Review

ANNALS OF MEDICINE & SURGERY

OPEN

Knowledge mapping of core decompression in osteonecrosis of the femoral head: a bibliometric analysis

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Background: Osteonecrosis of the femoral head (ONFH), caused by disrupted blood supply leading to bone cell death and joint collapse, remains a critical orthopedic challenge. While core decompression has advanced significantly in ONFH treatment, no bibliometric analysis has mapped its research landscape.
Method: We analyzed 854 articles from the Web of Science Core Collection (1986–2023) using VOSviewer, CiteSpace, and bibliometrix.
Results: Publications surged from 5.4/year (1986–2001) to 52.3/year (2015–2023), reflecting intensified interest. China (253 articles, 29.6%) and the United States (232, 27.2%) dominated contributions, with Stanford University and Johns Hopkins University as top institutions. International collaborations linked China to the United States, Germany, and England. *Clinical Orthopaedics and Related Research* was the most cited journal (4708 citations). Keyword analysis revealed emerging hotspots: mesenchymal stem cells (19 occurrences), cell therapy, and angiogenesis. Citation bursts highlighted Mont MA's seminal work (burst strength: 19.67) on joint-preserving strategies and stem cell-enhanced core decompression.
Conclusion: This first bibliometric study delineates trends, collaborations, and frontiers in core decompression for ONFH, emphasizing the translational potential of stem cell therapies.

Keywords: bibliometrics, citeSpace, core decompression, osteonecrosis of the femoral head, VOSviewers

Introduction

Osteonecrosis of the femoral head (ONFH) is a prevalent orthopedic condition characterized by bone tissue necrosis resulting from impaired or interrupted blood supply. This condition precipitates structural alterations in the femoral head, potentially culminating in significant hip pain, collapse of the articular surface, and eventual osteoarthritis[1]. The global incidence of ONFH is increasing, particularly among young and middle-aged populations[2,3]. In the United States, the estimated annual incidence of ONFH ranges from approximately 15 000–20 000 new cases[2,4]. Similar trends are observed in East Asian countries, including Japan, China, and South Korea, affecting a significant portion of the population[5–7]. Early-stage management of ONFH presents a consistent clinical challenge. Primary treatment objectives include symptom improvement, collapse delay, and postponement of total hip replacement surgery. A variety of methods aim to prevent or decelerate ONFH progression, with core decompression being the most prevalent treatment approach[8].

Seventy years ago, Phemister[9] introduced the marrow decompression theory, positing that impaired venous return in the femoral head increases medullary pressure, leading to femoral head necrosis. This theory underpins the marrow decompression technique still in use today[9]. Arlet and Ficat[10], French

HIGHLIGHTS

- First bibliometric analysis of core decompression in osteonecrosis of the femoral head, covering 854 publications.
- China and the United States are the top contributors, with Stanford University and Johns Hopkins University leading institutions.
- Mont MA and Goodman SB are the most influential authors, significantly contributing to the field.
- Emerging research hotspots include clinical outcomes and mechanisms involving mesenchymal stem cells and angiogenesis.
- Advanced bibliometric tools (VOSviewer, CiteSpace, bibliometrix) used to visualize and analyze research trends and collaborations.

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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Annals of Medicine & Surgery (2025) 87:2718–2735

Received 25 December 2024; Accepted 19 February 2025

Published online 4 April 2025

http://dx.doi.org/10.1097/MS9.0000000000003110

physicians, serendipitously found that bone tissue biopsies of the femoral head in early-stage patients rapidly alleviated postoperative pain. This discovery led to the development of core decompression as a treatment method for ONFH. After summarizing 159 studies, Roth *et al*[11] concluded that core decompression can effectively treat ONFH with an area smaller than 30% and is included in the German guidelines for the treatment of ONFH. Core decompression alleviates bone pressure, mitigates the hardening zone obstructing osteonecrosis repair, promotes blood vessel formation around the decompression tunnel, facilitates new bone replacement, and slows osteonecrosis progression. This approach is supported by numerous studies[2,12,13].

Bibliometrics is a literature analysis method that quantitatively and qualitatively analyzes the output and status of publications within a specific research field. This analysis provides detailed information about authors, keywords, journals, countries, institutions, references, and more within the relevant research field[14]. To achieve this, three established bibliometric tools were utilized: CiteSpace[15], which identifies research frontiers and citation bursts through temporal network analysis; VOSviewer[16], which visualizes collaborative networks and keyword co-occurrence patterns; and the R package "bibliometrix"[17], which tracks thematic evolution and geographic contributions. These tools have been widely applied in medical disciplines including rheumatology[18], neurology[19], dentistry[20], and orthopedics[21], demonstrating their robustness in mapping scientific landscapes.

Despite previous bibliometric analyses on ONFH's international research status[22–25], specific progress in core decompression research has not been detailed. Recent studies, however, suggest promising prospects for core decompression in ONFH treatment. Addressing this research gap, this study aims to conduct a bibliometric analysis of core decompression publications in ONFH. By delineating global collaboration patterns and tracking technical evolution, this analysis provides actionable insights for evidence-based policymaking. Identifying institutional productivity gaps can promote collaborative efforts to accelerate multicenter clinical validation. Moreover, temporal keyword shifts will highlight areas where patient selection for minimally invasive decompression techniques can be refined, driving progress in early-stage ONFH interventions.

Methods

Search strategy

On 11 January 2024, a literature search was conducted using the Web of Science Core Collection (WoSCC) database (https://www.webofscience.com/wos/alldb/basic-search). The search strategy employed was TS = (Osteonecrosis of the Femoral Head) OR TS = (ONFH) OR TS = (Femur Head Necrosis) OR TS = (Osteonecrosis of Femur Head) AND TS = (Core Decompression) AND LA = (English), restricting document types to "articles" and "reviews" (Fig. 1). The publication timeframe was not limited. WoSCC was chosen for its comprehensive citation indexing and reliable dataset. While limiting the scope to English-language publications, this approach ensures a consistent and focused analysis of key research trends.

