Global research trends in lumbar lateral interbody fusion (LLIF): a bibliometric and visualization study

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Abstract: Lateral Lumbar Interbody Fusion (LLIF) surgery has received increasing attention in research. This study investigates the global status and trends in this field. LLIF literature publications from January 1, 1900, to August 1, 2023, were identified from the Web of Science - Science Citation Index Expanded database. Bibliometric methods were used for studying and indexing the source data. VOSviewer version 1.6.19 software was used for co-authorship, co-occurrence analysis, bibliographic coupling, and co-citation analysis of LLIF studies to analyze the overall trend of LLIF research in recent years. A total of 1808 articles were identified. The number of global research and publications on LLIF is increasing every year. The United States is the leading contributor to global LLIF research, with the most citations and the highest h-index. Spine and World Neurosurgery have the highest number of publications. The top four institutions with the greatest contribution are the Hospital for Special Surgery, University of California, San Francisco, St Joseph Hospital, and Rush University. The research can be categorized into three areas: complications, vertebral fusion, and surgical procedures. Postoperative complications are predicted to be the upcoming focus in this field. The number of LLIF-related publications is predicted to continue increasing based on current global research trends. Currently, the United States is the leading contributor in this field of research. Most research will focus on clinical studies, particularly postoperative complications in LLIF, which may emerge as the next significant area of study in the LLIF research field.

Keywords: Lateral lumbar interbody fusion; Treatment; Global trends; Bibliometrics; Visualization study

1. Introduction

LLIF is more prevalent among elderly Asian men [1]. Various diseases are associated with LLIF, such as diffuse idiopathic hyperostosis, ankylosing spondylitis, and other spinal disorders [2]. Several factors have been reported to be involved in the formation and progression of LLIF, including genetic factors, hormone levels, environmental factors, and lifestyle [3]. However, the specific pathogenesis of LLIF remains unclear. Most patients with symptomatic LLIF present with neurological dysfunction, such as the corresponding symptoms caused by spinal cord or nerve root lesions [4]. Clinically, plain X-ray, CT and MR Imaging are used to comprehensively evaluate LLIF extension length and spinal cord compression area. At present, the treatment of LLIF is still controversial. Each operation has its advantages and disadvantages, and the specific treatment plan should be determined based on the patient's condition, the type of LLIF, and the surgeon's experience [5].

However, the global development trend of LLIF has not been fully studied [6]. Therefore, it is necessary to summarize the current state of LLIF research and predict emerging keywords and trends [7]. As the core part of scientific research, publication is an important indicator to measure research contribution. Bibliometric analysis can provide information based on literature databases and bibliometric characteristics for qualitative and quantitative assessment of the changing trends in research

activities over time [8]. It provides a way to grasp developments in a field and compare the contributions of scholars, journals, institutions, and countries. Bibliometric analysis has also been used to develop policy and clinical practice guidelines [9]. Moreover, this approach has successfully assessed research trends in various areas, including osteoarthritis, hypertension, diabetes, and injury; however, to our knowledge, the quantity and quality of research in the LLIF area have not been reported [10]. Therefore, the objective of this study was to evaluate the current research status and global trends in LLIF treatment [11].

2. Materials and methods

2.1 Data Sources

Bibliometric analysis in this study was conducted using the Web of Science - Science Citation Index Expanded (WOS), which is widely regarded as the best database for bibliometric analysis [12].

2.2 Search Strategy

The search terms used in this study were as follows: subject = (Lumbar lateral interbody fusion), year of publication = (1900-01-2023-08-01), language = (English), and literature type = (paper).

2.3 Data Collection

The full details (including title, year of publication, author name, country, publication journal name, affiliation, keywords, and abstracts) were extracted and analyzed from the WOS database and uploaded to Microsoft office mondo 2016. The two authors (LHV and WWW) independently performed the filtering and extraction process. Data were manually cleaned and analyzed using Microsoft Office Mondo 2016 and GraphPad Prism 9.

