



Global research characteristics and trends of infection after spinal implant surgery: a bibliometric analysis

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Contributions: (I) Conception and design: C Li, H Wu; (II) Administrative support: A Trampuz; (III) Provision of study materials or patients: C Li, H Wu; (IV) Collection and assembly of data: Z Sun, M Donara; (V) Data analysis and interpretation: C Li, H Wu, Z Chen; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Background: With the growing awareness of postoperative infection, increasing focus has been placed on infection after spinal implant surgery (IASIS). This study aimed to explore the development and trends of research regarding IASIS using bibliometric analysis.

Methods: Scientific articles on IASIS research published between February 1, 2000, and December 31, 2020 were retrieved from the Web of Science database.

Results: A total of 820 publications were included in the bibliometric analysis, with studies originating from 46 countries and 6 languages. Researchers from the United States published the highest number of articles and collaborated closely with researchers in Canada, Germany, and Japan. The author with the most publications was Alexander R. Vaccaro. The journal with the most articles and citations was *Spine*. Most of the research was performed on risk factors and the incidence of IASIS. Co-occurrence analysis revealed that the most recent research trend was likely related to the management of IASIS and the international consensus meeting. Three clusters of research were identified through a thematic map: diagnosis and treatment of IASIS, scoliosis-related infection, and risk factors and prevention of IASIS.

Conclusions: Research on IASIS increasingly grew between 2000 and 2020. Spinal surgeons and institutes from the United States had the highest number of publications and academic impact in this field. Diagnosis-related problems and multidisciplinary work on IASIS require further attention in the future. Current trends in IASIS are likely associated with IASIS management and the international consensus meeting.

Keywords: Bibliometric analysis; infection after spinal implant surgery; publications; research trends; social media

Submitted Sep 23, 2021. Accepted for publication Mar 28, 2022. Published online Jan 14, 2023.

doi: 10.21037/atm-21-5044

View this article at: <https://dx.doi.org/10.21037/atm-21-5044>

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Introduction

Spinal fixation is the most successful and prominent technique used for spinal fractures, tumors, and deformities (1). As the number of spinal implant surgeries increases, the relative frequency of postoperative complications is also rising (2,3). Over the last few years, infections related to orthopedic devices have generated much attention (4-7). Infection is one of the most challenging complications following spinal implant surgery and is also associated with higher postoperative mortality, a longer length of stay, and higher hospital costs (8,9). Therefore, to further improve strategies in response to infection after spinal implant surgery (IASIS), a comprehensive and systematic approach to investigating the knowledge surrounding IASIS is required. Bibliometric analysis is an essential tool that applies statistical and mathematical approaches to explore the study characteristics and subject trends in a specific field (10-15). In recent years, several bibliometric studies of spinal disorders, such as cervical spondylotic myelopathy and spinal cord injury, have been conducted (16,17). To the best of our knowledge, the global status and research trends of IASIS have not yet been explored. Accordingly, the objectives of this study are to identify the global research characteristics and trends of IASIS from academic papers using a bibliometric approach.

Methods

Data source and search strategy

Literature was retrieved using Web of Science (data last updated on June 6, 2021) with the following search terms: spinal implant infection, infection associated with spinal implants, infection after instrumented spinal surgery, infection with spinal instrumentation, spine, spinal implant, instrumentation, instrumented, fusion, infection, and surgical site infection.

Two investigators (Cheng Li and Haiyang Wu) read the article titles and abstracts independently. Research articles were included if they (I) reported on research describing instrumented spine surgery with postoperative infection, (II) reported on basic research in spinal implant-associated infection, and (III) were published from January 1, 2000 to December 31, 2020. Articles were excluded if they contained research reporting infection in the absence of spinal implant surgery and/or were an article type that included conference proceedings, book chapters, retracted papers, editorials, errata, or letters.

Statistical analysis

Total records from the Web of Science were exported to plain text and Microsoft Excel (Microsoft, Redmond, WA, USA). WPS Office (Kingsoft, Beijing, China), VOSviewer (Leiden University, Leiden, the Netherlands), CiteSpace v. 5.7 R2 (Drexel University, Philadelphia, PA, USA), and Bibliometrix (University of Naples Federico II, Naples, Italy) software were used for analysis. Information analyzed included author, country, research direction, research trend, digital object identifier, journal title, institution, journal impact factor (2020), abstract, keywords, article title, language, and publication year. Research directions were defined into 5 groups: incidence, prevention, risk factor, diagnosis, and treatment. In the list of the top 5 most contributive authors, if several authors belong to the same institution, the author with the most publications was selected. As a useful bibliometric indicator, the h-index was also included to assess scholarly productivity in IASIS (18).

Results

The specific literature screening steps are shown in *Figure 1*. A total of 820 publications on IASIS published over the last two decades were identified using the electronic Web of Science database. Of these, 805 papers were written in English, followed by German [7], French [4], and Spanish [2]. The remaining 2 publications were in Czech and Portuguese. The sum of times cited was 22,714 (16,851 without self-citations). The average number of citations per document was 27.7. The h-index of all articles related to IASIS was 74.

Number of publications per year

Figure 2A outlines the specific number of annual publications related to IASIS. A model-fitting curve revealed a significant exponential growth trend in the past two decades ($R^2=0.9448$). After 2012, the number of articles exceeded 40 per year. The year 2018 ranked as the most productive year [96], followed by 2019 and 2020 [88 and 86, respectively].