Data analysis

VOSviewer (version 1.6.20) is a bibliometric analysis tool designed to extract pivotal information from numerous publications. It is widely used to construct networks of collaboration, co-citation, and co-occurrence[26,27]. In this study, the software was primarily used to perform analyses on countries and institutions, journals and co-cited journals, authors and co-cited authors, as well as keyword co-occurrence. The map produced by VOSviewer depicts various entities like countries, institutions, journals, and authors, each represented as a node. Node size denotes the item count, color indicates classification, and line thickness between nodes reflects the degree of collaboration or co-citation among items[28].

CiteSpace, created by Professor Chen Chaomei, facilitates bibliometric analysis and visualization. It helps researchers understand the development of a field, identify seminal literature and leading research groups, and discern research frontiers and trends. It has the potential to greatly enhance literature research

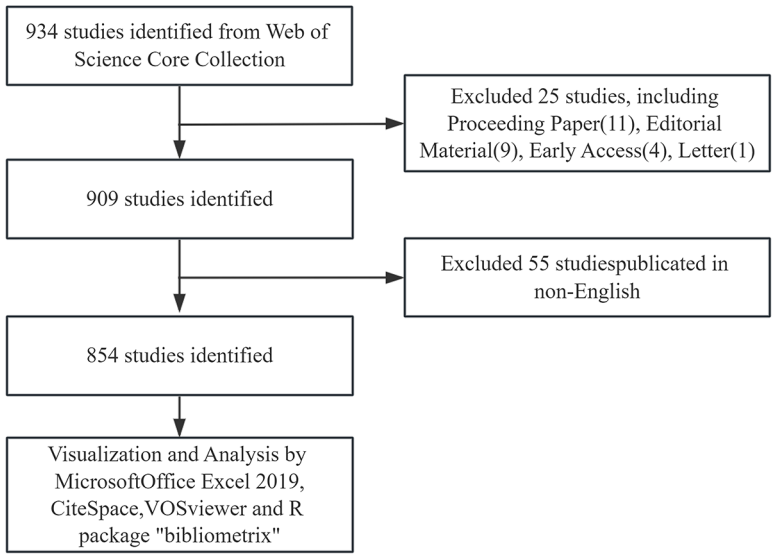

Figure 1. Publications screening flowchart.

efficiency[29,30]. In this study, CiteSpace was used to generate a dual-map overlay of journals and to analyze references through Citation Bursts.

The R package "bibliometrix" (version 4.1.4) was employed to conduct a thematic evolution analysis and to map the global distribution of publications on core decompression in ONFH[31]. Journal quartiles and impact factors were sourced from the 2023 *Journal Citation Reports*. Additionally, quantitative analysis of publications was conducted using Microsoft Office Excel 2021.

Results

Quantitative analysis of publication

The search strategy identified a total of 854 studies on core decompression in ONFH, consisting of 726 articles and 128 reviews. Analysis of the annual publication growth rate categorizes the timeline into three phases: Period I (1986–2001), Period II (2002–2014), and Period III (2015–2023). Figure 2 shows an average annual publication count of 5.4 papers during Period I. Research output on core decompression in ONFH was limited in this period. Period II witnessed a steady increase in publications, averaging about 22.8 papers per year. Period III experienced a marked rise in publications, with an average of 52.3 papers per year. The year 2018 saw the publication of 60 relevant papers, 1.7 times the number published in 2017. This marked an important surge in research output on core decompression in ONFH. Over the last 8 years (Period III), a consistent upward trend in publications on core decompression in ONFH has led to a significant increase in total papers relative to the previous periods.

Country and institutional analysis

This study encompasses publications from 51 countries and 985 institutions. The top 10 contributing countries span Asia (5), Europe (4), and North America (1), as detailed in Table 1. China leads with the highest publication count (253, 29.6%), followed by the United States (232, 27.2%), Germany (77, 9.0%), and France (45, 5.3%). Together, China and the United States contribute over half of the total publications (56.8%). While these countries lead the research output, there is a notable underrepresentation of regions such as Africa, South America, and parts of Southeast Asia. For example, countries like Brazil (three publications, 0.4%) and South Africa (two publications, 0.2%) have minimal contributions to the literature on core decompression for ONFH. This highlights a global research gap, where certain regions are not adequately represented in the scientific discourse surrounding this important treatment. Subsequently, we identified countries with at least two publications, visualizing a collaborative network that reflects publication volume and inter-country relationships (Fig. 3). Significantly, the data reveal extensive international collaboration. Specifically, China closely cooperates with the United States, Germany, and England. Meanwhile, the United States engages actively with England, Poland, Japan, and South Korea.

Six out of the top 10 institutions are based in China, with the others distributed among two countries. The leading four institutions by publication count include Stanford University (23 papers, 1.7%), Johns Hopkins University (23 papers, 1.7%), Shanghai Jiao Tong University (19 papers, 2.2%), and Dalian University (18 papers, 2.1%). Subsequently, a visual representation was created for 43 institutions with at least six publications each, forming a collaborative network mapped by the volume and interrelations of their work (Fig. 4). The nodes in the network represent individual institutions, and the lines between them indicate their collaborative relationships. In the case of institutions with multiple collaborations, some nodes may appear to overlap, which is a result of the close and frequent interactions between these institutions. Figure 4 illustrates strong collaboration among Harvard Medical School, Brigham and Women's Hospital, and Massachusetts General Hospital, as well as notable cooperation among Ohio State