2.4 Bibliometric analysis

Bibliometric analysis has emerged as a vital tool for comprehensive analysis and exploration in diverse scientific domains. It uses mathematical and statistical techniques to analyze numerous literature and research trends [13]. The WOS function has been employed to delineate the fundamental attributes of the aforementioned eligible articles [14]. The h-index, serving as an alternative to conventional metrics, is considered the most effective method for quantifying the influence of scientific research. It indicates that a scientist or country has published h articles that received at least h citations from other publications [15]. The logistic growth model, represented as $f(x) = a/(1+e^{b-cx})$, demonstrates reliable applicability and predictive capabilities in envisaging future trends [16]. Generate a graphical representation depicting the temporal evolution of publication volumes utilizing GraphPadprism9 [17]. The independent variable x represents the year, while the dependent variable $f(x)$ captures the accumulated number of publications. Microsoft office mondo 2016 was employed to analyze the number of yearly publications, the top 20 countries worldwide, authors, institutions, funding agencies, research directions, total citation frequency, journals, average citation frequency, and h-index. [18]. VOSviewer software (VOS) is a suitable tool for visualizing publications and has been widely employed in bibliographic coupling, co-citation analysis, co-occurrence analysis, and co-analysis [19].

3. Results

3.1 Global trends in publications

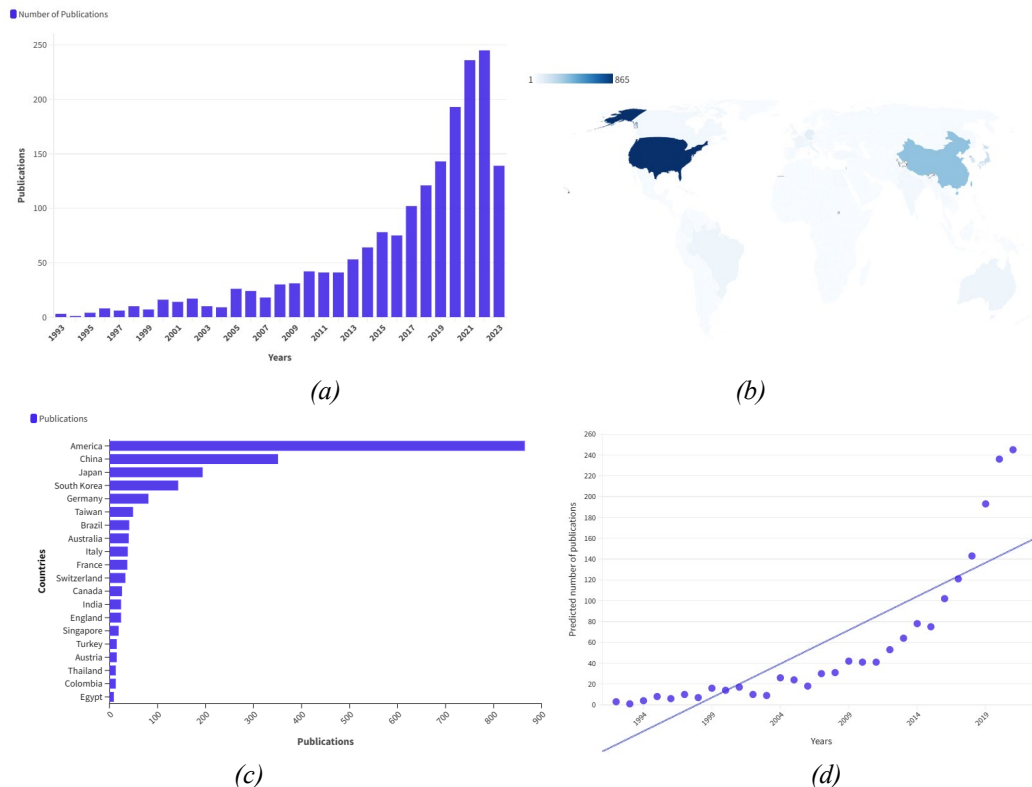#### 3.1.1 Total number of publications worldwide

An analysis was conducted on the global number of publications from January 1, 1900, to August 1, 2023, and it was found that a total of 1808 articles met the search criteria. The majority of studies (1179, 65.21%) were published between 2017 and 2023, focusing on the yearly publication count. There is an evident increasing trend in the number of publications worldwide each year, observed from 1900 to 2023. Furthermore, there has been a recent surge in research interest in the current trend within the field (Figure 1 a).

