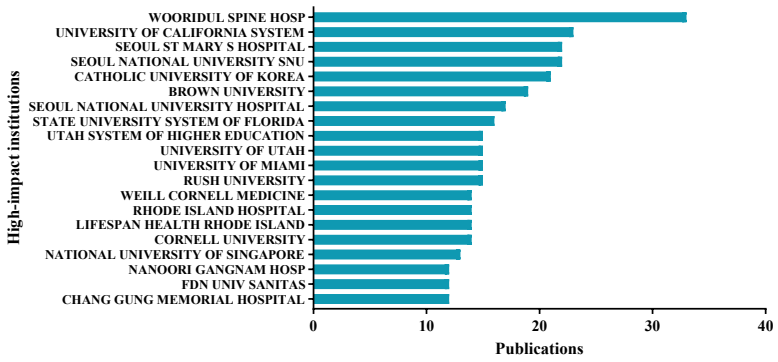

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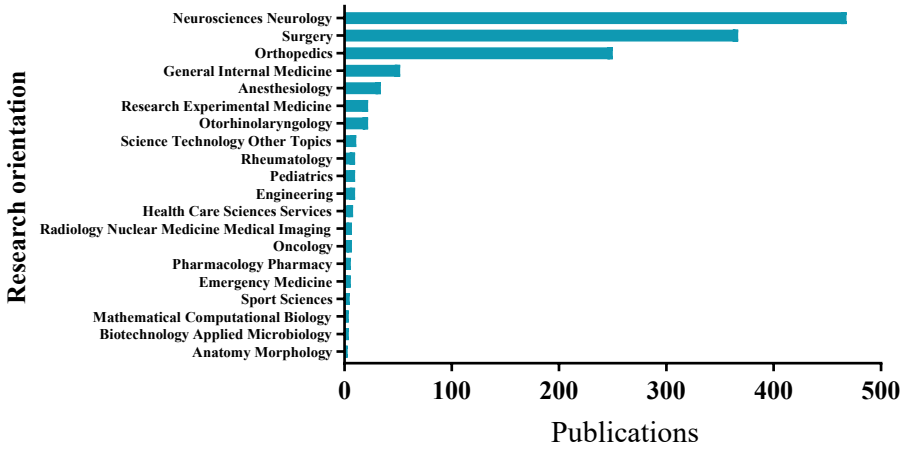

(e)

(a) Publication output of the top 20 journals. (b) Number of publications supported by the top 20 funding sources. (c) Number of publications by the top 20 authors. (d) Number of publications from the top 20 institutions. (e) Distribution of the top 20 research areas.

Figure 3: Global publication assessment of OSE-related research.

3.4 Bibliographic Coupling Analysis

3.4.1 Journals

A bibliographic coupling analysis of journals was performed using VOSviewer, setting the minimum number of documents per journal at five. Of the analyzed sources, thirty-five journals met the threshold. The five journals with the highest Total Link Strength were as follows: *World Neurosurgery* (Total Link Strength = 8,814), *Spine* (Total Link Strength = 6,994), *European Spine Journal* (Total Link Strength = 6,941), *Pain Physician* (Total Link Strength = 5,574), and *International Journal of Spine Surgery* (Total Link Strength = 5,291).

3.4.2 Countries

A VOS analysis was conducted on articles from 26 countries, applying a minimum threshold of five articles per country (Figure 4b). The top five countries ranked by Total Link Strength were as follows: the United States (Total Link Strength = 54,646), South Korea (Total Link Strength = 42,958), China (Total Link Strength = 32,537), Germany (Total Link Strength = 25,404), and Brazil (Total Link Strength = 14,459).

3.4.3 Institutions

An analysis was performed on institutional publications from 68 organizations meeting the minimum threshold of three documents per institution using VOSviewer (Figure 4c). The top five institutions, ranked by Total Link Strength, were as follows: Wooridul Spine Hospital (Total Link Strength = 10,222), Fachhochschule für Diagnostik und Nachhaltigkeit Universität Sanitas (Total Link Strength = 8,473), Surgical Institute of Tucson (Total Link Strength = 7,933), The University of Seoul (Total Link Strength