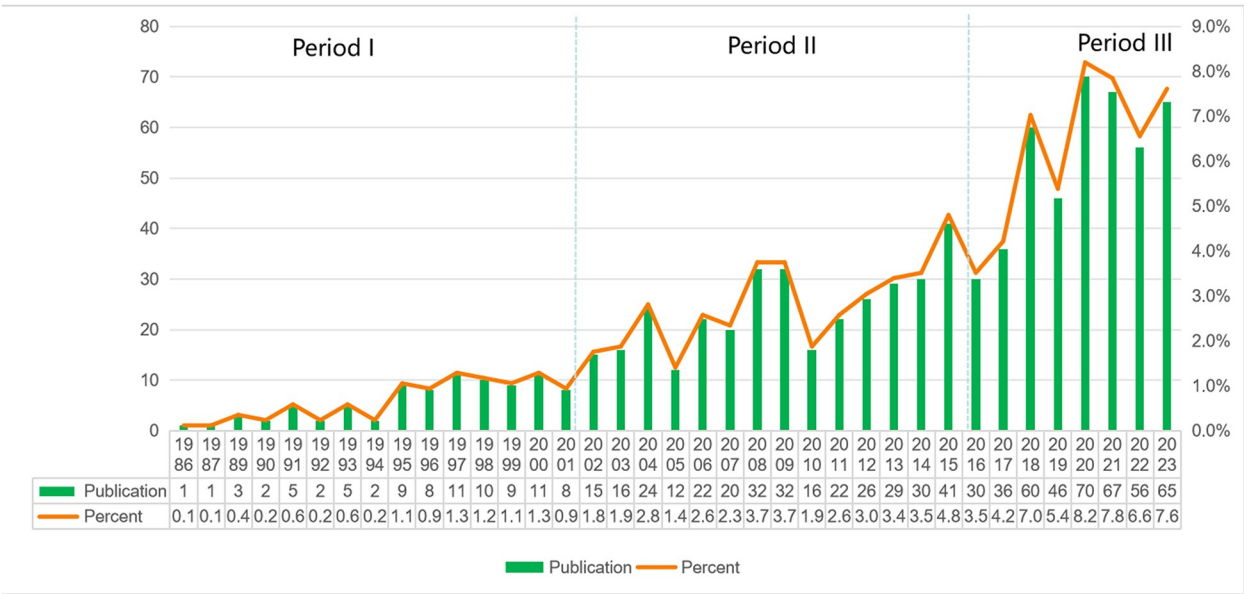

Figure 2. Annual output of research of core decompression in ONFH.

Table 1

Top 10 countries and institutions on research of core decompression in ONFH

Rank	Country	Counts	Institution	Counts
1	China (Asia)	253 (29.6%)	Stanford University (United States)	23 (2.7%)
2	United States of America (North America)	232 (27.2%)	Johns Hopkins University (United States)	23 (2.7%)
3	Germany (Europe)	77 (9.0%)	Shanghai Jiao Tong University (China)	19 (2.2%)
4	France (Europe)	45 (5.3%)	Dalian University (China)	18 (2.1%)
5	Japan (Asia)	43(5.0%)	China Japan Friendship Hospital (China)	18 (2.1%)
6	South Korea (Asia)	36 (4.2%)	Xi'an Jiao Tong University (China)	18 (2.1%)
7	England (Europe)	29 (3.4%)	Seoul National University (South Korea)	16 (1.9%)
8	Taiwan, China (Asia)	29 (3.4%)	Sichuan University (China)	16 (1.9%)
9	India (Asia)	25 (2.9%)	Sinai Hospital (United States)	16 (1.9%)
10	Italy (Europe)	21 (2.5%)	Chang Gung University (Taiwan, China)	14 (1.6%)

University, University of California, Stanford University, and the University of Pittsburgh.

Journals and co-cited journals

A total of 284 publications across various journals have addressed the topic of core decompression in ONFH. *Clinical Orthopaedics and Related Research* published the most papers on the topic (66 papers, 23.2%), followed by *International Orthopaedics* (47 papers, 16.5%), *Journal of Bone and Joint Surgery—American Volume* (43 papers, 15.1%), and *Journal of Arthroplasty* (32 papers, 11.3%). These journals have been pivotal in disseminating research on core decompression in ONFH. *Stem Cell Research & Therapy*, among the top 15 journals, boasted the highest impact factor at 7.5, with *Journal of Bone and Joint Surgery—American Volume* following at an impact factor of 5.3. Subsequently, we screened 50 journals each with at least four relevant publications and visualized the journal network (Fig. 5A), where node size reflects publication count per journal. Figure 5A illustrates active citation relationships between *Clinical Orthopaedics and Related Research* and journals like *Journal of Bone and Joint Surgery*, *Archives of Orthopaedic and Trauma Surgery*, and *Orthopedic Clinics of North America*.

Table 2 reveals that 6 out of the top 15 co-cited journals accumulated more than 1000 citations each. Clinical Orthopaedics and Related Research was the most cited journal, receiving 4708 co-citations, followed by *Journal of Bone and Joint Surgery—American Volume* (4136 co-citations), *Journal of Bone and Joint Surgery—British Volume* (2485 co-citations), and *Journal of Arthroplasty* (1213 co-citations). Furthermore, Radiology holds the highest impact factor at 19.7, with *Journal of Bone and Joint Surgery—American Volume* following at 5.3. Journals having at least 150 co-citations were selected for creating a co-citation network visualization (Fig. 5B). In this network, line thickness between journals represents the frequency of simultaneous citations in source articles. Figure 5B shows that there are positive co-citation relationships between *Journal of Bone and Joint Surgery—American Volume* and both *Journal of Bone and Joint Surgery—British Volume and Clinical Orthopaedics and Related Research*.

The dual-map overlay of journals illustrates the citation dynamics between citing journals (clustered on the left) and co-cited journals (clustered on the right)[32]. Figure 6 reveals the primary citation trajectory, highlighted in green, showing that research from Medicine/Medical/Clinical journals is chiefly cited by works in Health/Nursing/Medicine, Dermatology/Dentistry/Surgery, and Sports/Rehabilitation/Sport domains.

Authors and co-cited authors

In the study on core decompression in ONFH, a total of 3606 authors participated. Among the top 10 authors, 2 have published more than 20 papers each (Table 3). A collaborative network was constructed for authors who published three or more papers (Fig. 7A), where node size indicates publication output and line thickness shows co-authorship frequency. Mont MA, Goodman Stuart B, Zhao Dewei, and Hernigou Philippe are represented by the largest nodes, reflecting their significant publication counts. Furthermore, tight collaborations were observed among several authors. Notably, Mont MA had close collaborations with Hungerford DS and Marker David R, and Goodman Stuart B actively collaborated with Maruyama Masahiro.

Among the 9249 co-cited authors, three were cited more than 500 times each (Table 3). Mont MA emerged as the most co-cited author (1350 citations), followed by Hernigou P (728 citations) and Steinberg ME (631 citations). Authors with at least 100 co-citations were selected to generate co-citation network graphs (Fig. 7B), where larger nodes denote higher co-citation counts and connecting lines represent citation frequency. Figure 7B shows active collaborations between co-cited authors, notably between Mont MA and Zhao DW, and between Steinberg ME and Gangji V.