3.1.2 Contributions of countries

A total of 61 countries and regions were included in this study. Among these, the United States had the highest number of published articles (865 articles, 47.843%), followed by China (351 articles, 19.414%), Japan (194 articles, 9.071%), South Korea (143 articles, 7.901%), and Germany (81 articles, 4.480%) (Figure 1b, c).

3.1.3 Global publication trends

The global publication trends were analyzed using a logistic regression model, which was employed to construct a time curve that allows for the prediction of future trends. (Figure 1d) displays the curve fitted by the model, showing the projected growth in the number of global publications for upcoming years [20].

(a)   *(b)*

(c)   *(d)*

(a) Total number of publications on LLIF and related research interests (b) World distribution map on LLIF and related research (c) Total number of LLIF-related publications in the top 20 countries (d) Fitted curves predicting global growth trends in the number of publications in the coming years

Figure 1: Global trends in publications on LLIF and related research

3.2 Quality of publications in different countries

3.2.1 Total frequency of reference

Among publications from different countries, the United States had the highest total citation frequency of 19,353. China ranked second in total citation frequency with 2,491, followed by South Korea (2,373), Germany (2,296), and Japan (2,292) (Figure 2a).

3.2.2 Average frequency of reference

Average citation frequency German publications had the highest average citation frequency (28.35). Greece ranked second in mean citation frequency (27.50), followed by Australia (26.35), Switzerland (22.94), and Taiwan (22.71) (Figure 2b).

3.2.3 H index

The United States had the highest h-index (68), followed by South Korea (29), China (24), Japan (24), and Germany (24) (Figure 2c).
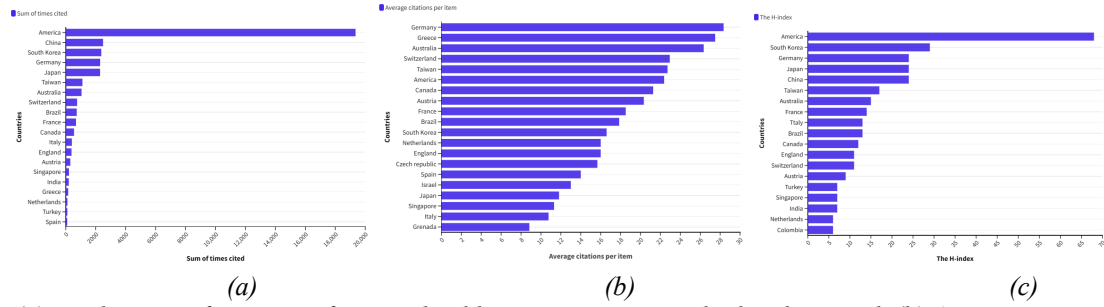
(a) Total citation frequency of national publications on LLIF and related research (b) Average citation frequency of national publications on LLIF and related research (c) h-index of national publications on LLIF and related research

Figure 2: Publication quality by countries

3.3 Assessments of publications around the world

3.3.1 Journals analysis

The journal ranked first in publishing about the LLIF study is the Journal of Spine, with an impact factor (IF) of 2.902 and 182 published papers. World Neurosurgery published 165 articles (IF = 1.834), while the European Spine Journal published 141 articles (IF = 2.708). The Journal of Neurosurgery-Spine published 134 articles (IF = 2.740) related to LLIF studies. (Figure 3a) shows the top 20 journals with the highest number of published research articles.

3.3.2 Fundings agencies

(Figure 3b) illustrates the initial 20 funding sources. The National Natural Science Foundation of China (NSFC) funded 78 studies, ranking first, while Medtronic funded 32 studies, ranking second.

3.3.3 Authors

Among the top 20 authors in this field, one author has published 527 articles, accounting for 29.15% of all publications (Figure 3c). Mr. Juan Uribe leads the list with 65 articles on LLIF. Following him, Kanter and Adams have published 34 articles, while Hughes, Alexander P., and Chou, Dean have published 32 and 31 articles respectively on LLIF.

3.3.4 High-impact institutions

The top 20 institutions accounted for a total of 626 published articles, which represents 34.62% of all articles in this field (Figure 3d). Specifically, the Hospital for Special Surgery published 65 articles, while the University of California, San Francisco published 55 articles.