Contributions of countries

A total of 46 countries published research on IASIS, including 24 European countries, 13 Asian countries, 4 South American countries, 2 North American countries, 2 African countries, and 1 Oceanian country (*Figure 2B*). The most prolific country was the United States, with

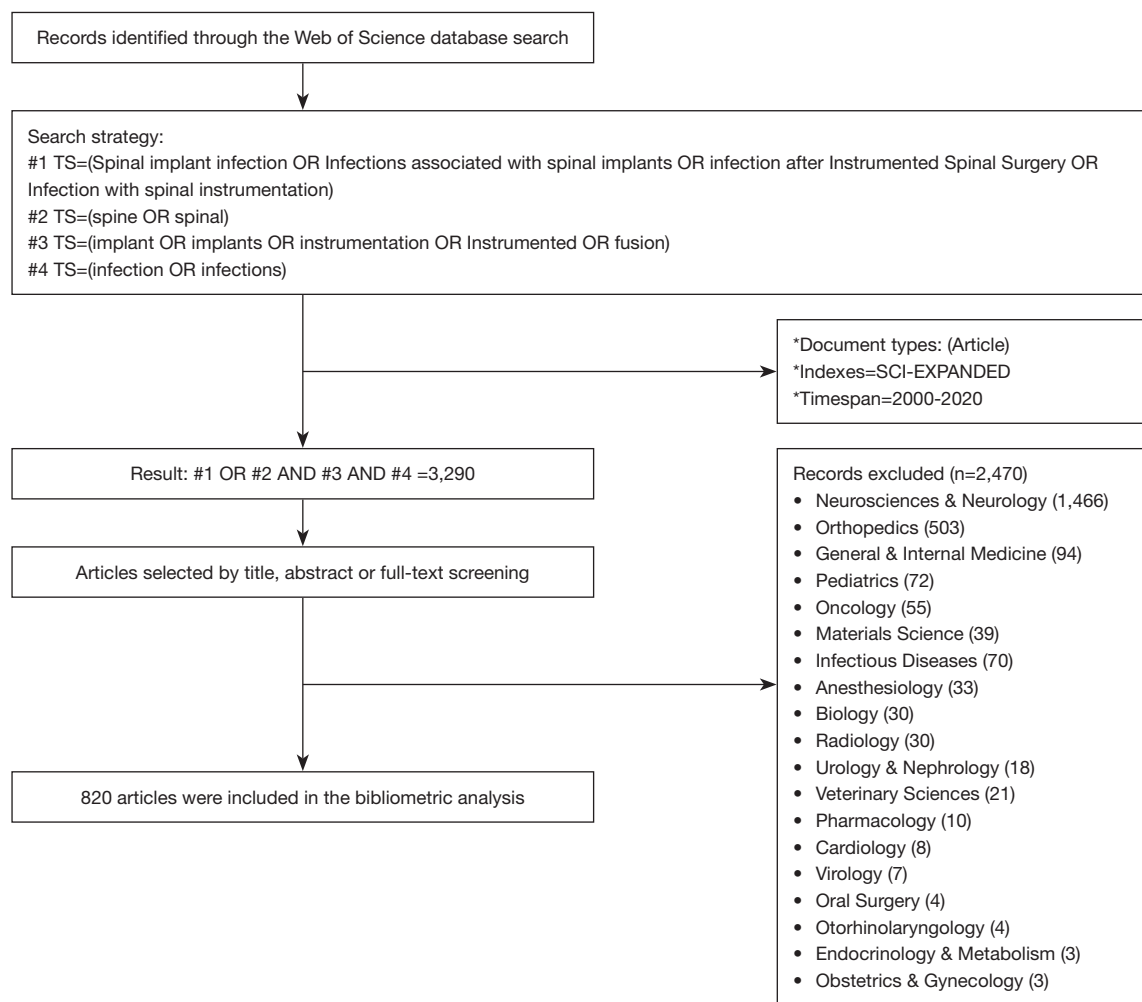


Figure 1 The specific literature screening steps.

the highest total citation count, average article citations, and h-index. Japan ranked second (77 articles), followed by China (73 articles; *Table 1*). The annual number of publications from the top 10 countries between 2000 and 2020 is illustrated in *Figure 2C*. The United States was consistently the major contributor in this field, and the number of publications from Asian countries, such as Japan and China, gradually increased from 2010. *Figure 2D* displays the international cooperation analysis among different countries. Researchers from the United States collaborated the most closely with those from Canada, Germany, and Japan.

Analysis of prolific institutions

Table 2 shows that the top 5 institutions contributing to

the highest number of papers on IASIS were from the United States. The most productive organization was Johns Hopkins University (54 articles), followed by the University of California (49 articles) and the University of Virginia (30 articles). Regarding total citations, the University of California ranked first (1,914 citations), followed by Johns Hopkins University (1,840 citations) and Thomas Jefferson University (1,403 citations). With an h-index of 22, Johns Hopkins University was at the top of the ranking list, with the University of California second (h-index 21) and Thomas Jefferson University third (h-index 18). *Figure 3A* shows the network map of institution coauthorship analysis as conducted using VOSviewer. Publications originating from 31 institutions were selected, with a minimum number of 10 documents for each institution. The University of Virginia, the University of California San Francisco, and

