European Review for Medical and Pharmacological Sciences 2024; 28: 1662-1679

The top 100 most cited articles on intramedullary nail fixation from 2018-2022: a bibliometric and visualized analysis

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Abstract. – OBJECTIVE: Intramedullary nails are commonly used for the purposes of internal fixation in the repair of tubular bone fractures, allowing for optimal fixation while minimizing intraoperative bleeding, surgical incision size, and associated stress. These nails are thus often utilized to repair hip and peripheral fractures, femur fractures, tibial fractures, humerus fractures, and clavicle fractures. Recent life expectancy increases, rising economic standards, and technological innovations have led to the application of a wider range of materials and techniques in the context of orthopedic device production, further expanding the clinical indications for intramedullary nailing. Despite the growing importance of this technique, there is currently a lack of any bibliometric or visual analyses that provide a robust overview of recent progress in the intramedullary nailing research space. Accordingly, this study was developed to succinctly and comprehensively summarize the current research status and major hotspots in this field through a bibliometric review of major relevant scientific articles focused on intramedullary nailing published in recent years.

MATERIALS AND METHODS: For this analysis, the top 100 most-cited articles focused on intramedullary nails published between 2018 and 2022 were identified through a search of the Web of Science Core Collection database. Countries, institutions, journals, and other specific parameters associated with these articles were then analyzed using tools including CiteSpace, VOS-viewer, Origin, and SCImago Graphica in an effort to more clearly define the latest trends in the intramedullary nail-related research space.

RESULTS: The top 3 most-cited articles related to intramedullary nailing over the past five years were "Antibacterial and immunogenic behavior of silver coatings on additively manufactured porous titanium", "Diaphyseal long bone nonunions - types, etiology, economics, and treatment recommendations", and "Epidemiology, treatment, and mortality of trochanteric and subtrochanteric hip fractures: data from the Swedish fracture register", all of which were published in 2018, respectively exhibiting 93, 83, and 81 citations. Of the 100 most-cited intramedullary nailing-related articles, 38, 20, and 12 were respectively published by researchers from the USA, China, and the UK, while research groups from Italy and Spain each published 7 articles. Four of this field's most highly cited articles were published by individuals affiliated with the US-based University of California System and the University System of Ohio. Of the 15 journals that published the largest number of these top 100 articles, the "Injury International Journal of The Care of The Injured" and the "Journal of Orthopaedic Trauma" published 9 manuscripts each, which was more than any other journal, while the "Journal of Orthopaedic Surgery" and the "Journal of Pediatric Orthopaedics" published 7 each. In total, 73 highly cited articles focused on utilizing intramedullary nailing in orthopedic applications. Rozbruch SR from the USA published 3 high-quality articles in this research space, while the Chinese researchers Chang Shi Min, Du Shou Chao, Hou Zhi Yong, and Hu Sun Jun exhibited a total linkage strength of 21 in global interaction analyses. The most common keywords associated with intramedullary nail-related research identified in these analyses included "Hip fracture", "Nonunion", "Limb lengthening", "Proximal humeral fractures", "Additive manufacturing", "Induced membrane", and "Endoprosthetic replacement". Promising areas of potential future research focus may include "Limb reconstruction", "Pediatric deformity", and "Congenital femoral deficiency".

CONCLUSIONS: This analysis revealed that the highest volume of high-impact research output focused on intramedullary nailing over the past 5 years has been produced by the USA, followed by China and the UK. The most influential journals in this research space were Injury International Journal of The *Care of The Injured and the Journal of Orthopaedic Trauma*, while the institutions associated with the most highly cited articles were the University of California System and the University System of Ohio. Intramedullary nailing is commonly utilized to treat intertro-

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chanteric fractures and other tubular bone fractures. In the future, the application of augmented and virtual reality technologies may help shorten the learning curve for orthopedic surgeons and trauma surgeons who are learning intramedullary nailing-related techniques, and the combination of intramedullary nailing with antibacterial drugs, metal alloys, 3D navigation, and sensor devices may help improve patient outcomes.

Key Words:
Intramedullary nail, Bibliometric, Visualization, CiteSpace, VOS-viewer.

Introduction

Intramedullary nailing is a strategy that is widely employed in the field of orthopedics as the utilized nails exhibit ideal biomechanical properties, and the associated incisional requirements are very small, making this the gold standard approach to treating long bone fractures of the extremities[1]. The intramedullary nail is a central fixation device that can withstand large loads despite its poor performance in rotational resistance. Intramedullary nail fixation uses closed penetration of the nail into the bone marrow, thus effectively avoiding soft tissue injury and hematologic disruption of the periosteum, thereby reducing the risk of postoperative infection and improving fracture healing. Intramedullary nail fixation can simultaneously ensure excellent bone union during fracture repair procedures[2], decrease the overall operative duration[3], and reduce the risk of intraoperative bleeding and perioperative infection[4].

Intramedullary nailing is also a technique that remains integral to limb-lengthening procedures[5], and it is frequently deployed in a range of cross-disciplinary contexts related to trauma orthopedics, including the use of sensor devices[6], magnetic navigation, and intelligent imaging strategies[7]. Intramedullary nailing is an increasingly common approach in clinical practice that is used across a growing range of applications, and the limitations associated with the fixation strategy continue to decrease in severity as through further reductions in operation-related infection risk[8,9].

While intramedullary nailing remains a gold standard treatment option in the field of trauma orthopedics, there remains a pressing need for a systematic survey of the recent research related to intramedullary nail fixation in an effort to define better the current focus of this research field and associated hotpots. Bibliometric and visual analyses provide an opportunity to comprehensively monitor research progress, leading to extensive interest in the application of these approaches in the fields of orthopedic surgery and trauma[10-13]. Citation counts can serve as a valuable tool when assessing research from an econometric perspective, as they generally correspond to the influence that a specific article has on a particular research field[14,15]. A bibliometric assessment[16] of the 100 most-cited articles related to intramedullary nailing revealed that all of these studies were published from 1984-2017, with 80% having been published from 1994-2012 and just 5 having been published from 2013-2017. A survey[12] of these top 100 articles revealed that their findings and conclusions were largely dissimilar to the current focus of this research field, such that providing a bibliometric overview of these studies would not provide a practical reference for future research. Accordingly, in an effort to provide a timelier overview of current orthopedic trends related to intramedullary nail fixation, the present bibliometric analysis was conducted by specifically focusing on the 100 most-cited articles on intramedullary nailing published in the Web of Science Core Collection (WoSCC) database over the past 5 years, with these articles being subjected to subsequent metrological and visual analyses. The overall goal of this approach was to offer a systematic and accurate overview of the scope of this research field, thereby providing a robust foundation for researchers interested in understanding the key trends and hotspots related to this topic.