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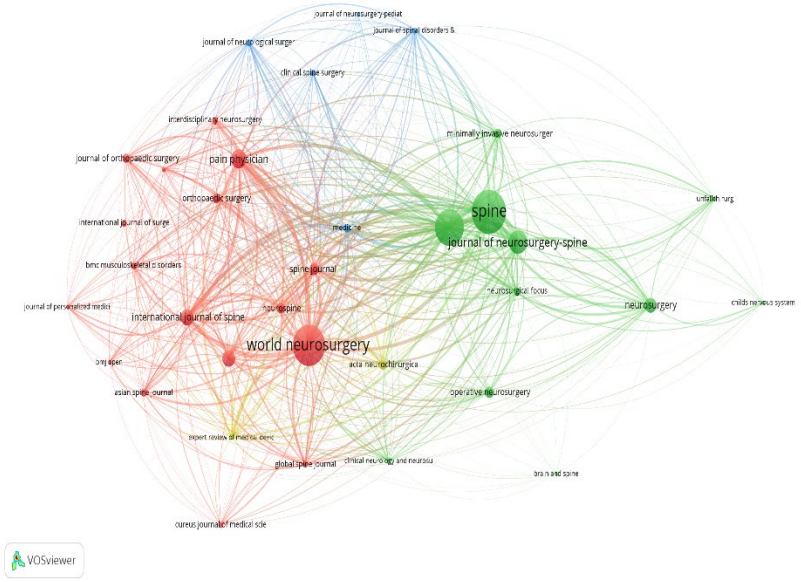
= 7,783), and Brown University (Total Link Strength = 6,894).



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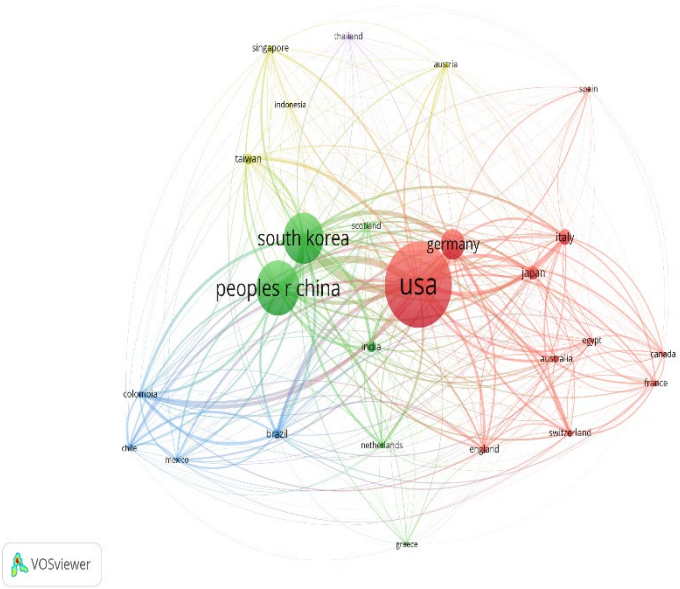

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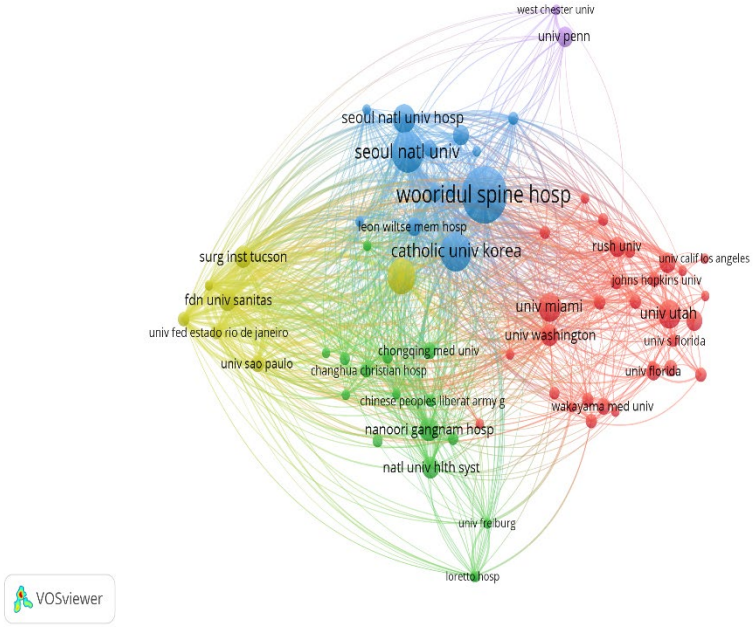

(c)

(a) Network visualization of 35 journals based on bibliographic coupling. (b) Network visualization of 26 countries based on bibliographic coupling. (c) Network visualization of 68 institutions based on bibliographic coupling.

Figure 4. Bibliographic coupling analysis of OSE-related research.