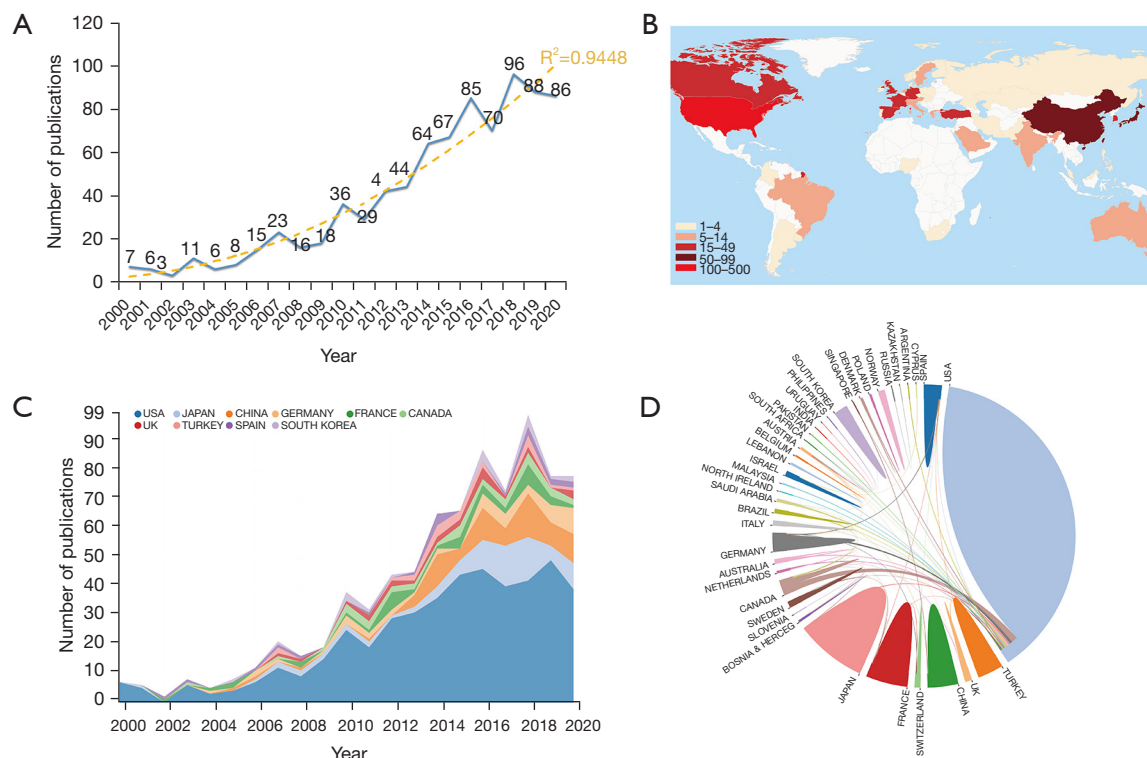


Figure 2 The distribution of publications and countries. (A) The specific number of annual publications on the topic of IASIS. (B) A world map depicting the contribution of each country in terms of publication counts. (C) The annual publication counts of the top 10 countries from 2000 to 2020. (D) The international cooperation analysis among different countries. The thickness of the line between 2 countries reflects the strength of the cooperation; the thicker the line, the stronger the cooperation. IASIS, infection after spinal implant surgery.

Table 1 The top 10 contributing countries in IASIS research

Country	Number of articles	Total citations	Average article citations	h-index
USA	473	17,032	36.01	69
Japan	77	1,189	15.44	19
China	73	930	12.74	17
Germany	44	641	14.57	14
France	36	610	16.94	13
Canada	32	1123	35.09	17
United Kingdom	22	675	30.68	12
Turkey	20	178	8.9	7
Spain	19	221	11.63	9
South Korea	19	510	26.84	8

IASIS, infection after spinal implant surgery.

Johns Hopkins University were located centrally on the network map. Moreover, different nodes representing institutions were assigned distinct colors according to the average appearing year (AAY) based on the color gradient in the lower right corner. These institutions, including the Washington University, the University of Maryland, and Twin Cities Spine Center, are depicted in blue with smaller AAY values, indicating that most participants were potential early contributors to IASIS research. Correspondingly, Brown University, Columbia University, and Yale University were potential new entrants in this domain.

Analysis of influential authors

A total of 3,569 authors contributed to this field. The author with the highest number of publications was Alexander R. Vaccaro (18 publications), followed by Justin S Smith (14 publications) and Amit Jain (12 publications). Alexander R. Vaccaro and Justin S Smith had the highest h-index (Table 3).

Table 2 The top 5 institutions with the greatest number of publications on IASIS

Institution	Number of articles	Total citations	h-index	Country
Johns Hopkins University	54	1,804	22	USA
University of California	49	1,914	21	USA
University of Virginia	30	1,279	17	USA
Thomas Jefferson University	29	1,403	18	USA
Mayo Clinic	26	691	14	USA

IASIS, infection after spinal implant surgery.