Materials and Methods

Study Selection

Figure 1 shows the flowchart for the selection of literature in the study. Two reviewers independently screened all titles and abstracts for potentially eligible studies. Studies that were deemed potentially relevant by at least one reviewer were retrieved in full text. The eligibility of retrieved articles for final inclusion was assessed independently by two reviewers. Differences of opinion were resolved through discussion, and if no consensus was reached, the third reviewer made the final decision.

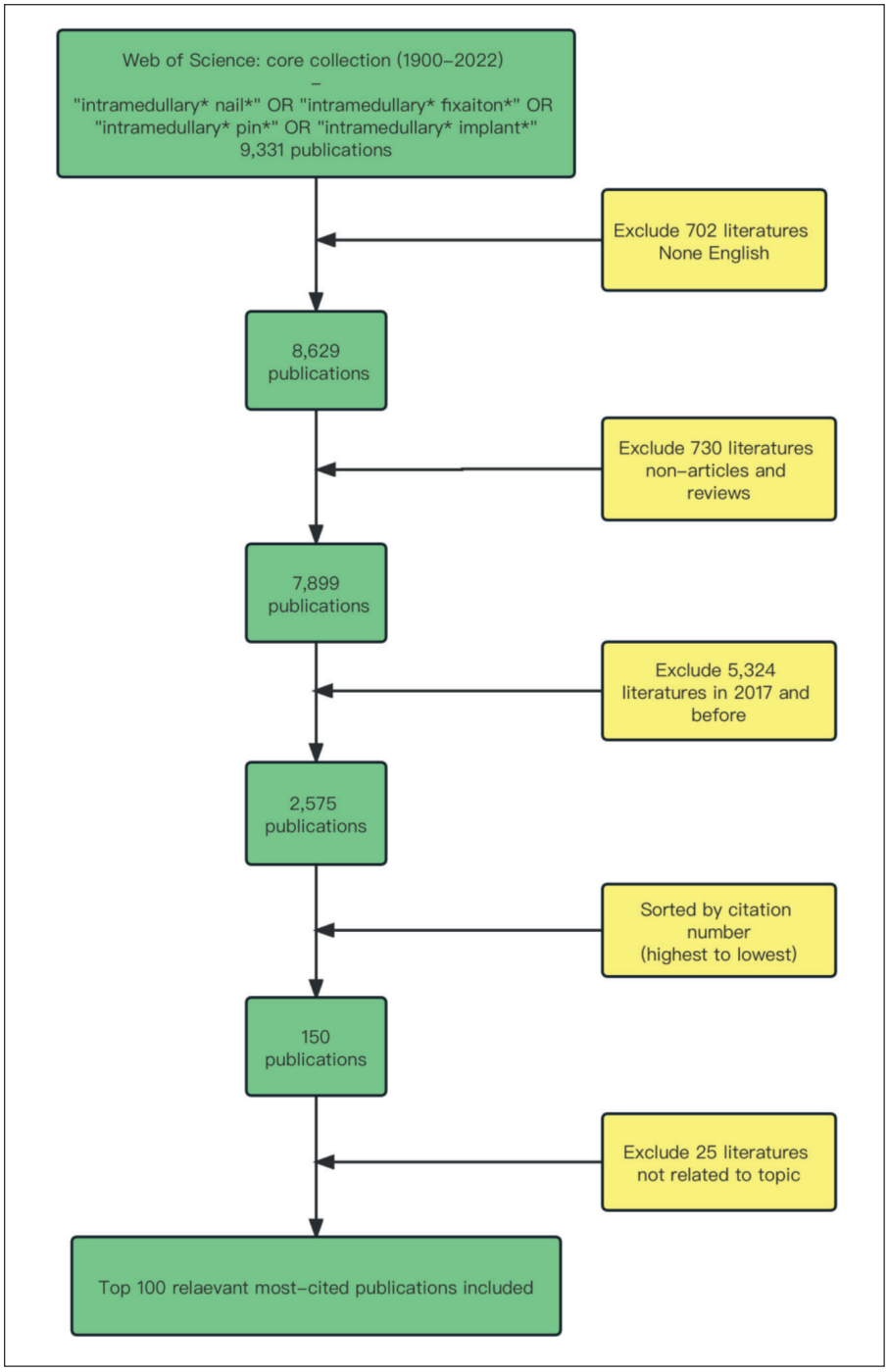

Figure 1. Flowchart for the selection of literature in the study.

Search Strategy

The WoSCC is a specialized academic database produced by Clarivate Analytics that compiles publications from over 12,000 academic journals[17], making it an ideal authoritative source for literature searches aimed at facilitating bibliometric and visualized analyses of a given research space[18-20]. For this study, relevant publications in the WoSCC published from January 2018 - November 2022 were identified with the following search terms: Theme= ((Intramedullary* nail*) OR (Intramedullary*) OR (Intramedullary* Pin*)) AND Theme= ((Fixation*) OR (Implant*)) AND Publishing year= (2018-2022) AND Document types= (ARTICLE OR REVIEW) AND Language= (English).

Data Collection

All valid information on these studies was extracted from the WoSCC database, and a spreadsheet was used to compile specific details about the included studies, including the authors, countries, institutions, titles, research directions, journals, and keywords in Excel 2022 (Microsoft Office 2022, Microsoft Corporation, WA, USA). The Web of Science "Analysis of search results" and "Citation Report" functions were additionally used, after which data were processed with CiteSpace V (Drexel University, PA, USA), Scimago Graphica (SCImago LAB, Spain), VOS-viewer (Leiden University, Leiden, The Netherlands), and Origin 2021 (OriginLab Corporation, MA, USA). Co-authors were responsible for independently searching and analyzing all literature, with any discrepancies being resolved through discussion and consultation with experts in the field.

Bibliometric Analysis and Visualization

CiteSpace V was used for clustering and labeling of co-cited keywords in order to establish a keyword timeline, while VOS-viewer was used for analyses of author co-citations and for the construction of a network map. Scimago Graphica was used to produce a map representing the number of publications produced by specific countries and to highlight network relationships among countries. Origin was utilized to assess research directions in the field of intramedullary nail fixation.