3.3.5 Research orientation

The orientation distribution of LLIF-related research is shown in (Figure 3e). Among the various areas of study, neuroscience, orthopedics, surgery, general internal medicine, and engineering emerged as the most popular.

(a)   *(b)*

(c)

(d)

(e)
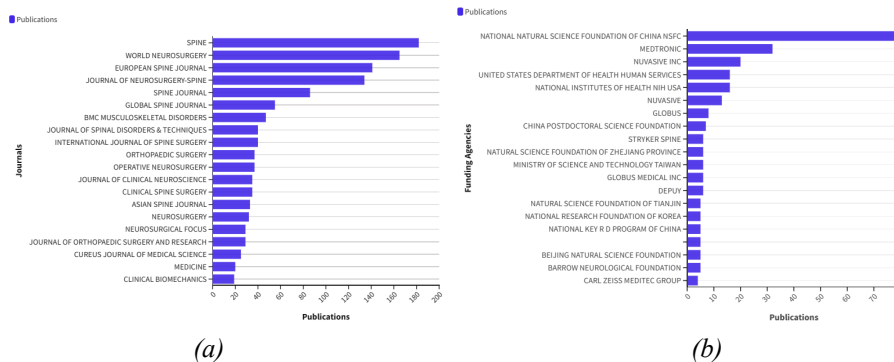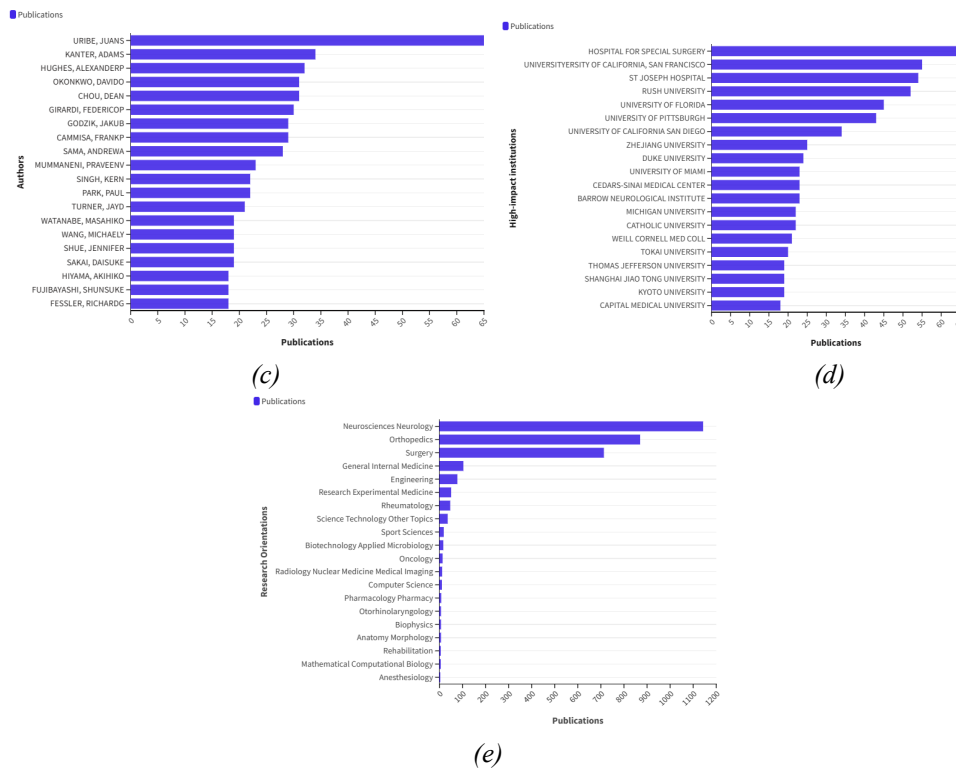
(a) Before the number 20 journals published an article about LLIF related research (b) Before 20 sources about LLIF related research published an article number (c) The former 20 author published an article about LLIF study number (d) About 20 before publication LLIF related research published an article number (e) Before 20 about LLIF related research orientation of direction

Figure 3: About LLIF assessments of publications around the world

3.4 Bibliographic coupling analysis

3.4.1 Journals

We analyzed the journal names, which were defined as the minimum number of articles that were used more than five times by each journal. VOSviewer (Figure 4a) was used for this analysis. Fifty-six journals were identified in terms of total link strength. The top five journals with the highest total link strength are as follows: World Neurosurgery (total link strength =3273.93 times), Spine (total link strength =3204.53 times), European Spine Journal (total link strength =3089.31 times), Journal of Neurosurgery-Spine (total link strength =2889.22 times) and Spine Journal (total link strength =1911.45 times).