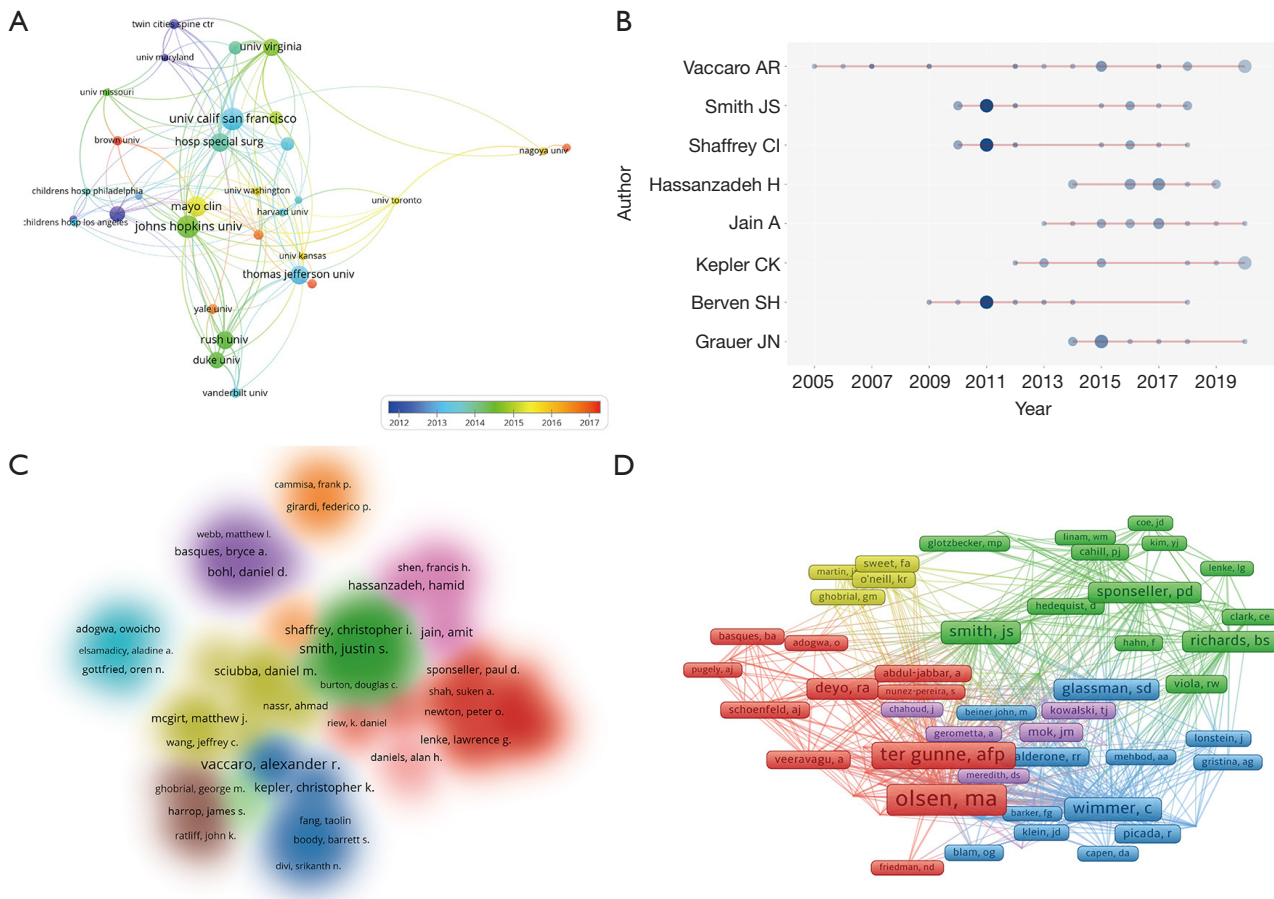


Figure 3 The distribution of institutions and authors. (A) Network map of institution coauthorship analysis. (B) The average outputs of the top 8 authors between 2000 and 2020. (C) Cluster density visualization map of author coauthorship analysis. (D) Network visualization map of author cocitation analysis.

Figure 3B depicts the average outputs of the top 8 authors between 2000 and 2019. A cluster density visualization map of the author coauthorship analysis is shown in Figure 3C. Authors with close associations were assigned to a cluster with the same color. Only authors with more than

5 publications were included, forming a total of 11 author clusters. As for author cocitation analysis, 100 authors with at least 30 citations were included in the analysis. The author with the most citations was Margaret A Olsen, followed by AFP ter Gunne and Albert F Pull (Figure 3D).

Table 3 The top 5 contributing authors to IASIS research

Author	Number of articles	h-index	Institution	Country	Specialized subject
Vaccaro, Alexander R.	18	11	Thomas Jefferson University	USA	Orthopedic surgery
Smith, Justin S.	14	11	University of Virginia	USA	Neurological surgery
Jain, Amit	12	8	Johns Hopkins University	USA	Orthopedic surgery
Lenke, Lawrence G.	11	9	Columbia University	USA	Orthopedic surgery
Grauer, Jonathan N.	11	9	Yale University	USA	Orthopedic surgery
Berven, Sigurd H.	11	10	University of California San Francisco	USA	Orthopedic surgery

IASIS, infection after spinal implant surgery.

Table 4 The top 10 journals ranked according to the number of publications on IASIS

Journal	Number of articles	Total citations	h-index	Journal impact factor	Journal quartile (category)
<i>Spine</i>	189	8,734	56	3.468	1 (orthopedics)
<i>European Spine Journal</i>	62	1,648	22	3.134	2 (orthopedics)
<i>Spine Journal</i>	47	1,530	20	4.166	1 (orthopedics)
<i>Journal of Neurosurgery-Spine</i>	41	1,609	20	3.602	1 (surgery)
<i>World Neurosurgery</i>	39	363	9	2.104	3 (surgery)
<i>Global Spine Journal</i>	30	88	5	2.915	2 (orthopedics)
<i>Journal of Pediatric Orthopaedics</i>	21	452	10	2.324	3 (orthopedics)
<i>Journal of Bone and Joint Surgery-American Volume</i>	20	1524	14	5.284	1 (orthopedics)
<i>Clinical Spine Surgery</i>	35	552	14	1.876	3 (orthopedics)
<i>Clinical Orthopaedics and Related Research</i>	16	585	14	4.176	1 (orthopedics)

IASIS, infection after spinal implant surgery.

Analysis of active journals

After reviewing the journal names, we ascertained that the *Journal of Spinal Disorders & Techniques* changed its name to *Clinical Spine Surgery*. This was also observed for the *Journal of Bone and Joint Surgery*, which changed its name to *The Bone & Joint Journal*. Hence, information on the respective journals was combined. In total, 145 different journals were found to contribute to this field.