Results

The Most-Cited Intramedullary Nailing Studies

In the Web of Science interface, all articles can optionally be sorted by frequency. Each article that appears as a result is shown with its number of citations. The top 100[6-9,21-116] most cited articles related to intramedullary nailing identified in this analysis are compiled in **Supplementary Table I**. Of these studies, the three[8,47,64] with the highest numbers of citations are depicted in **Supplementary Table I**. The citations count for "Antibacterial and immunogenic behavior of silver coatings on additively manufactured porous titanium"[8], "Diaphyseal long bone nonunions - types, aetiology, economics, and treatment recommendations"[47], and "Epidemiology, treatment and mortality of trochanteric and subtrochanteric hip fractures: data from the Swedish fracture register"[64] were 93, 83, and 81 respectively. Each of these studies was published in 2018, with average annual citation counts of 18.6, 16.6, and 16.2, respectively.

Publications by Country

The indicator "Country/Region" is available in the menu bar of the database interface and can be selected to display the total number of articles issued by country or region. The three countries with the largest numbers of publications among these top 100 most-cited publications were the USA, China, and the UK, with 38[6,10,14,15,26,31,36,39,42,43,46-48,50,53,55,60,61,64,66,68,70-79,83,84,88,99,103,104,108,111,112,114,116-118], 20[7,9,20-23,25,31,32,37,38,41,68,69,71-74,91,97], and 12[5,27,28,30,58,62,67,87,89,90,93,115] respective publications (Figure 2). Overall, 36 countries have contributed to the intramedullary nailing field, with collaboration among researchers from multiple countries being common among these top 100 articles. The USA was the country exhibiting the broadest global collaboration in this research field, with a total linkage strength of 1,436, followed by Australia and Brazil, with respective values of 1,186 and 1,158.

Research Areas and Journals

The content and research directions of the top 15 journals included in this analysis are summarized in Figure 3. The most common research fields in this study were orthopedics, surgery, emergency medicine, and sport science, with 73[3,6,7,9-11,13,17-77,88,90,95,119,120], 36[2,3,8,21,22,24,31,32,40,41,43,44,52,53,59,61,65,67,69,70,73,74,80,82,83,86,90,93,96,102,107,109,111,115,116,119], 11[7,8,22,26,27,34,70,73,79,98,111], and 10[7,29,33,48,53,62,70,83,108,111] publications each, respectively. The top 15 most productive journals in the intramedullary nailing research space are summarized in Table I. "Injury International Journal of The Care of The Injured" (Impact Factor [IF]=2.678, Q2) and the "Journal of Orthopaedic Trauma" (IF=2.884, Q2) had published the most articles, with 9[2,5,26,27,48,60-63,70,72,82,90,103,105,113,114] publications each, followed by 4[25,43,49,91,94,111,115,116] publications each for the "Journal of Orthopaedic Surgery and Research" (IF=2.677, Q2) and the "Journal of Pediatric Orthopaedics" (IF=2.537, Q2). In bibliographic coupling analyses (Figure 4), the "Journal of Orthopaedic Trauma" exhibited the highest total linkage strength with a value of 225, followed by the "Journal of Orthopaedic Surgery and Research" and "Injury International Journal of The Care of The Injured" with respective values of 210 and 161.

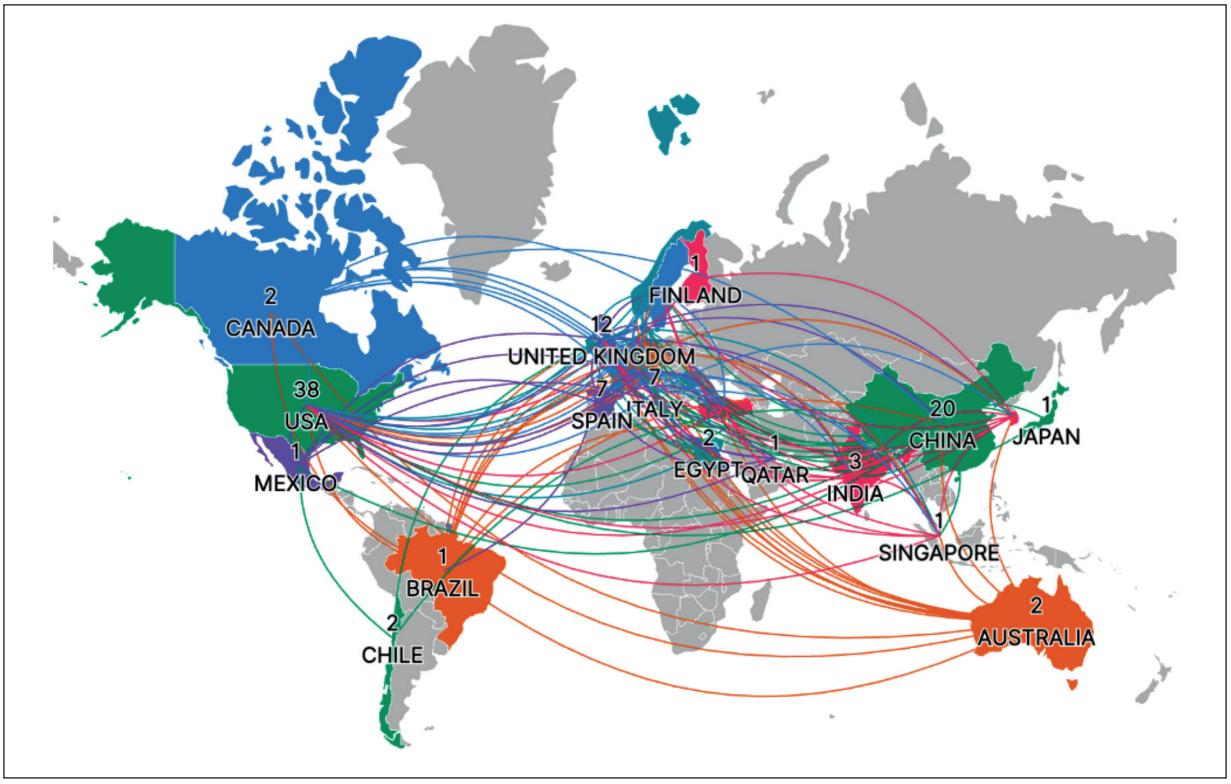

Figure 2. The world map displaying the top countries in the world in terms of volume of publications and network based on intramedullary nail.