3.5 Co-authorship Analysis

3.5.1 Authors

Co-authorship analysis was conducted to elucidate collaborative relationships among researchers, based on their co-authored publications. An analysis of 132 authors who met the minimum threshold of five documents each was performed using VOSviewer software (Figure 5a). The following five authors exhibited the highest Total Link Strength: Telfeian, Albert E. (Total Link Strength = 69), Yoshida, Munehito (Total Link Strength = 65), Minamide, Akihito (Total Link Strength = 64), Iyamada, Hiroshi (Total Link Strength = 64), and Iwasaki, Hiroshi (Total Link Strength = 62).

3.5.2 Institutions

A co-authorship analysis was performed on 68 institutions meeting the minimum threshold of five publications each, utilizing VOSviewer software (Figure 5b). The top five institutions ranked by Total Link Strength were as follows: Fachhochschule für Diagnostik und Nachhaltigkeit Universität Sanitas (Total Link Strength = 61), Brown University (Total Link Strength = 60), Surgical Institute of Tucson (Total Link Strength = 50), The University of Utah (Total Link Strength = 46), and The University of Seoul (Total Link Strength = 44).

3.5.3 Countries

Co-authorship analysis at the national level was conducted using VOSviewer, encompassing publications from 26 countries that met the minimum threshold of five documents per country (Figure 5c). The five countries demonstrating the highest Total Link Strength were as follows: the United States (Total Link Strength = 159), Germany (Total Link Strength = 95), Brazil (Total Link Strength = 59), Colombia (Total Link Strength = 47), and Italy (Total Link Strength = 42).

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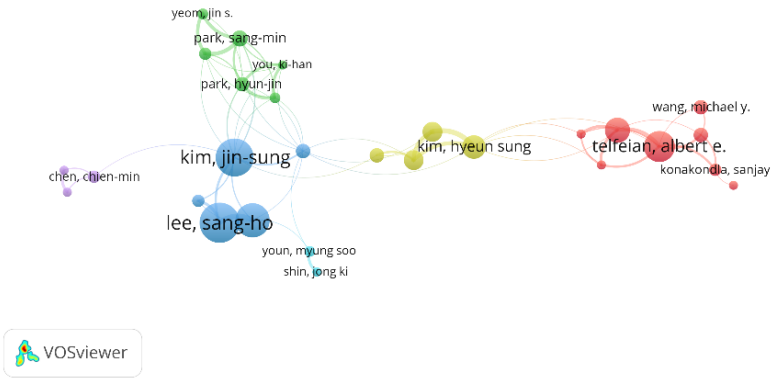

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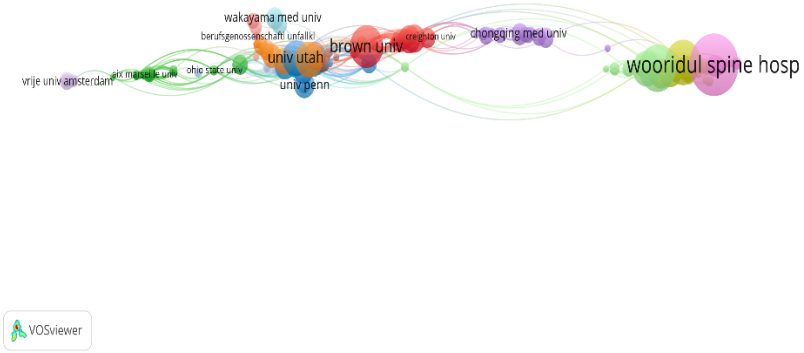

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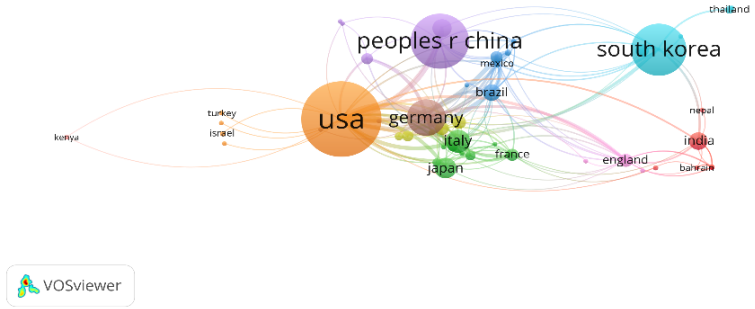

(c)

(a) Co-authorship network of 132 authors in OSE research. (b) Collaboration mapping among 68 institutions in OSE research. (c) Collaborative network of 26 countries in OSE research.