Table 4 shows the top 10 journals with the most published articles. The journal with the highest number of publications and highest h-index was *Spine* (189 and 56, respectively), followed by *European Spine Journal* (62 and 22, respectively) and *Spine Journal* (47 and 20, respectively). According to the 2021 Thomson Reuters journal impact factor report, 136 journals had an impact factor for 2020. Approximately 25.7% (n=35) of the

journals were ranked in the first quartile, 25% (n=34) were in the second quartile, 25% (n=34) were in the third quartile, and 24.3% (n=33) were in the fourth quartile. The top 10 journals with the most publications came from the first, second, and third quartiles (Table 5). The journal with the highest impact factor was *Biomaterials* (impact factor 12.479), followed by *Advanced Healthcare Materials* (impact factor 9.933) and *European Journal of Nuclear Medicine* and *Molecular Imaging* (impact factor 9.236). All of the top 10 highest impact factor journals were in the first quartile. Figure 4A depicts the year of each journal's first paper on IASIS, with most journals appearing in 2016, 2017, and 2020 (14).

Figure 4B is the cocitation network visualization map of journals created by VOSviewer. Only journals with a minimum of 30 citations were visualized. The map contains

Table 5 The top 10 journals for IASIS research ranked according to the impact factor

Journal	Number of articles	Journal impact factor	Journal quartile (category)
<i>Biomaterials</i>	1	12.479	1 (engineering, biomedical)
<i>Advanced Healthcare Materials</i>	1	9.933	1 (engineering, biomedical)
<i>European Journal of Nuclear Medicine and Molecular Imaging</i>	1	9.236	1 (radiology, nuclear medicine & medical imaging)
<i>Clinical Infectious Diseases</i>	4	9.079	1 (infectious diseases)
<i>Acta Biomaterialia</i>	1	8.947	1 (engineering, biomedical)
<i>JCI Insight</i>	1	8.315	1 (medicine, research & experimental)
<i>Clinical Microbiology and Infection</i>	3	8.067	1 (infectious diseases)
<i>Anesthesiology</i>	1	7.892	1 (anesthesiology)
<i>Materials Science & Engineering C-Materials for Biological Applications</i>	1	7.328	1 (materials science, biomaterials)
<i>International Journal of Nanomedicine</i>	1	6.400	1 (pharmacology & pharmacy)

IASIS, infection after spinal implant surgery.

83 nodes, 3,174 links, and 6 clusters. The top 5 journals with the most citations were *Spine*, *Journal of Bone and Joint Surgery-American Volume*, *European Spine Journal*, *Spine Journal*, and *Journal of Neurosurgery-Spine*. Additionally, a dual-map overlay of the journals on IASIS research was also created (*Figure 4C*), which clarifies the citation patterns and knowledge flows in a given area. Four core citation paths are marked in pink on this map. It can be further observed that papers published in medicine, medical, or clinical journals cited journals mainly in the fields of molecular biology, genetics, health, nursing, medicine, psychology, education, and social science.

Research direction and trends

Regarding research type, 41 articles focused on basic research, whereas the remaining 779 publications were human studies. Among these 820 studies, 788 research directions were identified through article titles and abstracts. A single research topic was found in 770 papers, whereas 2 research subjects were identified in 18 articles. Most studies focused on the risk factors and the incidence of IASIS (*Figure 5A*). The changing pattern of the annual appearance frequency of author keywords, including *risk factors*, *management*, *outcomes*, *prevention*, and *mortality*, from 2000 to 2020 is illustrated in *Figure 5B*. Risk factors of IASIS were always a frequent focus in this field.

VOSviewer was used to explore research trends. Of the 1,496 keywords, the minimum number of occurrences of a

keyword was set to 4. *Figure 6* is the co-occurrence overlay visualization of 158 items; the closer the color is to red, the closer the research topic is to the present.

The thematic map was established using Bibliometrix software, which outlined the internal relationships in different groups. Cluster 1 comprised the topics of diagnosis and treatment of IASIS, and the top 3 most frequent keywords were *infection*, *spine*, and *surgery*. Cluster 2 was associated with scoliosis-related infection, and the most used keywords were *scoliosis*, *spinal deformity*, and *neuromuscular scoliosis*. Cluster 3 was associated with risk factors and prevention of IASIS, and the most commonly occurring keywords were *surgical site infection*, *spine surgery*, and *risk factors* (*Table 6*).

Discussion

We conducted a bibliometric analysis to attain a comprehensive overview of the development and trends of scientific publications in the IASIS field over two decades and further analyzed relationships among citations and alternative indicators.

Number of publications per year

From 2000 to 2020, 820 IASIS-related studies were identified in this bibliometric study, with the annual global publication showing a substantial rise from 2012. This result may suggest that IASIS has generated increasing