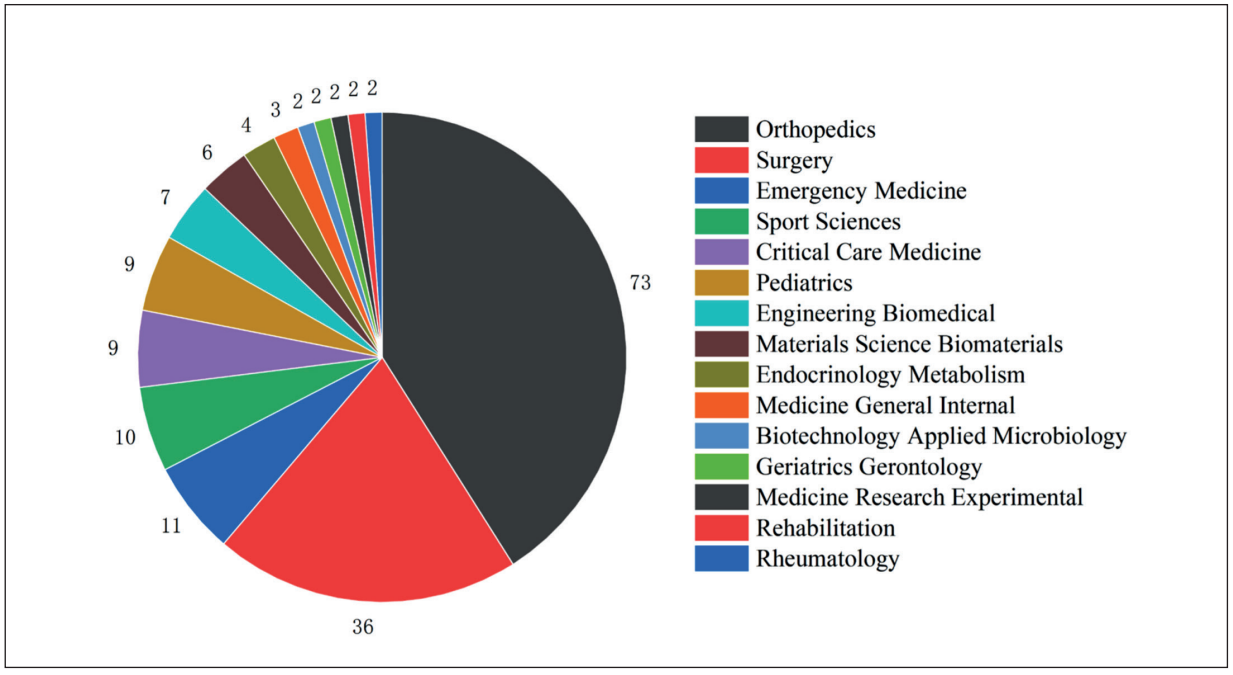

Figure 3. Mapping of the top 15 research directions related to intramedullary nail.

Table I. The top 15 journals with multiple publications.

Ranking	Journal	Number of publications	IF (2022)
1	INJURY INTERNATIONAL JOURNAL OF THE CARE OF THE INJURED	9	2.687
2	JOURNAL OF ORTHOPAEDIC TRAUMA	9	2.884
3	JOURNAL OF ORTHOPAEDIC SURGERY AND RESEARCH	7	2.677
4	JOURNAL OF PEDIATRIC ORTHOPAEDICS	7	2.537
5	CLINICAL ORTHOPAEDICS AND RELATED RESEARCH	5	4.755
6	JOURNAL OF THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS	5	4
7	INTERNATIONAL ORTHOPAEDICS	4	3.479
8	ACTA BIOMATERIALIA	3	10.633
9	ARCHIVES OF ORTHOPAEDIC AND TRAUMA SURGERY	3	2.928
10	BIOMATERIALS	2	15.304
11	BIOMED RESEARCH INTERNATIONAL	2	3.246
12	BMC MUSCULOSKELETAL DISORDERS	2	2.562
13	BONE JOINT JOURNAL	2	5.385
14	EUROPEAN JOURNAL OF TRAUMA AND EMERGENCY SURGERY	2	2.374
15	GERIATRIC ORTHOPAEDIC SURGERY REHABILITATION	2	1.924

Authors and Institutions

The most highly published author in this analysis was Rozbruch SR with 3 publications[50,88,108]. VOS-viewer visualizations and cluster network analyses for included authors are provided in Figure 5, revealing that the most collaborative authors during this period from 2018-2022 were Chang Shi Min, Du Shou Chao, Hou Zhi Yong, and Hu Sun Jun, with each contributing a total linkage strength of 21.

The top 15 most productive institutions in the intramedullary nailing research space are presented in Table II. The top-ranked institutions were the University of California System and the University System of Ohio, each of which generated 4 publications[9,26,42,46,68,83,109,112], followed by the Autonomous University of Barcelona, Harvard Medical School, Harvard University, Shanghai Jiao Tong University, and the University of Cincinnati with 3 publications each. As shown in the network diagram representing institutional collaboration in Figure 6, Shanghai Jiao Tong University engaged in the highest levels of collaboration with a total linkage strength of 185.

Keyword Analysis

As shown by the timeline provided in Figure 7, intramedullary nail fixation-related keywords can be classified into 7 categories by CiteSpace, including "Hip fracture", "Nonunion", "Limb lengthening", "Proximal humeral fractures", "Additive manufacturing", "Induced membrane" and "Endoprosthetic replacement". Relationships among keywords and the timeline were then used by CiteSpace to automatically identified research hotspots over the past 2 years, which included "Limb reconstruction", "Pediatric deformity", and "Congenital femoral deficiency".

Discussion

The results of this overview of the 100 most-cited articles published on the topic of intramedullary nail fixation over the past 5 years indicate that the USA has been the largest contributor to this research field. Indeed, 38 of these articles were published by researchers in the USA, and the USA was also the home to 4 of the top 5 most productive research institutions in this field, including the University of California System and the University System of Ohio, which were tied for the most published articles on intramedullary nailing. China was home to researchers associated with the second-highest number of publications related to intramedullary nailing (n=20). Notably, the most productive Chinese institution was Shanghai Jiao Tong University, which also ranked first in an analysis of global network collaboration, highlighting the global recognition that China's top universities have attained with respect to their academic achievements in this research space and suggesting that they are likely to continue performing pioneering work related to intramedullary nail fixation. Additional focus on the research contributions of Capital Medical University, China Medical University, and Chinese People's Liberation Army General Hospital to this research field are also warranted in the future. While the UK was the third most productive