3.4.2 Countries

We analyzed thirty-one country articles, which were defined as the minimum number of articles that were used more than five times by each country. We used VOSviewer for this analysis (Figure 4b).The top 5 countries in total link strength are as follows: the United States (total link strength = 12,404.39 times), China (total link strength = 5,962.19 times), South Korea (total link strength = 3,462.82 times), Japan (total link strength = 3,224.28 times) and Germany (total link strength = 2,365.15 times).

3.4.3 Organizations

Institutional articles identified from 172 institutions (defined as the minimum number of articles used more than 5 times by an institution) were analyzed using VOSviewer (Figure 4c). The top 5 organizations in total link strength are as follows: Hospital for Special Surgery (total link strength =1685.64 times), Universityersity of California, San Francisco (total link strength =1462.86 times), Rush University (total link strength =1379.41 times), University of Pittsburgh (total link strength =1319.21 times), and University of Pittsburgh Florida (total link strength =116.56 times).

(a)   *(b)*   *(c)*
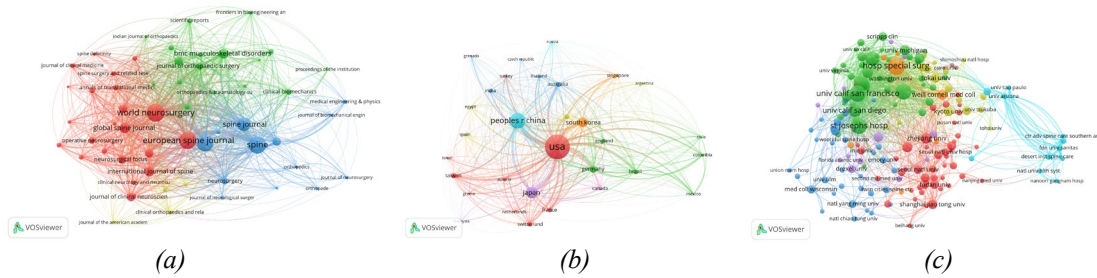
(a) About 56 LLIF related research journal of network diagram (b) Network diagram about LLIF related research in 31 countries (c) On the network diagram of LLIF related research 172 organizations

Figure 4: Bibliographic coupling analysis regarding LLIF studies
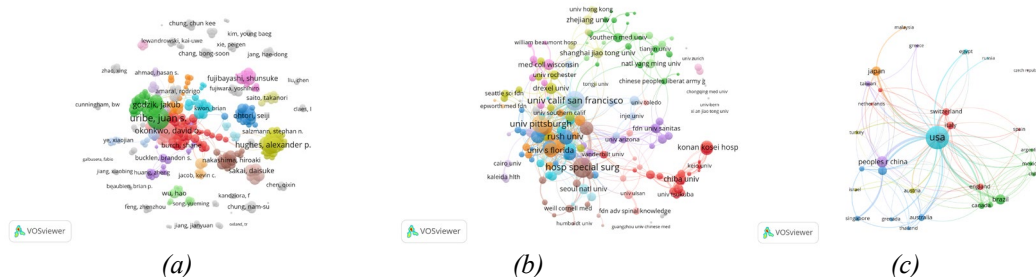
3.5 Co-authorship analysis

3.5.1 Authors

Co-authors analysis showed that the relevance of a project depended on the number of co-authored papers. Use VOSviewer analyzed 338 authors (defined as one of the authors use more than 5 times the minimum number of articles) (Figure 5a). The top five authors for overall link strength were: Uribe, Juans (total link strength =63.00 times), Kanter, Adams (total link strength =33.00 times), Hughes, Alexanderp (total link strength =32.00 times), Okonkwo, Davido (total link strength =31.00 times) and Godzik, Jakub (total link strength =29.00 times).