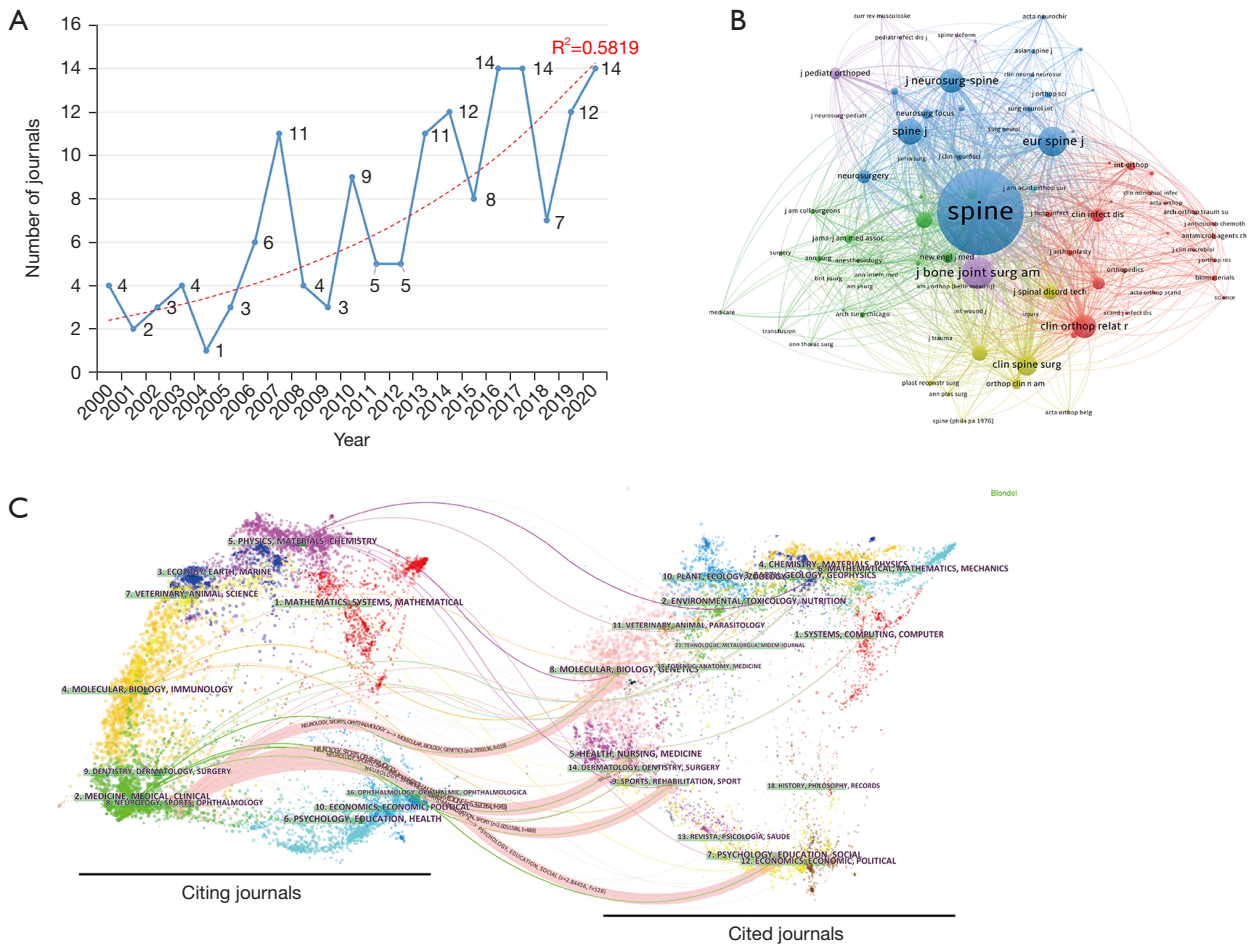


Figure 4 The distribution of journals. (A) Year of each journal’s first publication. (B) Network visualization map of the journal cocitation analysis. (C) A dual-map overlay of the journals on IASIS administration research. IASIS, infection after spinal implant surgery.

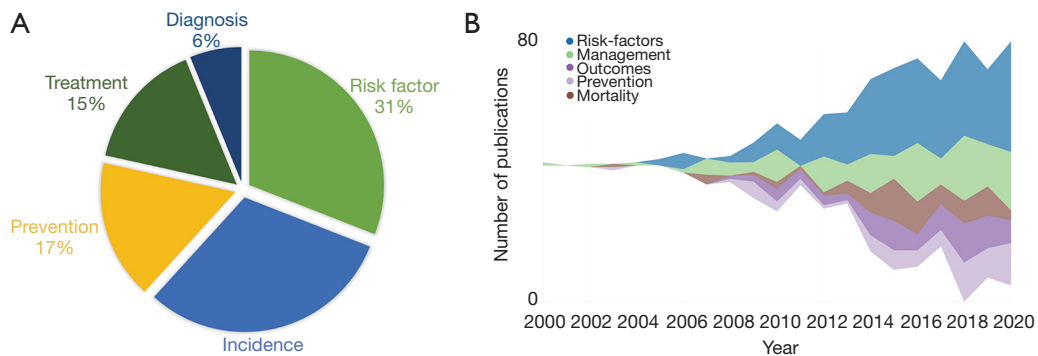


Figure 5 The distribution of the main research direction and author keywords. (A) Research directions of IASIS. (B) The changing pattern of annual appearance frequency in author keywords from 2000 to 2020. IASIS, infection after spinal implant surgery.