Figure 5: Co-authorship analysis of OSE research.

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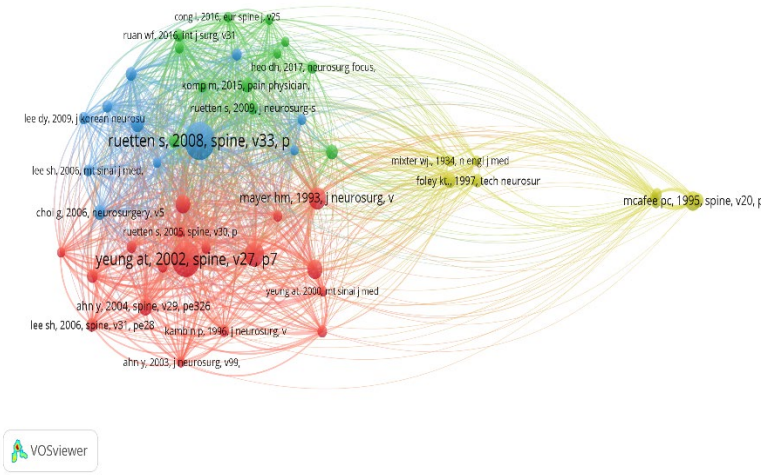
3.6 Co-citation Analysis

3.6.1 Cited References

In co-citation analysis, the strength of association between items is determined by the frequency with which they are cited together within the same reference lists. VOSviewer was employed to analyze 50 cited references that met the minimum threshold of 20 citations each (Figure 6a). The following five references demonstrated the highest total link strength:1.Ruetten S, 2008, *Spine*, V33, P931, DOI 10.1097/BRS.0b013e31816c8af7 2.Yeung AT, 2002, *Spine*, V27, P722, DOI 10.1097/00007632-200204010-00009 3.Hermantin FU, 1999, *J Bone Joint Surg Am*, V81A, P958, DOI 10.2106/00004623-199907000-00008 4.Mayer HM, 1993, *J Neurosurg*, V78, P216, DOI 10.3171/jns.1993.78.2.0216 5.Hoogland T, 2006, *Spine*, V31, PE890, DOI 10.1097/01.brs.0000245955.22358.3a

3.6.2 Journals

A co-citation analysis of journal sources was performed using VOSviewer, employing a minimum threshold of 20 co-citations per journal. As shown in Figure 6b, 118 journals were identified and met this criterion. The five journals demonstrating the highest Total Link Strength were as follows: *Spine* (Total Link Strength = 92,506), *European Spine Journal* (Total Link Strength = 43,999), *Neurosurgery* (Total Link Strength = 42,583), *World Neurosurgery* (Total Link Strength = 42,512), and *Journal of Neurosurgery: Spine* (Total Link Strength = 36,517).



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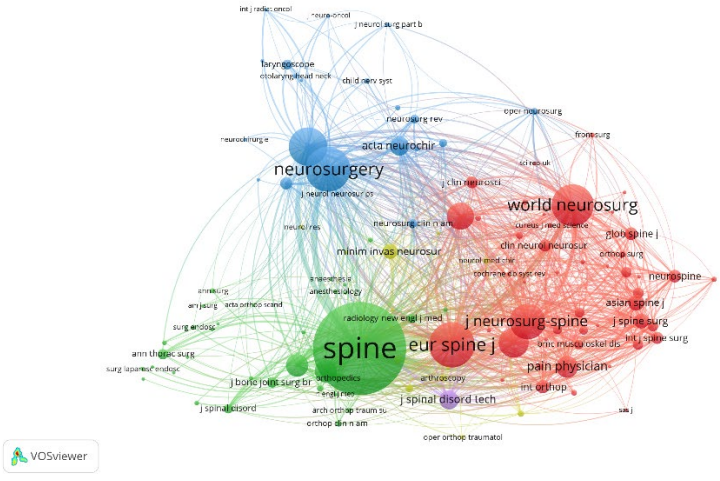

(b)

(a) Network visualization of co-cited references. (b) Network visualization of co-cited journals.

Figure 6: Co-citation networks in OSE research.