3.5.2 Organizations

Studies from 172 organizations (defined as the minimum number of articles used more than five times by institutions) were analyzed using VOSviewer (Figure 5b). Total link intensity of the top five organizations are as follows: Hospital for Special Surgery (total link strength =37.00 times), Universityersity of California, San Francisco (total link strength =35.00 times), University of Pittsburgh (total link strength =28.00 times), Rush University (total link strength =21.00 times), and St Joseph Hospital (total link strength =19.00 times).

3.5.3 Countries

Publications from 31 countries (defined as the minimum number of articles used more than five times by the country) were analyzed using VOSviewer (Figure 5c). Always link the strength of the top five countries are as follows: the United States (total intensity of link = 192.00 times), China (total intensity of link = 44.00 times), Brazil (total intensity of link = 36.00 times), Germany (total intensity of link = 36.00 times) and Japan (total intensity of link = 30.00 times).

(a)   *(b)*   *(c)*

(a) Analysis of 338 co-author for the LLIF study (b) Mapping of the LLIF collaboration analysis for 172 institutions (c) Mapping of the LLIF study for the collaboration of 31 countries

Figure 5: LLIF study co-authorship analysis
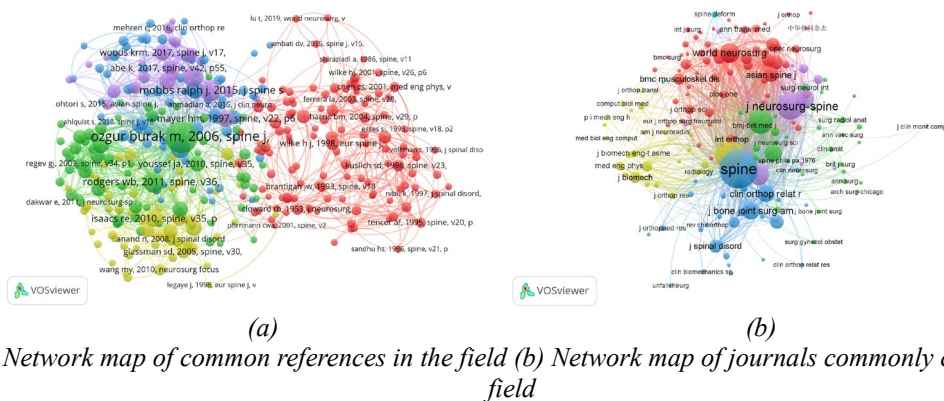
3.6 Co-citation analysis

3.6.1 Cited-references

According to co-citation analysis, the correlation between things depends on the number of co-citations they appear in. VOSviewer was used to analyze 343 articles (defined as the minimum number of articles with more than 20 references) (Figure 6a). Here are the first five studies with high total link

intensity: Ozgur Burak m, 2006, Spine j, V6, P435, doi: 10.1016 / j.s. Pinee 2005.08.012; Mobbs Ralph j, 2015, j Spine Surg, V1, P2, doi 10.3978/j.issn.2414-469x.2015.10.05; Silvestre c, 2012, Asian Spine j, V6, P89, doi 10.4184/asj.2012.6.2.89; Rodgers Wb, 2011, Spine, V36, he, doi: 10.1097 / BRS. 0 b013e3181e1040a; Oliveira l, 2010, Spine, V35, Ps331, doi: 10.1097 / BRS. 0 b013e3182022db0

3.6.2 Cited-sources

The VOSviewer software was utilized to investigate the co-citation of journal names, which is determined by the minimum number of citations required for journals to be jointly cited at least 20 times. The resulting analysis in (Figure 6b) identifies a total of 162 journals with significant link strength. Among them, the top five journals, ranked by their total link strength, are as follows:Spine (total link strength =8827.02 times), European Spine Journal (total link strength =3935.58 times), Journal of Neurosurgery-Spine (total link strength =3330.55 times), Spine Journal (total link strength =2712.72 times) and Journal of Spinal Disorders & Techniques (total link strength = 1659.34 times).