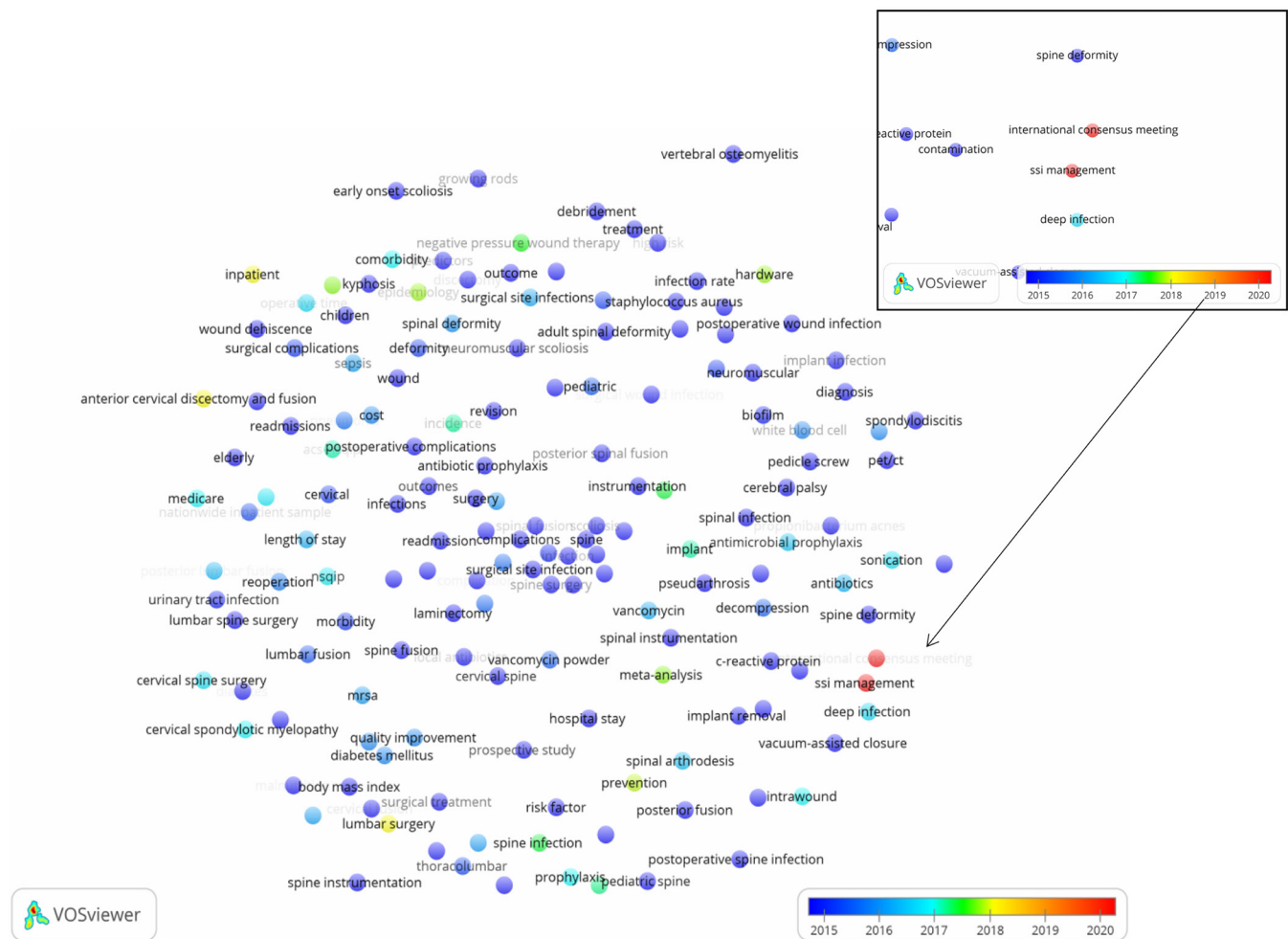


Figure 6 Analysis of the co-occurrence of keywords between 2000 and 2020.

attention and interest over recent years.

Countries, institutions, and authors

Countries from Europe, Asia, and North America accounted for the top 10 contributing nations for IASIS research. The United States had the highest number of publications and academic impact worldwide. In addition to the IASIS research subject, earlier bibliometric analyses revealed that the United States also had the greatest number of publications in other areas of spinal research (19-21).

All the top 5 contributing authors and organizations were from the United States. Furthermore, US experts and institutions dominated the area of IASIS. Alexander R. Vaccaro from Thomas Jefferson University had the

most publications and was one of the authors engaged in developing the consensus about infections of implants after spine surgery (6). The list of the top 5 contributing authors showed all authors to be surgeons, whereas a previous bibliometric study of periprosthetic joint infection (PJI) demonstrated microbiologists and infectious disease specialists to be key members in the management of IASIS (22). This finding likely reflects a current lack of multidisciplinary teams in IASIS management, and the creation of such teams could be helpful (23-25). The top 8 authors' annual publications between 2000 to 2020 showed a higher yearly output and better continuity in the second decade than in the first decade. This finding may suggest that authors have increased their attention and concern for IASIS in the last decade.

Table 6 Thematic map for IASIS research

Words	Frequency (%)
Cluster 1	
Infection	157 (26.9%)
Spine	97 (16.6%)
Surgery	49 (8%)
Instrumentation	43 (7%)
Complication	30 (5%)
Surgical site infections	30 (5%)
<i>Staphylococcus aureus</i>	28 (5%)
Implant	21 (4%)
Surgical site	21 (4%)
Biofilm	16 (3%)
Treatment	11 (2%)
Wound	11 (2%)
Outcome	10 (2%)
C-reactive protein	10 (2%)
Antibiotics	8 (1%)
Diagnosis	8 (1%)
Contamination	7 (1%)
Debridement	6 (1%)
Sonication	5 (1%)
<i>Staphylococcus</i>	4 (1%)
<i>Staphylococcus epidermidis</i>	4 (1%)
Titanium	4 (1%)
Vacuum-assisted closure	4 (1%)
Cluster 2	
Scoliosis	57 (31.8%)
Spinal deformity	20 (11.2%)
Neuromuscular scoliosis	18 (10%)
Adolescent idiopathic scoliosis	17 (9%)
Pediatric	16 (9%)
Infections	12 (7%)
Posterior spinal fusion	9 (5%)
<i>Propionibacterium acnes</i>	8 (4%)
Readmissions	5 (3%)
Epidemiology	5 (3%)

Table 6 (continued)**Table 6** (continued)