Co-cited references

This study co-cited a total of 13 085 references on core decompression in ONFH research. Each of the top 10 co-cited references (Table 4) was cited at least 109 times, with the highest reaching 254 citations[33]. References receiving 50 or more co-citations were selected for the co-citation network map construction (Fig. 8). "Ficat RP, 1985, Journal of Bone and Joint Surgery" demonstrates active co-citations with "Steinberg ME, 1995, Journal of Bone and Joint Surgery" and "Mont MA, 1996, Clinical Orthopaedics and Related Research."

Reference with citation bursts

The term "reference with citation bursts" denotes references that are frequently cited by scholars in a particular field over a defined period. Using CiteSpace, our study identified 13 references exhibiting significant citation bursts (Fig. 9). Figure 9

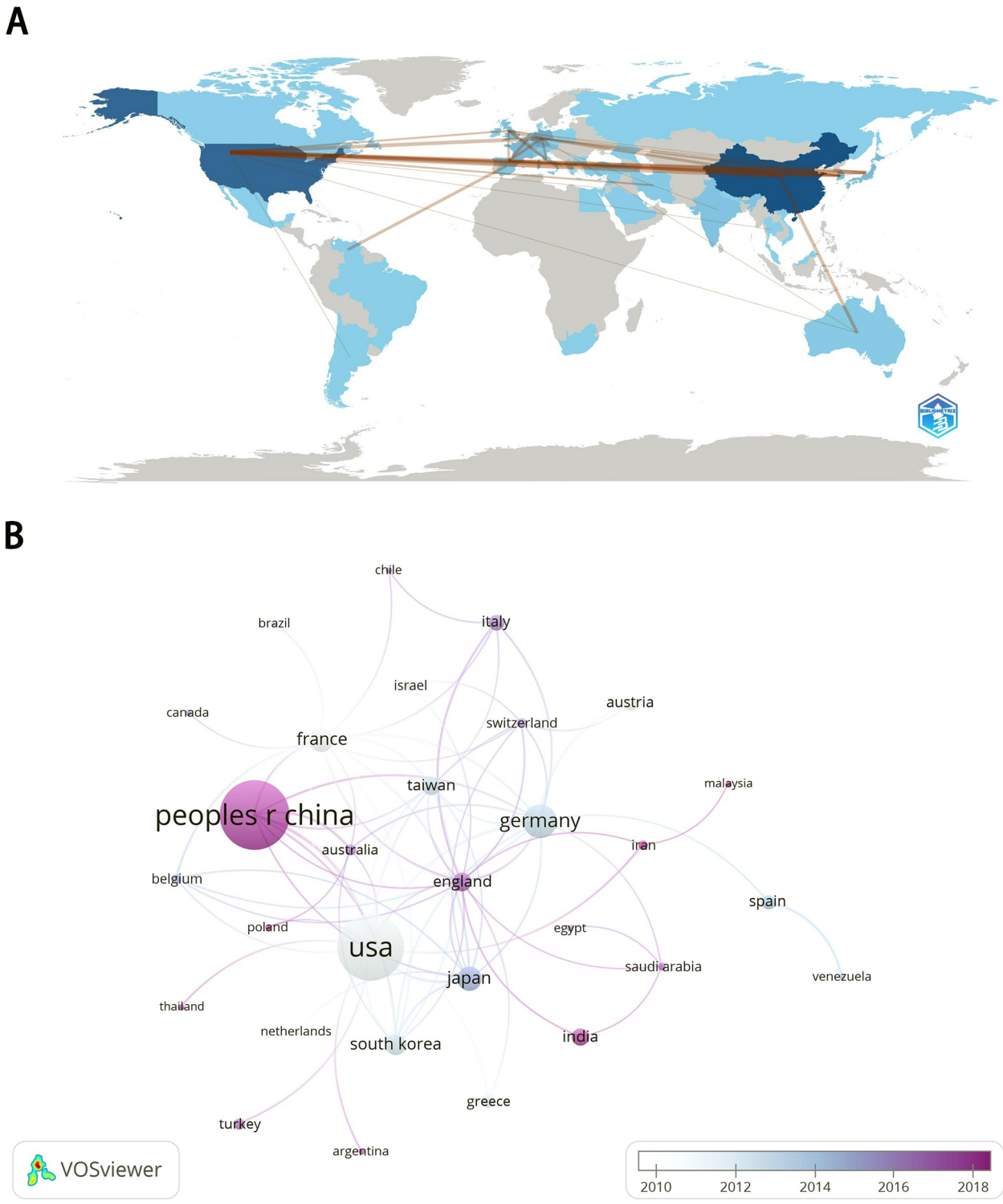

Figure 3. The geographical distribution (A) and visualization of countries (B) on research of core decompression in ONFH.

shows that the red bar indicates the year of each significant citation burst[34]. Citation bursts for these references spanned from 1996 to 2023. The reference "Nontraumatic Osteonecrosis of the Femoral Head: Where Do We Stand Today? A Ten-Year Update" by Mont MA *et al* showed the highest citation burst strength of 19.67 from 2017 to 2022, reflecting its significant impact on the field during this period. "Nontraumatic Osteonecrosis of the Femoral Head: Where Do We Stand Today?: A 5-Year Update" in the *Journal of Bone and Joint Surgery—American Volume* by Mont MA, had the second-highest citation burst strength of 19.00 from 2020 to 2023. These 13 references showed burst strengths between 11.49 and 19.67,