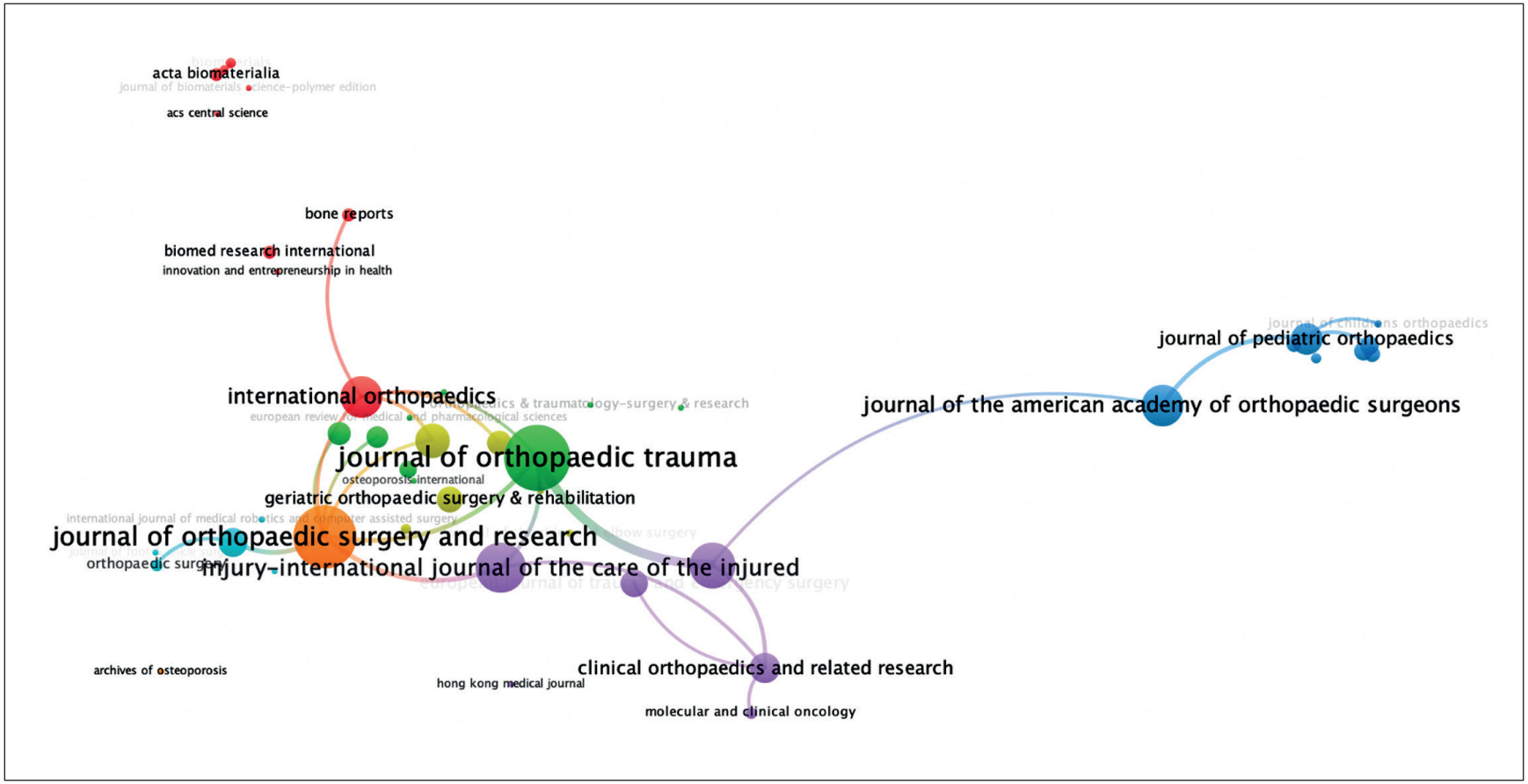

Figure 4. Graph of network interaction analysis of citation journals.

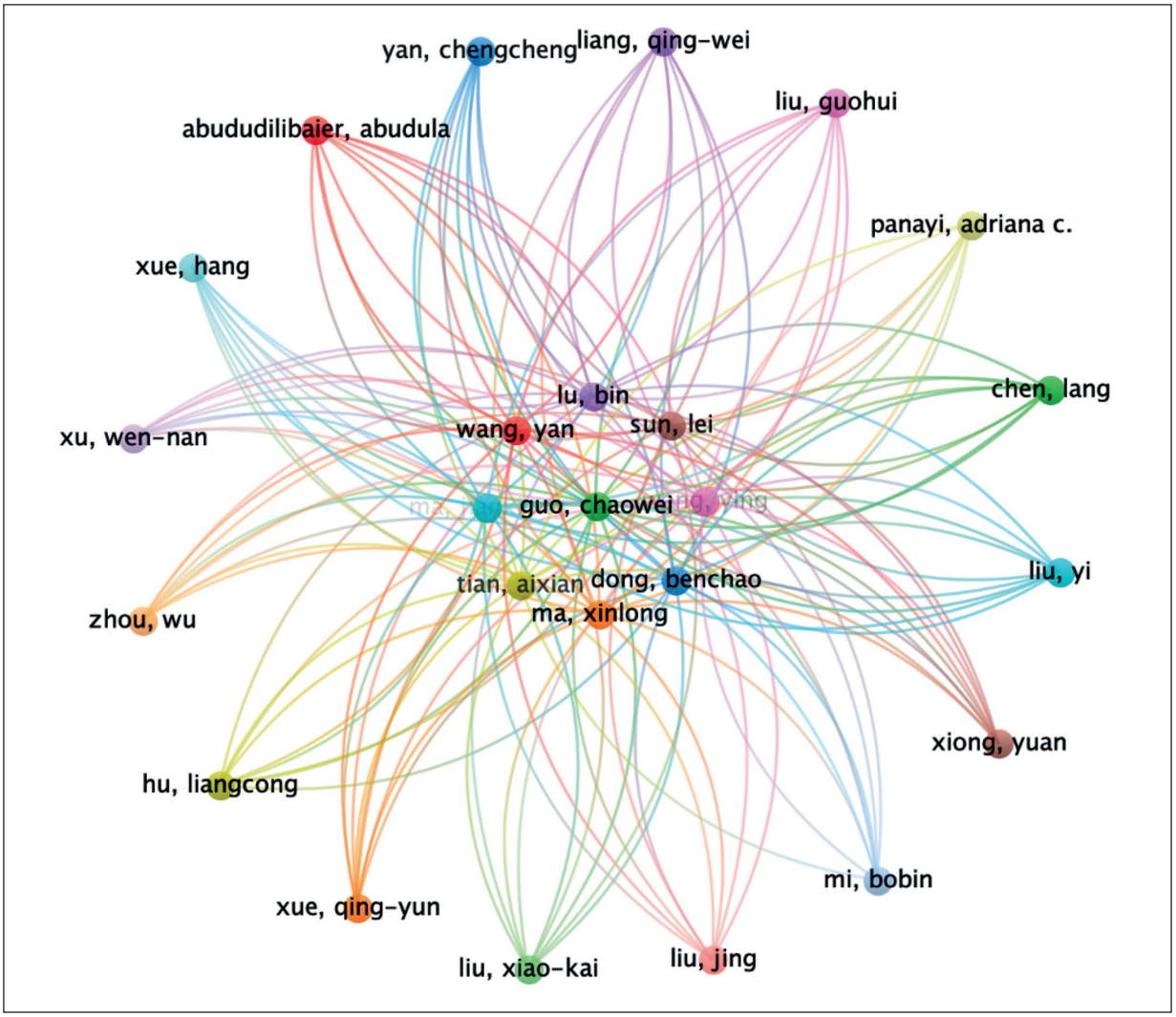

Figure 5. Network map of top 15 citation analysis of authors.