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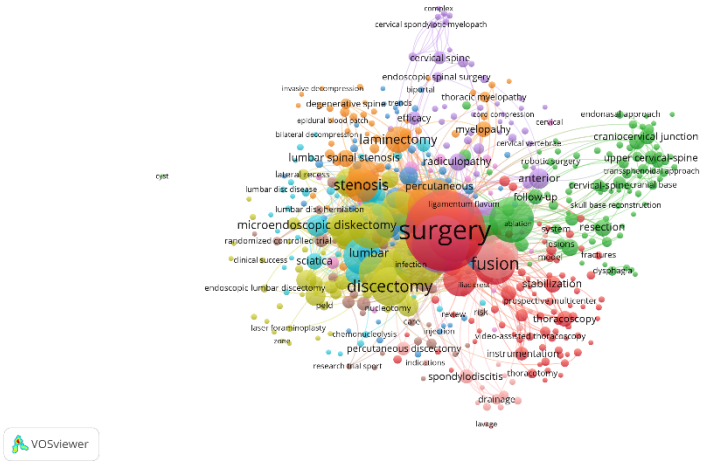

Figure 7: Co-occurrence analysis of OSE research.

3.7 Co-occurrence Analysis

Co-occurrence analysis was conducted to identify research directions and prevailing topics within the field, with keywords occurring more than 10 times considered significant for mapping the scientific landscape. As depicted in Figure 7, 100 identified keywords were categorized into three distinct clusters, broadly defined as: "Spinal Surgery and Treatment," "Spinal Disorders and Diagnosis," and "Technological Innovation." The "Spinal Surgery and Treatment" cluster comprised frequently used keywords including: surgery, spine, minimally invasive spine surgery, discectomy, fusion, endoscopy, lumbar disc herniation, and spinal stenosis. The "Spinal Disorders and Diagnosis" cluster featured principal keywords such as: spine, intervertebral disc displacement, low back pain, lumbar vertebrae, sciatica, spondylolisthesis, myelopathy, and diagnosis. Meanwhile, the "Technological Innovation" cluster was characterized by major keywords including: endoscopy, minimally invasive, endoscopic spine surgery, foramen, unilateral biportal endoscopy, robot-assisted surgery, and augmented reality. These results demonstrate that the most prominent research domains in OSE technology encompass the three aforementioned thematic directions.

4. Discussion

4.1 Global Publication Status and Quality

Analysis of research trends through bibliometric and visualization techniques applied to OSE-related literature serves to elucidate the current progression within this scientific domain and enables projections regarding its future trajectory [20]. Consequently, this study was designed to systematically evaluate the contributing nations, institutions, funding agencies, and research priorities characterizing OSE research [21].

Recent advancements in the therapeutic applications of OSE represent a dynamic and rapidly evolving field of scientific inquiry. As demonstrated by the present analysis, the annual number of publications exhibits a marked and consistent increase. Furthermore, scholarly interest in OSE has intensified substantially over the past several years, with contributions identified from 63 countries. Based on the current data and observed trends, a continued escalation in publication output is projected, foreseeing the emergence of more studies yielding profound insights into OSE. These encouraging developments are expected, in turn, to establish a robust foundation for subsequent high-quality investigations.

4.2 Research Trends in OSE

Analysis of national contributions reveals that the United States demonstrates notable prominence in OSE research, producing the highest volume of publications. While China ranks second in quantitative output, the qualitative impact of its research requires further enhancement. The observed disparity in research quality between these nations may be attributed to multifaceted factors. The American research

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ecosystem emphasizes innovation and long-term impact, benefits from extensive international collaborations, and leverages accumulated expertise within research teams, thereby facilitating the generation of high-quality, influential clinical studies. Conversely, China's academic evaluation system has historically prioritized quantitative output over qualitative impact, resulting in a concentration of studies focusing on technical descriptions, short-term efficacy validation, and learning curve analyses, with comparatively less emphasis on long-term outcomes, technical optimization, and mechanistic investigations. However, ongoing increases in research funding and evolving research cultures in China are anticipated to substantially elevate the quality of scientific publications. The National Natural Science Foundation of China (NSFC) has emerged as the leading funding agency in this domain. In terms of publication output supported by funding sources, the NSFC and the Wooridul Spine Foundation rank first and second, respectively. The United States has made the most substantial contribution to OSE research in terms of total publications, total citation frequency, and h-index, solidifying its global recognition as a pioneer and leader in this field. As previously discussed, differences in research environments and developmental stages between the two nations constitute significant contributors to these observed disparities. The historical orientation of China's academic assessment framework has sometimes encouraged researchers to prioritize submission quantity over methodological rigor. Nevertheless, the expanding research funding landscape in China, spearheaded by the NSFC, is expected to progressively bridge this qualitative gap and align the country's research output with global standards in the field.