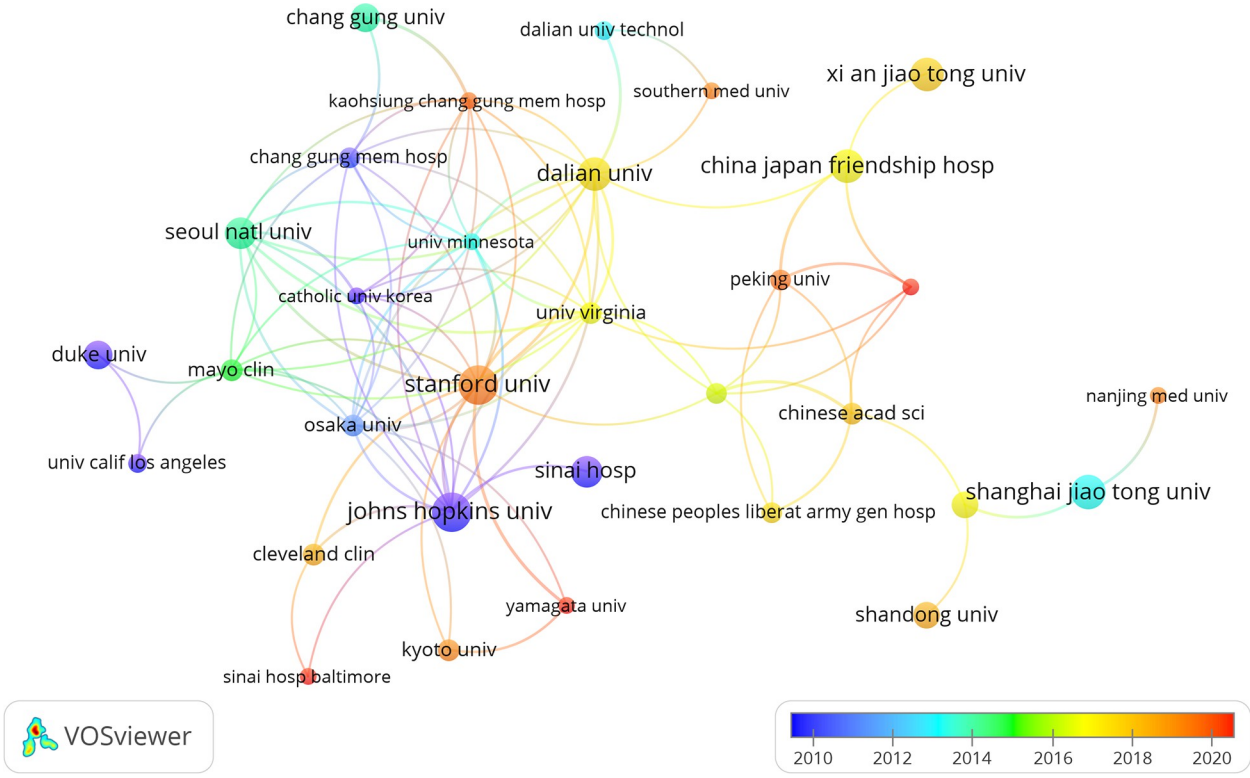

Figure 4. The visualization of institutions on research of core decompression in ONFH.

with durations spanning 3 to 7 years. Table 5 summarizes the main research findings of the 13 references, organized by the intensity of their citation bursts as shown in Figure 9.

Hotspots and frontiers

The analysis of keyword co-occurrence facilitates the swift identification of research hotspots within a particular domain. Table 6 outlines the top 20 high-frequency keywords linked to core decompression in ONFH studies. Among these keywords, mesenchymal stem cells (MSCs) appeared 19 times, highlighting their central role in ONFH research related to core decompression.

We filtered keywords with five or more occurrences and conducted cluster analysis using VOSviewer (Fig. 10A), where colors denote distinct research themes and node size reflects keyword frequency. Thicker lines between nodes denote stronger keyword connections. Figure 10A depicts two distinct clusters representing different research directions. The blue cluster comprises keywords such as osteonecrosis, bone marrow edema, systemic lupus erythematosus, sickle cell disease, collapse, and corticosteroids. The green cluster includes core decompression, stem cells, bone graft, cell therapy, MSCs, angiogenesis, bone regeneration, osteogenesis, and arthroplasty. Trend analysis (Fig. 10B) indicated that pre-2015 research primarily focused on clinical symptoms and interventions, with key terms like systemic lupus erythematosus, magnetic resonance imaging, conservative treatment, bone marrow edema, osteotomy, alendronate, and transient osteoporosis. In the trend visualization (Fig. 10B), vertical positioning indicates the temporal emergence of topics (higher nodes = recent trends). Post-2016, there was a shift toward exploring ONFH pathogenesis and the therapeutic role of stem cells, with prominent terms including hip preservation, biomaterials, angiogenesis, sickle cell disease, and stem cells. These keywords reflect the growing interest in regenerative medicine and novel therapeutic strategies.

Discussion

General information

From 1986 to 2001, an average of 5.4 papers were published annually, reflecting the nascent stage of research on core decompression in ONFH. The period between 2002 and 2014 saw a consistent rise in research output, with an average of 22.8 papers published per year. Subsequently, from 2015 to 2023, there was a remarkable surge in publications, averaging 52.3 papers annually. This rapid growth in publications over the past 8 years signifies an explosive phase of research in core decompression for ONFH. This surge reflects the growing interest in understanding the underlying mechanisms of ONFH and exploring innovative treatment options. As the field continues to expand, it provides a solid foundation for future clinical trials aimed at refining core decompression techniques.

China and the United States are the leading countries in conducting research on core decompression in ONFH, with China taking the lead. Six out of the top 10 research institutions are located in China, followed by 3 in the United States (30%) and 1 in South Korea (10%). Close cooperation was observed among four countries: China, the United States, Germany, and England. In particular, while cooperation between China and the United States in the field of ONFH research has grown, including