Words	Frequency (%)
Deep infection	4 (2%)
Irrigation and debridement	4 (2%)
Deep wound infection	4 (2%)
Cluster 3	
Surgical site infection	171 (23.4%)
Spine surgery	134 (18.3%)
Risk factors	69 (9%)
Spinal fusion	51 (7%)
Postoperative infection	38 (5%)
Wound infection	34 (5%)
Antibiotic prophylaxis	29 (4%)
Postoperative complications	26 (4%)
Spinal infection	22 (3%)
Spinal instrumentation	21 (3%)
Vancomycin powder	15 (2%)
Revision surgery	15 (2%)
Obesity	11 (2%)
Body mass index	9 (1%)
Prevention	9 (1%)
Diabetes	9 (1%)
Urinary tract infection	7 (1%)
Local antibiotics	6 (1%)
Cervical spine	6 (1%)
Cervical fusion	6 (1%)
Pedicle screw	6 (1%)
Hospital stay	5 (1%)
Lumbar spine surgery	4 (1%)
Albumin	4 (1%)
Spinal instrumentation surgery	4 (1%)
Management	4 (1%)
Infection rate	4 (1%)
Malnutrition	4 (1%)
Smoking	4 (1%)
Rheumatoid arthritis	4 (1%)

IASIS, infection after spinal implant surgery.

Journals

Of the 145 journals, *Spine* had the highest number of relevant publications and the greatest academic influence on IASIS. Of the 136 journals with an impact factor, *Biomaterials* had the highest impact factor. According to data on the year in which journals published their first article, there was an increasing number of new journals interested in IASIS research.

Research direction and trends

Analysis of the research directions for the topic of IASIS showed that risk factors and incidence were most commonly investigated, whereas diagnosis-related research was least frequently researched. Due to the current lack of credible diagnostics for IASIS (26-29), further exploration is required. Keyword co-occurrence maps showed that the latest trends in IASIS research were likely linked to surgical site infection management and international consensus meeting (6,30-33).

Three research groups were identified in the cluster analysis. Cluster 1 encompassed the topic of diagnosis and treatment of IASIS. The C-reactive protein (CRP) blood test was highlighted in group 1, and it is also commonly used as a first-line diagnostic method for other orthopedic implant-associated infections, such as PJI and fracture-related infection (34-36). However, for low-virulence microorganisms, there was a high occurrence of CRP in the normal range (37,38). Thus, novel serum biomarkers are continually being explored (39-41). Sonication was the only microbiological diagnostic method present in cluster 1. One retrospective study (42) reported the diagnostic value of 2 intraoperative methods—tissue culture and sonication—for spinal implant infection. Implant sonication had a higher sensitivity and specificity than did tissue culture. Prinz *et al.* (43) reported the frequent detection of low-virulence bacteria via pedicle screw sonication. Cluster 1 contained the microbial-related words of *Staphylococcus aureus* and *Staphylococcus epidermidis*. An epidemiological study from 2000 to 2012 observed the most frequently isolated bacterial pathogens to be *Staphylococcus epidermidis*, followed by methicillin-sensitive *Staphylococcus aureus*, *Cutibacterium acnes*, and *Escherichia coli* (44). IASIS is commonly caused by *Staphylococcus* spp; therefore, the relationship between IASIS and *Staphylococcus* spp warrants further attention in clinical diagnosis. In terms of treatment, combined surgical debridement with antibiotic therapy is the major strategy

for IASIS management (45,46). Additional studies also supported vacuum-assisted closure as a viable method for IASIS treatment (47-49).

Cluster 2 was associated with scoliosis-related infection. A study of 108,419 operations following spine surgery reported a higher postoperative infection rate in scoliosis surgery than in surgery for degenerative diseases, spondylolisthesis, and fractures (50). Therefore, infection prophylaxis and postoperative follow-up for patients with scoliosis require special attention. Neuromuscular and adolescent idiopathic scoliosis were identified in cluster 2, likely reflecting a difference in the incidence of infection among various scoliosis etiologies. A multicenter, retrospective study of surgical site infection among pediatric patients following scoliosis surgery found that patients with neuromuscular scoliosis had the highest infection rate (9.2%), followed by those with syndromic scoliosis (8.8%), other scoliosis types (8.4%), congenital scoliosis (3.9%), and idiopathic scoliosis (2.6%) (44). *Cutibacterium acnes* is a pathogen frequently found in infections following scoliosis surgery, especially in delayed infections (51-53). Cluster 3 was associated with risk factors and prevention of IASIS. The main concerns of IASIS in cluster 3 appeared to focus on obesity, body mass index, urinary tract infection, diabetes, albumin, malnutrition, smoking, and rheumatoid arthritis (54-61). Vancomycin powder is the most relevant research topic in IASIS prevention, and the efficacy of local vancomycin powder in decreasing the infection rate after spine surgery has become a research hotspot involving considerable controversy (62,63).

Conclusions

The number of publications on IASIS showed an increasing trend from 2000 to 2020. The United States was the most productive country and was home to the top authors and institutes. The most relevant and academically influential journal on IASIS was *Spine*. Risk factors and the incidence of IASIS were of interest to academics and clinicians, whereas diagnosis-related issues were overlooked. The most recent research trend is likely related to the management of IASIS and consensus on the topic.

Acknowledgments

We would like to thank Dr. Sundrela Kamhieh-Milz for editorial assistance.

Funding: The study was funded by the German Research

Foundation (DFG) and the Open Access Publication Fund of Charité—Universitätsmedizin Berlin, Beijing Postdoctoral Research Foundation (No. 2022-ZZ-040), China Postdoctoral Science Foundation (No. 2022M720385).

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <https://atm.amegroups.com/article/view/10.21037/atm-21-5044/coif>). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: Li C, Wu H, Sun Z, Donara M, Chen Z, Trampuz A. Global research characteristics and trends of infection after spinal implant surgery: a bibliometric analysis. *Ann Transl Med* 2023;11(6):255. doi: 10.21037/atm-21-5044