Table II. The top 15 institutions with multiple publications.

Ranking	Institution	Number of publications	Country
1	UNIVERSITY OF CALIFORNIA SYSTEM	4	US
2	UNIVERSITY SYSTEM OF OHIO	4	US
3	AUTONOMOUS UNIVERSITY OF BARCELONA	3	Spain
4	HARVARD MEDICAL SCHOOL	3	US
5	HARVARD UNIVERSITY	3	US
6	SHANGHAI JIAO TONG UNIVERSITY	3	China
7	UNIVERSITY OF CINCINNATI	3	US
8	BRIGHAM WOMEN S HOSPITAL	2	US
9	CAPITAL MEDICAL UNIVERSITY	2	China
10	CATHOLIC UNIVERSITY OF THE SACRED HEART	2	Italy
11	CHINA MEDICAL UNIVERSITY	2	China
12	CHINESE PEOPLE S LIBERATION ARMY GENERAL HOSPITAL	2	China
13	CIBER CENTRO DE INVESTIGACION BIOMEDICA EN RED	2	Spain
14	CIBERFES	2	Spain
15	COMPLEXO HOSPITALARIO UNIVERSITARIO DE SANTIAGO DE COMPOSTELA	2	Chile

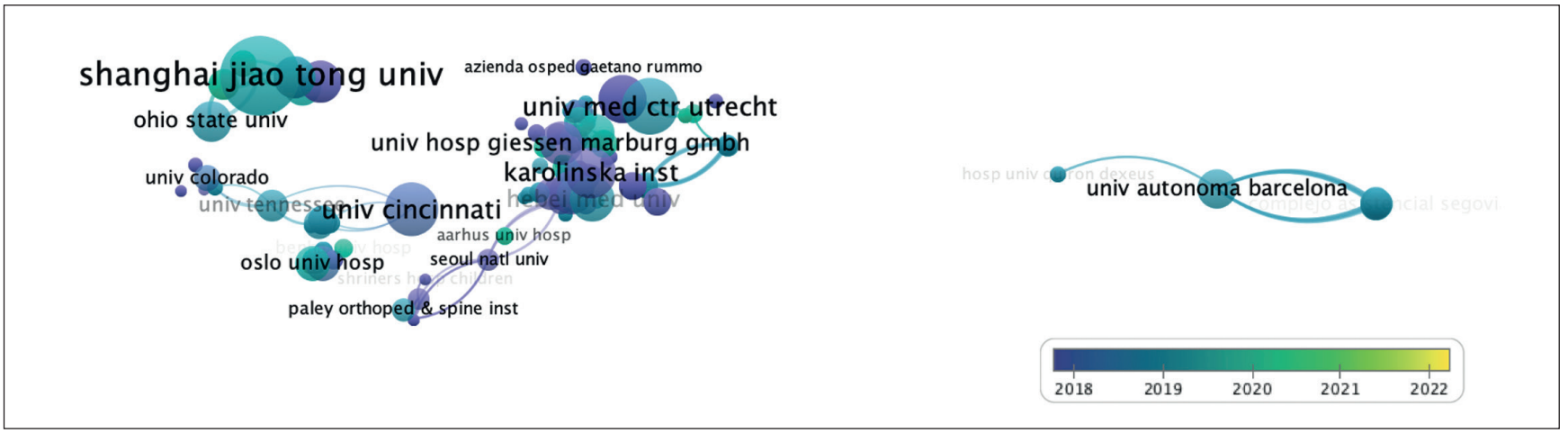

Figure 6. The bibliographic coupling analysis of institutions involved in intramedullary nail.