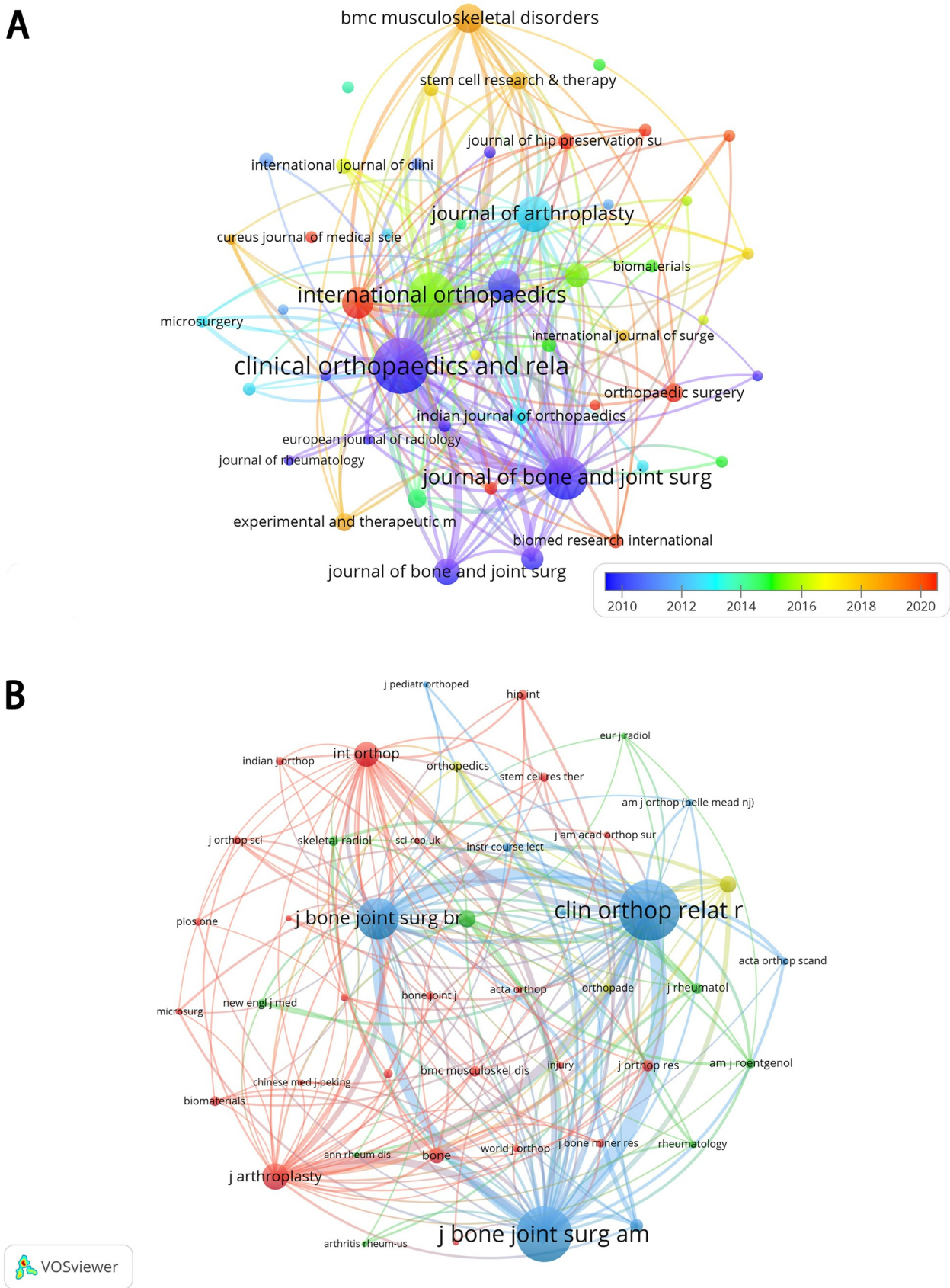

Figure 5. The visualization of journals (A) and co-cited journals (B) on research of core decompression in ONFH.

Table 2

Top 15 journals and co-cited journals for research of core decompression in ONFH

Rank	Journal	Count	IF	Q	Co-cited journal	Co-citation	IF	Q
1	*Clinical Orthopaedics and Related Research*	66 (23.2%)	4.2	Q1	*Clinical Orthopaedics and Related Research*	4708	4.2	Q1
2	*International Orthopaedics*	47 (16.5%)	2.7	Q2	*Journal of Bone and Joint Surgery -American Volume*	4136	5.3	Q1
3	*Journal of Bone and Joint Surgery -American Volume*	43 (15.1%)	5.3	Q1	*Journal of Bone and Joint Surgery -British Volume*	2485	4.6	Q1
4	*Journal of Arthroplasty*	32 (11.3%)	3.5	Q1	*Journal of Arthroplasty*	1213	3.5	Q1
5	*Archives of Orthopaedic and Trauma Surgery*	26 (9.2%)	2.3	Q2	*International Orthopaedics*	1072	2.7	Q2
6	*Journal of Orthopaedic Surgery and Research*	25 (8.8%)	2.6	Q2	*Radiology*	593	19.7	Q1
7	*BMC Musculoskeletal Disorders*	23 (8.1%)	2.3	Q3	*Archives of Orthopaedic and Trauma Surgery*	562	2.3	Q2
8	*Journal of Bone and Joint Surgery—British Volume*	19 (6.7%)	4.6	Q1	Bone	507	4.1	Q2
9	*Hip International*	16 (5.6%)	1.5	Q2	*Orthopedic Clinics of North America*	379	1.8	Q3
10	*Orthopedic Clinics of North America*	15 (5.3%)	1.8	Q1	*Journal of Orthopaedic Research*	285	2.8	Q2
11	*Orthopedics*	11 (3.9%)	1.1	Q3	*Journal of Rheumatology*	259	3.9	Q2
12	*Orthopaedic Surgery*	11 (3.9%)	2.1	Q2	*BMC Musculoskeletal Disorders*	256	2.3	Q3
13	*Stem Cell Research & Therapy*	10 (3.5%)	7.5	Q1	*Orthopedics*	248	1.1	Q3
14	*Experimental and Therapeutic Medicine*	10 (3.5%)	2.7	Q3	*American Journal of Roentgenology*	246	5	Q1
15	*Indian Journal of Orthopaedics*	9 (3.2%)	1	Q4	*Hip International*	243	1.5	Q2

shared academic publications and joint research efforts, there is still room for greater collaboration. The involvement of institutions like Harvard Medical School and Brigham and Women's Hospital from the United States has led to advancements in the surgical techniques for core decompression, which have been significant for the broader field. Similarly, Germany and the United Kingdom have contributed to innovations in diagnostic tools, particularly through imaging technologies used in core decompression surgeries. Additionally, the United States has active collaborations with England, Poland, Japan, and South Korea. Among research institutions, a strong cooperative relationship exists, including those at Harvard Medical School, Brigham and Women's Hospital, and Massachusetts General Hospital. However, it was also observed that Shanghai Jiao Tong University, the most prolific institution in China, had limited collaboration with other institutions, potentially hindering the long-term development of academic research. While cooperative relations exist between certain countries, the breadth and intensity of cooperation between institutions are suboptimal. For example, the level of cooperation between institutions in the United States and China is relatively low, potentially impeding the long-term development of the research field. Therefore, we strongly recommend that research institutions in various countries engage in extensive cooperation and communication to collectively advance the development of core decompression in ONFH.