Bibliographic coupling arises when two publications share references to a common third work [22]. In this study, we established similarity linkages among different articles through bibliographic coupling analysis conducted from three perspectives: journals, institutions, and countries. The core journals central to OSE research include *Spine*, *World Neurosurgery*, *European Spine Journal*, *Journal of Neurosurgery: Spine*, and *Pain Physician*. These periodicals demonstrate a higher propensity for disseminating cutting-edge research advancements in this domain. Furthermore, *Spine* and *World Neurosurgery*, being among the most prolific publishers in this field, position themselves at the forefront of international OSE investigation.

Wooridul Spine Hospital attained the highest total link strength, establishing itself as a leading institution in OSE research. Notably, nearly all top 20 contributing institutions originate from the top five contributing nations, underscoring the indispensable role of establishing elite research institutions in enhancing a country's academic standing.

As illustrated in Figure 3d, Telfeian, Albert E. and Yoshida, Munehito emerge as particularly influential contributors whose ongoing research and future publications warrant close monitoring for the latest developments in OSE. Co-authored publications significantly advance scientific progress by fostering research innovation, facilitating knowledge sharing, and enhancing study quality. Co-authorship analysis effectively evaluates collaborative patterns among countries, institutions, and authors, where higher total link strength indicates stronger collaborative propensity. For instance, researchers like Telfeian, Albert E. and Yoshida, Munehito, institutions such as Wooridul Spine Hospital, and nations including the United States represent optimal candidates for scientific collaboration. Co-citation analysis serves to determine research impact based on citation frequency. Our findings reveal that seminal OSE studies exhibit high total citation frequencies and provide substantial meaningful references, thereby offering valuable guidance for understanding future research directions and driving scientific progress. As established in our analysis, *Spine* and *European Spine Journal* represent the most extensively co-cited sources on this topic.

4.3 Research Foci in OSE

We employed co-occurrence analysis to delineate the research directions and identify prevalent topics within this domain [23]. A co-occurrence network was constructed utilizing terms extracted from article titles and abstracts. As presented in Figure 7a, three primary research directions were identified: "Spinal Surgery and Treatment," "Spinal Disorders and Diagnosis," and "Technological Frontiers." These findings provide valuable insights for clarifying future research trajectories.

Keywords such as "minimally invasive spine surgery," "spine," and "surgical procedures" demonstrated particularly high prevalence and occupied central positions within the co-occurrence network. Consequently, further high-quality investigations focusing on OSE remain imperative, with these three identified directions serving as critical guiding frameworks. Based on our analytical findings, minimally invasive spinal surgery is projected to emerge as the next research hotspot in this field. Therefore, clinical studies concerning OSE applications are anticipated to constitute a primary focus of

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future scientific endeavors.

4.4 Strengths and Limitations

Although this study provides a systematic evaluation of the current research status and emerging trends in One-hole Split Endoscope (OSE) technology through comprehensive visualization analysis, it is imperative to acknowledge several limitations. The analysis was exclusively based on English-language literature retrieved from the Web of Science database. Consequently, non-English publications were not included, potentially introducing a language bias. Furthermore, a potential disconnect may exist between the research landscape depicted by bibliometric data and the actual clinical reality. For instance, real-world clinical application of OSE technology involves considerable patient diversity, varying hospital resources, specific procedural details, and heterogeneous postoperative recovery trajectories. Moreover, non-academic factors—such as healthcare policies, economic considerations, patient preferences, and regional disparities—significantly influence its adoption and implementation, yet these are often inadequately reflected in academic publications.

While our findings indicate that the United States leads in publication output, identify key journals, and highlight emerging research hotspots, this study has inherent constraints. Its reliance on a specific database and English-only sources may result in an incomplete assessment and exhibit temporal lag, failing to fully capture non-English scientific contributions or the most recent clinical advancements. Therefore, it remains essential for the research community to actively monitor emerging clinical evidence and relevant non-English studies in daily scientific practice to further refine and enhance the understanding of OSE technology.

5. Conclusion

This bibliometric investigation delineates the global research landscape of One-hole Split Endoscope (OSE) technology. The United States emerges as the most prolific contributor, maintaining a preeminent position in this field [24]. *Spine* stands as the journal publishing the highest number of OSE-related articles [25]. It is projected that research output concerning OSE technology will continue to escalate in the forthcoming years. Furthermore, clinical investigations focusing on OSE applications are anticipated to garner substantial attention and emerge as the next prominent research frontier in this domain.

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