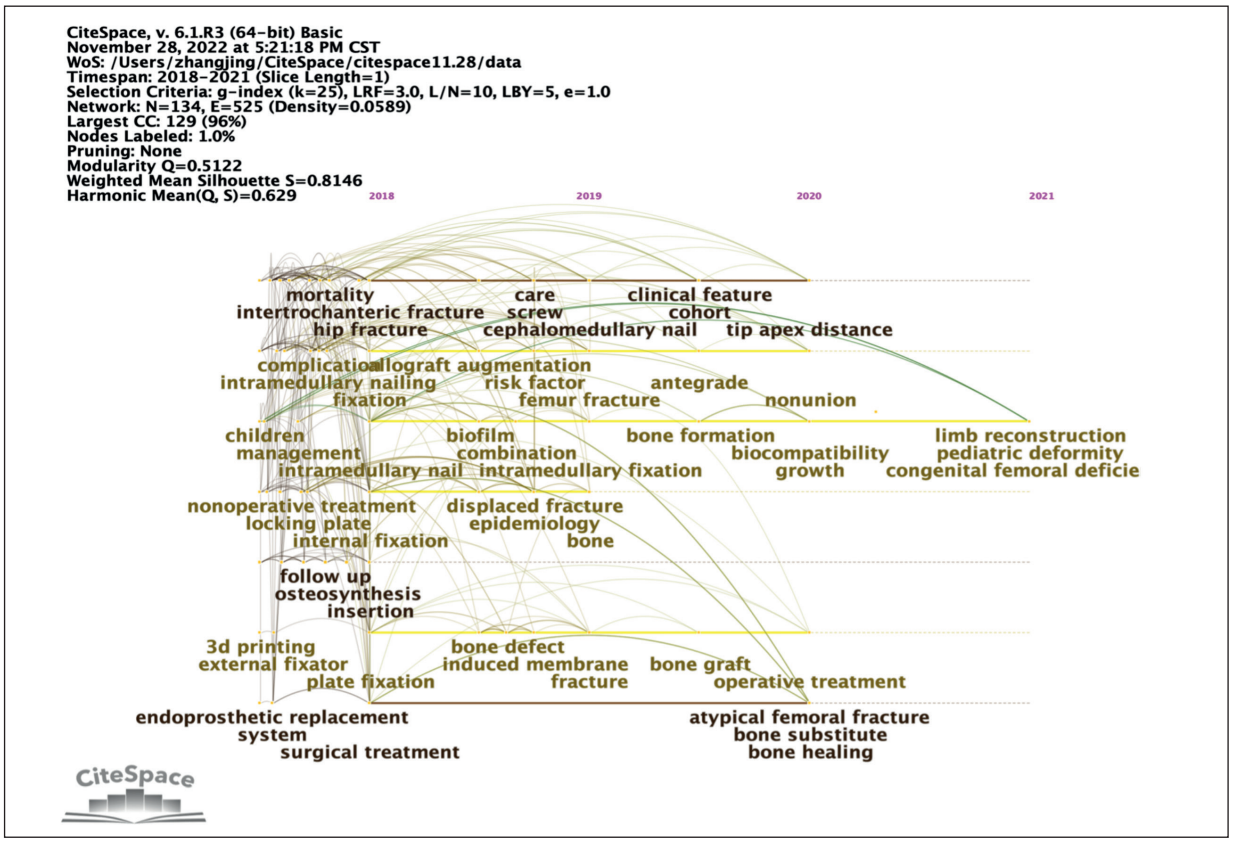

Figure 7. Clustering analysis of the keywords network based on time-line.

nation with 12 publications[5,27,28,30,58,62,67,87,89,90,93,115], no UK-based research institutions were among the top 15 in terms of research output, suggesting a lack of focused, sustained breakthroughs in this research space over the past 5 years. In contrast, Spain was home to three institutions among the top 15 and published 7[51,56,82,94,98,100,102] of the 100 most-cited articles, suggesting that researchers from these Spanish institutions are key contributors to the intramedullary nailing research space. The top three countries in terms of the impact of research on intramedullary nailing, based on national and institutional publications, are the United States, China, and Spain. The above three countries are North America, Asia, and Europe, respectively, with large populations and strong economies, which is the basis of their high level of medical scientific research.

Rozbruch SR, affiliated with the Hospital Special Surgery, Limb lengthening & Complex Reconstruction Service (NY, USA), was the most prolific author identified in this study, and no other authors published more than 3 articles among the 100 most-cited. The most collaborative authors identified through this bibliometric analysis were Chang Shi Min, Du Shou Chao, and Hu Sun Jun from Tongji University, School of Medicine, Yangpu Hospital, Department of Orthopaedical Surgery, and Hou Zhi Yong from The Third Hospital of Hebei Medical University, Department of Orthopaedical Surgery. Bibliographic coupling refers to the degree of correlation between multiple cited literature citing the same paper. When multiple authors jointly complete several articles with similar research contents, the literature cited will also be similar, so the co-authorship has a certain degree of correlation with the bibliographic coupling. It is highly probable that Chinese researchers, including the four authors mentioned, and their institutions will continue to make significant contributions to the field of intramedullary nail fixation in the near future. This is due to the fact that all four authors are from China, indicating that the country is likely to continue to produce important research in this area.

Based on the most-cited intramedullary nailing-focused studies over the past 5 years, the areas in which intramedullary nailing is most often

employed include orthopedic surgery, emergency surgery, critical care science, sports medicine, and pediatric orthopedics, with research focused on the use of intramedullary nailing in orthopedic settings exceeding the combined volume of research focused on the remaining four directions combined. As can be deduced from the 100 high-quality intramedullary nailing-related articles from the last 5 years, there are far more studies involving the clinical direction of intramedullary nailing than the basic medicine direction, with most of them focusing on acute severe fractures of adolescent tubular bones due to trauma or sports injuries.

With respect to the most prominent journals associated with these top 100 most-cited articles, the top 15 journals in terms of article output included 10 focused on the field of orthopedic and trauma surgery, 3 focused on biomedical materials, 1 focused on geriatric orthopedics, and 1 focused on pediatric orthopedics. This is because the current research on intramedullary nails is not only focused on adult traumatic fractures, but also achieved mature research foundation and achievements in the field of material science and non-adult fractures. The journals with the largest numbers of publications were "Injury International Journal of The Care of The Injured" and the "Journal of Orthopaedic Trauma", respectively published in the UK and the USA, which are both focused on the field of orthopedic and trauma surgery, exhibiting IF values of less than 3. In contrast, the journals in this field with the highest IF values are "Biomaterials and Acta Biomaterialia", with respective values of 15.304 and 10.633. This is due to the generally higher impact factor of journals in the field of materials compared to those in the field of orthopedic specialties. There is still room to improve the material properties of intramedullary nails in the bone marrow in terms of safety and practicality. Therefore, it is likely that more articles related to intramedullary nailing will be published in materials journals in the future.

Of the 100 most highly cited intramedullary nail fixation-related articles, the most highly cited with 93 total citations was "Antibacterial and immunogenic behavior of silver coatings on additively manufactured porous titanium"[8], while the 10th[65] and 100th[82] most cited articles respectively exhibited 39 and 15 citations. Of the 10 most-cited articles, 7, 2, and 1 were respectively published in 2018, 2019, and 2020. Higher numbers of citations generally indicate that a given study exhibited a degree of fundamental importance within a given field and may be related to an important research hotspot. Analyses of the top 10 most-cited[6,8,9,38,46,47,60,64,65,74] articles indicated that research pertaining to intramedullary nailing is focused on the properties of nail surface materials[8,9,74], the treatment of bone defects[65], the treatment of osseous nonunion[47], the treatment of tubular bone fractures[38,46,60,64], and crossover applications of smart devices[6]. Given that the time since publication has an impact on the number of citations for a given article, higher quality studies are increasingly likely to be overlooked with the passage of time, such that the top 3 most cited studies over the past three years are particularly likely to represent important hotspots for research in the near future. Only two articles[21,89] published in 2021 were among the 100 most-cited intramedullary nailing-related studies, including "PRECICE Nail: Our Experience With 50 Cases" and "Risk factors for mechanical failure of intertrochanteric fractures after fixation with proximal femoral nail antirotation (PFNA II): a study in a Southeast Asian population". Of these studies, the former specifically focused on the efficacy of intramedullary nailing as a means of treating congenital developmental abnormalities of the lower limbs, while the latter was focused on the analysis of the causative factors underlying PFNA internal fixation failure. The three articles[9,39,107] published in 2020 with the most citations were "Biodegradable Zn-Cu alloys show antibacterial activity against MRSA bone infection by inhibiting pathogen adhesion and biofilm formation", "Intertrochanteric Femur Fracture Treatment in Asia What We Know and What the World Can Learn" and "Development and Internal Validation of Machine Learning Algorithms for Preoperative Survival Prediction of Extremity Metastatic Disease". These studies respectively explored the clinical application of zinc-copper alloys for intramedullary nailing, the utilization of intramedullary nailing in inter-rotor fractures, and the combination of machine learning with intramedullary nailing in extremity bone tumors. The three most[38,65,70] highly cited articles in 2019 included "Hybrid fracture fixation systems developed for orthopedic applications: A general review", "Very long-term results of post-traumatic bone defect reconstruction by the induced membrane technique", and "Nail Plate Combination Technique for Native and Periprosthetic Distal Femur Fractures". These studies respectively assessed the application of intramedullary nailing in compari-