The majority of core decompression research in ONFH has been published in *Clinical Orthopaedics and Related Research* (impact factor = 4.2, Q1), making it the predominant journal in this research field. Among these journals, *Stem Cell Research &*

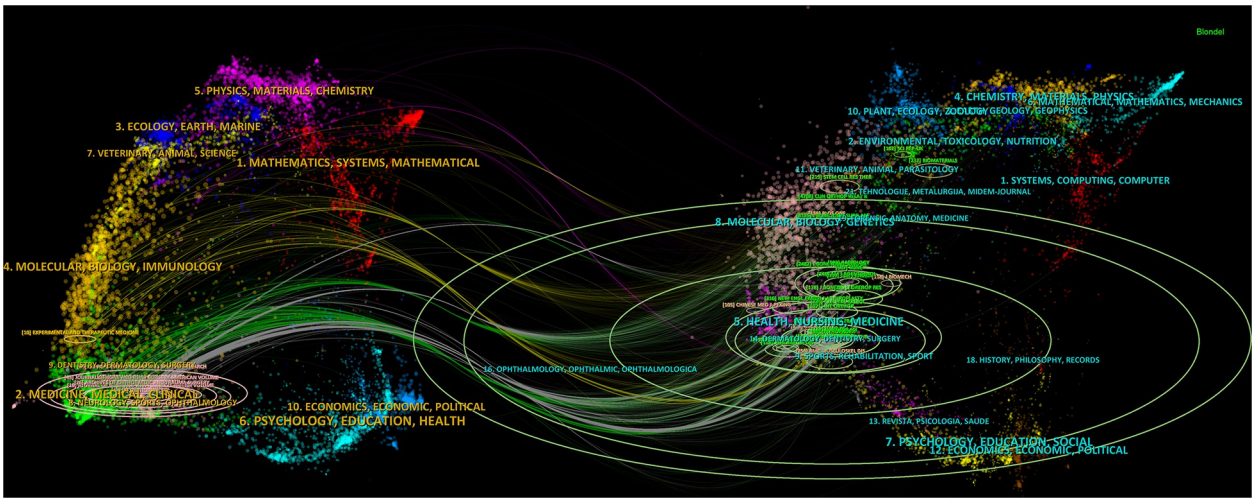

Figure 6. The dual-map overlay of journals on research of core decompression in ONFH.

Table 3

Top 10 authors and co-cited authors on research of core decompression in ONFH

Rank	Authors	Count	Co-cited authors	Citations
1	Mont MA	39	Mont MA	1350
2	Goodman Stuart B.	20	Hernigou P	728
3	Zhao Dewei	18	Steinberg ME	631
4	Hernigou Philippe	15	Ficat RP	363
5	Sun Wei	15	Gangji V	281
6	Jones Lynne C.	10	Zhao DW	281
7	Wang Benjie	10	Hungerford DS	266
8	Hungerford DS	10	Koo KH	259
9	Landgraeber Stefan	10	Lieberman JR	219
10	Maruyama Masahiro	9	Wang CJ	176

Therapy (impact factor = 7.5, Q1) has the highest impact factor, followed by the *Journal of Bone and Joint Surgery—American Volume* (impact factor = 5.3, Q1). These journals are internationally recognized for their high quality, thereby providing valuable support for core decompression research in ONFH. Furthermore, current core decompression research in ONFH is primarily published in clinically oriented journals, suggesting that a significant portion of the research is in the clinical study stage.

Mont MA and Goodman Stuart B have authored the most articles on this topic. Mont MA has contributed to 39 articles, with a primary focus on three key research areas. The first area of focus is "Advancements in Core Decompression Techniques," wherein they explore the evolution of core decompression for ONFH by examining innovative surgical methods and contrasting them with traditional techniques[43,46,47]. These articles highlight notable advancements, such as precise drilling techniques to minimize trauma, bone grafting, and the use of bone marrow aspirate concentrate. These innovations enhance core decompression, particularly in early-stage osteonecrosis, leading to improved patient outcomes and slowed disease progression[12,48,49]. The second area of focus is "Surgical Outcomes and Prognostic Factors." They analyze the outcomes of core decompression surgery for osteonecrosis, taking into account factors such as pathologic features, prognostic indicators, and specific patient subgroups, including individuals with systemic lupus erythematosus or steroid-associated osteonecrosis. These articles underscore the importance of early diagnosis and treatment, emphasizing factors such as the stage of the disease, the size of the necrotic area, and patient-specific considerations. The studies suggest that early-stage osteonecrosis and smaller lesions yield better results following core decompression, underscoring the significance of timely intervention[50–54]. The third area of focus is "Comparative Efficacy of Treatments." These articles encompass comparisons between core decompression and alternative treatments for osteonecrosis, scrutinizing clinical outcomes, success rates, and the advantages of early intervention. The primary focus of these articles is core decompression's effectiveness in comparison to alternative treatments for ONFH, highlighting its superior success rate when administered early, as opposed to nonoperative approaches. These articles also emphasize that timely core decompression can postpone or obviate the necessity for more invasive procedures such as total hip arthroplasty[55,56]. Goodman Stuart B authored 20 papers on this subject. Like Mont MA, Goodman Stuart B has authored numerous articles addressing various clinical treatments for ONFH, including core decompression and the utilization of bone marrow aspirate concentrate. These articles assess the outcomes of these treatments, considering success rates, complications, and the long-term viability of the femoral head[57–60]. Additionally, it is noteworthy that Goodman Stuart B delves into innovative research methods, encompassing advanced biological techniques and preclinical models. This entails the exploration of novel surgical techniques, the use of genetically modified cells for treatment, and the evaluation of the efficacy of these approaches in experimental settings, with a particular focus on animal models[61–65]. In conclusion, the aforementioned studies primarily center on the clinical and experimental investigations of core decompression in ONFH, offering a comprehensive perspective on clinical treatment outcomes, surgical innovations, and the exploration of novel adjunctive therapies. These foundational works lay the groundwork for future studies that will integrate clinical and preclinical insights, advancing the therapeutic approach for ONFH.