(a)   *(b)*

(a) Network map of common references in the field (b) Network map of journals commonly cited in the field

Figure 6: LLIF co-citation network diagram

3.7 Co-occurrence analysis

The co-occurrence analysis aims to identify research trends and notable topics that significantly contribute to the advancement of scientific research. It involves identifying the minimum number of keywords that are used more than 10 times. In our study, a total of 305 keywords were identified, and these were classified into three main clusters: "complications," "interbody fusion," and "surgery" (Figure 7a). The "complications" cluster includes commonly used keywords such as efficacy, LLIF, and anterior. The "interbody fusion" cluster focuses on keywords like spine, LIF, and lumbar spine. Lastly, the "surgery" cluster is centered around keywords such as decompression, spondylolisthesis, and Transferaminal Lumbar Interbody. The presence of these clusters helps to shape the overall research direction in the field (Figure 7a).

The findings indicate that the study of lateral lumbar interbody fusion (LLIF) predominantly focuses on the three aforementioned directions.

The VOSviewer software was employed to analyze the average time of publication for the included keywords, and the results were visualized using color coding (Figure 7b). In this visualization, the earlier keyword occurrences are represented by the color blue, while the later occurrences are represented by the color yellow. Prior to 2016, the research primarily focused on three main areas: "complication," "fusion between vertebral body," and "surgery" at the early stages. However, the latest trend indicates that the third cluster, specifically "complications," will gain significant attention in the future.
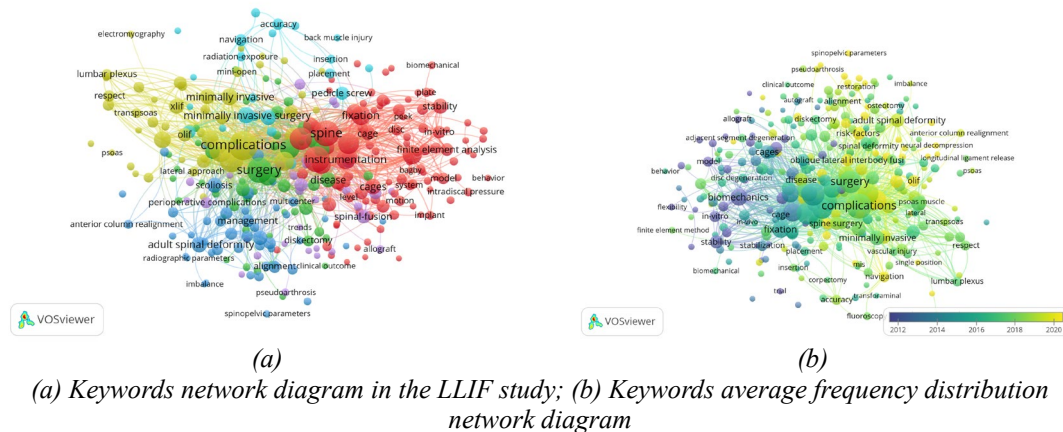
(a)   *(b)*

(a) Keywords network diagram in the LLIF study; (b) Keywords average frequency distribution network diagram

Figure 7: Co-occurrence analysis of LLIF studies

4. Discussion

4.1 Global publishing status and quality

Research trends in LLIF references and visual analysis can demonstrate the advancement of current scientific research fields and facilitate predictions [21]. Hence, this study aims to assess the countries, institutions, funding sources, and research priorities contributing to LLIF research [22].

Recent advancements in LLIF therapy represent an exciting and rapidly evolving research area [23]. As demonstrated in this study, there has been a substantial increase in the annual number of publications. Furthermore, there has been a remarkable surge in research interest in LLIF in recent years. In total, 61 countries have contributed studies to this area. The current data enables us to forecast the number of upcoming publications, indicating a growing number of studies that will further enhance our understanding of LLIF. These promising findings will consequently encourage researchers to pursue further high-quality studies.

4.2 LLIF research trends

The analysis of contributions according to country reveals that the United States has the highest number of publications, with the most significant contribution coming from a 2006 paper by Ozgur Burak et al. in the journal Spine (volume 6, page 435, doi: 10.1016/j.spinee.2005.08.012). The National Natural Science Foundation of China (NSFC) ranked first in terms of research direction, while Medtronic ranked second in terms of funding, based on the number of papers published. The United States has made significant contributions to LLIF research in terms of the total number of published papers. It is globally recognized as a pioneer and leader on this topic, given its high citation frequency and h-index. China ranks second in terms of overall publications. Conversely, the United States ranked first in terms of overall citation frequency and h-index. In fact, the Chinese academic grading system tends to prioritize quality over quantity. This can explain the discrepancy between the number and quality of publications, as researchers and doctors may be eager to submit an article without prioritizing the quality of their research. The gradual expansion of research funding in China, specifically through the National Natural Science Foundation of China (NSFC), will significantly enhance the quality of publications (NSFC: 784.314%) and allow China to catch up with global standards in this field [24].