son to other built-in devices, in combination with osteoinduction techniques, and in combination with plate fixation. Through the use of the CiteSpace timeline and clustering algorithm analyses of the keywords associated with these top 100 most-cited intramedullary nail fixation-related studies, topics in this field that were identified as the subjects of rapidly growing research interest in 2021 included work focused on the application of intramedullary nailing in the context of limb reconstruction, pediatric deformities, and congenital femoral shortening. A growing number of researchers focusing in particular on clinical outcomes associated with the use of intramedullary nailing for congenital bone diseases[33,45,53,57,88,111], limb lengthening reconstruction[59,89,92,93], intertrochanteric and peritrochanteric fractures[23,30,34,37,71-73,78,84-86,94,98,106], femoral fractu re[26,40,43,49,55,60,76,90,96,108,113-115], tibial fractu re[25,27,32,54,62,67,69,91,97,103,105], humeral fractures[35,36,41], clavicle fracture[29,75,101,112], metacarpal fractures[110], ankle fractures[87,102] and other forms of intramedullary nail grafts[24,50,66,80,83,100]. Hip fracture-related research[21,44,51,56,58,68,95,116] has centered around hip and peripheral fractures, with specific topics of research focus ranging from operative mortality in 2018 to the effectiveness of cephalomedullary intramedullary nailing in 2019, to the tip apex distance studies in 2020. Several orthopedic trauma studies[52,81,82] have recently focused on proximal humerus fractures, owing to ongoing debate centered around the relative benefits of conservative *vs.* surgical treatment and the value of intramedullary nailing when treating displaced fractures. In addition, the application of intramedullary nails in patients with proximal humeral fracture and tumor has been proven to achieve excellent clinical results in the early postoperative period[119]. Intramedullary nail fixation has been established as a common surgical approach to treating bone nonunion[48,104,119], and combining this strategy with the Masquelet technique has recently been used to treat a range of large segmental bone defects[79]. Notably, a growing number of studies since 2018 have reported positive outcomes associated with the application of tubular prostheses with intramedullary nailing at one end, particularly following the resection of bone tumors[28,61,63]. Continuous developments in technological approaches continue to transform this research space, and the combination of intramedullary nailing with induction devices as a means of exploring fracture microenvironmental conditions represented a promising research direction[6]. The application of virtual reality can also aid efforts to teach surgeons the techniques required to complete intramedullary nailing procedures[22]; while the use of navigation technologies to place intramedullary nails can help decrease the operative duration while improving overall operative precision[109]. In addition, using different metal alloys applied to the exterior of intramedullary nails offers the opportunity to improve the performance of these medical devices with respect to their antibacterial or pro-vascularization properties[7,42,99,100]. Meanwhile, for tubular bone fractures, intramedullary nails combined with drugs, such as clolophosphoric acid[120], or combined with wire cerclage, can significantly improve the functional recovery of the limb after operation[117]. In the articles[109,121,122] on high-quality intramedullary nailing, the application of virtual reality technology has expanded from simple intraoperative screw positioning to teaching and practicing the anatomy of intramedullary nail placement, incision selection, intramedullary nail placement, and positioning, and can also be applied to other orthopedic procedures. However, only 1[7] of the highly cited articles in the last 5 years describes the application of electromagnetic navigation techniques for the simulated placement of intramedullary nails in the tibia. However, the navigation technique has been implemented in clinical surgery with laser navigation and allows for semi-automatic navigation with orthopedic robots throughout the operation. As far as the material application of intramedullary nails is concerned in the top 100 cited articles, the articles mostly focus on the exploration of animal experiments. The study of materials for the surface coating of its intramedullary nail has changed from silver-titanium alloy and magnesium-zinc alloy in the past to titanium-aluminum alloy and then to zinc-copper alloy at present. The application of intramedullary nails is inseparable from the development of technology, and comprehensive clinical evaluation before surgery, such as medico-legal evaluation, will maximize the maximum benefit of intramedullary nail placement, such as fracture type, bone mass, and the type and specification of intramedullary nail selection[118]. Before performing intramedullary nailing surgery, a complete evaluation should not only include understanding the mechanism of injury but also pay attention to the ergonomics of the injured site and the whole limb. Only precise mechanical fixation can lead to excellent limb rehabilitation[123].

Conclusions

As most research progress focused on the current clinical applications of intramedullary nail fixation has occurred within the last 5 years, this bibliometric study was specifically restricted to the top 100 most-cited articles on this topic published from 2018-2022. The most cited article during this period was "Antibacterial and immunogenic behavior of silver coatings on additively manufactured porous titanium", the USA was the most productive country in this field, and the most influential journals were "Injury International Journal of The Care of The Injured" and the "Journal of Orthopaedic Trauma". The institutions responsible for the publication of the most highly influential articles were the University of California System and the University System of Ohio, while the most prolific author in this space was Rozbruch SR. Combinations of intramedullary nailing with magnetic navigation, induction devices, and virtual or augmented reality are increasingly being employed in clinical procedures and teaching settings. Most published studies[3,22,40,44,49,51,70,76,77,79,94,108,117] related to intramedullary nailing have focused on intertrochanteric fractures and femoral fractures. These analyses suggest that potentially promising future directions in this research space may include limb-lengthening procedures and efforts to correct congenital femoral shortening. We hope that this bibliometric analysis will serve as a valuable foundation and guide for researchers seeking to conduct additional high-quality research centered around intramedullary nail fixation in the coming years.

Ethics Approval
Not applicable

Informed Consent
Not applicable

Conflict of Interest
The authors have no competing interests to declare.

Funding
None.

Authors' Contributions
Concept and design: HH. Data collection and analysis: HH, FY. Drafting of the article: HH, HQZ. Study supervision: LJD. All the authors read and approved the final article.

Data Availability
All data that support the findings of the study are included in this manuscript.

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