When there are three books cited in the reference list, it is referred to as bibliographic coupling. We conducted a bibliographic coupling analysis to examine the similarity between different articles from three perspectives: journals, institutions, and countries. The main journals that focus on LLIF research are Spine, World Neurosurgery, European Spine Journal, Journal of Neurosurge-Spine, and Spine Journal. These journals are more likely to publish the latest research advancements in this field. Additionally, the papers published in Spine and World Neurosurgery show that these periodicals are at the forefront of international LLIF research. The Hospital for Special Surgery has the highest total link strength and is considered the leading institution for LLIF research. The majority of the top institutions are located in the United States, indicating their prominent position in this field. It is evident that the establishment of top-notch research institutions plays a crucial role in improving a country's academic stature. As depicted in (Figure 3d), Uribe, Juans, Kanter, and Adams are among the most significant contributors, and it is

important to closely track their future studies and newly published articles to stay updated on the latest progress in LLIF research. Co-publication is instrumental in promoting the advancement of science, fostering research innovation, facilitating knowledge sharing, and enhancing the quality of scientific research. Utilizing co-author analysis, we evaluated the collaborative efforts between different countries, institutions, and authors. The higher the total link intensity of authors, institutions, and countries, the more they are inclined to collaborate. For instance, Uribe, Juans, the Hospital for Special Surgery, and the United States are highly recommended choices for potential collaborations. The purpose of this co-citation analysis was to measure the impact of a study based on the number of citations it received. The research findings indicate that LLIF landmark studies are frequently cited and provide valuable references. It is well-known that Spine and European Spine Journal are the most frequently cited journals in this subject area.

4.3 LLIF Research Focus

We conducted co-occurrence analysis to identify research directions and hot topics in the field of LLIF. Using all the terms found in the research titles and abstracts, we created a co-occurrence network graph (Figure 7a). The graph illustrates three prominent research directions: complications, interbody fusion surgery, and surgical procedures. These studies provide valuable insights for shaping future research directions. Notably, complications, interbody fusion, spine, surgical procedures, and surgical outcomes are prevalent and hold a significant position in the co-occurrence network graph [25]. Therefore, further high-quality research is imperative in these three areas. In addition, we employed overlapping visual maps, similar to co-occurrence maps, to depict the publication years of the referenced studies. These visual maps, represented by different colors in (Figure 7b), provide a timeline-specific direction for tracking research progress. The survey results indicate that the prevention of postoperative complications may emerge as the next hot topic in this field. Furthermore, based on our findings, risk factors, surgical procedures, surgical outcomes, and postoperative complications are likely to be popular research directions for LLIF, particularly considering the increasing frequency of the term "complications" in recent literature. Consequently, clinical studies on LLIF are poised to become the primary focus in this field [26].

4.4 Advantages and Limitations

Although the current status and trends of various treatment modalities for lumbar lateral interbody fusion(LLIF) were evaluated through visual analysis in this study, it is important to address the following limitations [27]. The English language research was primarily based on data sources from the Web of Science - Science Citation Index Expanded. Consequently, there might be a linguistic bias, as non-English literature could have been omitted. Moreover, discrepancies between the real world and the study's findings should be taken into consideration. For instance, some recently published high-quality papers might not have gained immediate recognition due to low citation frequency. Therefore, it is crucial to stay updated with the latest primary research and non-English studies as part of our daily research efforts.

5. Conclusions

This study demonstrates the global trend of lumbar lateral interbody fusion(LLIF) [28]. Notably, the United States emerges as the largest contributor to research and holds a leadership position in this field on a global scale [29]. The academic journal "Spine" has the highest number of publications on this subject. It can be confidently predicted that there will be an increase in the number of studies focusing on lumbar lateral interbody fusion(LLIF) in the forthcoming years. Specifically, clinical studies in this area will receive heightened attention and become the next prominent area of interest in the future [30].

Acknowledgement

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