In terms of co-cited authors, Mont MA (citation = 1350) is the most frequently cited author, followed by Hernigou P (citation = 728) and Steinberg ME (citation = 631). The relevant research carried out by Mont MA has been mentioned above and will not be repeated here. Philippe Hernigou's work primarily focuses on regenerative medicine strategies, particularly stem cell therapy, for hip osteonecrosis. He explores the effectiveness of augmented core decompression, integrating cell therapy injection with computer-assisted navigation to improve surgical precision and outcomes[66–68]. Hernigou's research also extends to examining osteonecrosis in children's leukemia survivors, treated with MSCs[69]. His studies highlight core decompression's efficacy, especially when combined with bone marrow injection, and emphasize the importance of factors like necrosis volume and lesion size in predicting treatment outcomes[70,71]. In contrast, Marvin E Steinberg's articles delve into the effectiveness of core decompression and grafting, with a focus on lesion size as a significant predictor of outcomes. His work includes studies on bilateral core decompression and its safety and efficacy[72,73]. Steinberg's contributions also encompass the evaluation of core decompression's results in various stages of avascular necrosis, emphasizing the treatment's impact based on lesion size and etiology.

Knowledge base

A co-cited reference is one that multiple publications cite concurrently, serving as a foundational element in a research field[74]. In this bibliometric study, we selected the 10 co-cited references with the highest number of co-citations to determine the research basis of core decompression in ONFH. The seminal works in core decompression for ONFH offer a multifaceted understanding of the condition and its treatment. The studies by Maruyama *et al*[65] and Tsubosaka *et al*[58] lay the foundation by discussing the efficacy of core decompression in early-stage disease and its role in hip preservation. Complementing this, Mont[52,56] and Hernigou's studies[66] delve into advanced techniques like percutaneous drilling and bone marrow aspirate concentrate, underscoring the evolution of surgical methods. Koo and Kim[75] work on quantifying osteonecrosis using MRI marks a significant stride in diagnostic approaches, enhancing the ability to predict femoral head collapse. Mont's exploration of osteonecrosis etiology[76] provides a deeper understanding of the disease's pathogenesis, pivotal for developing targeted treatments. Hernigou advance

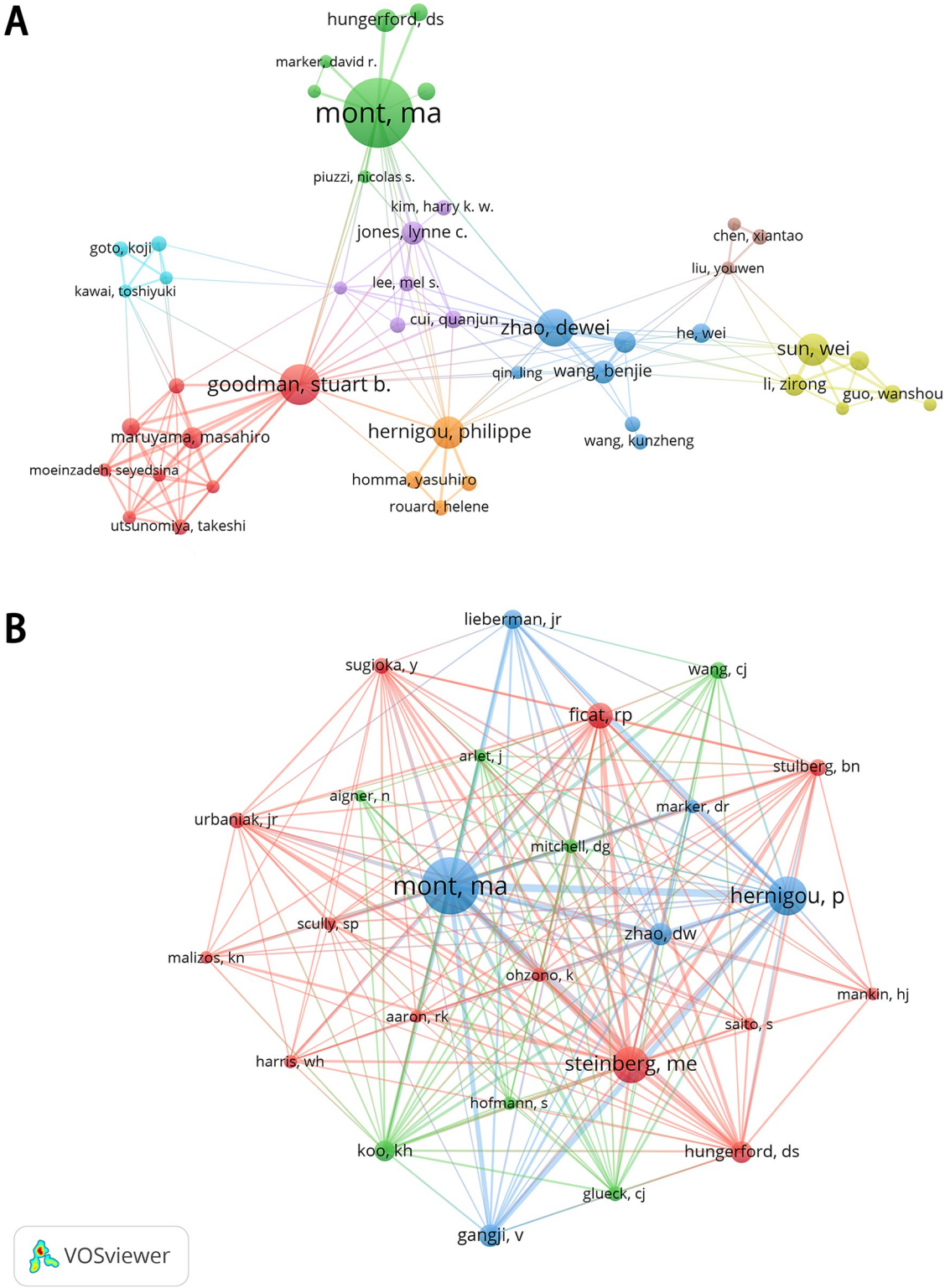

Figure 7. The visualization of authors (A) and co-cited Authors (B) on research of core decompression in ONFH.

this further with the use of computer-assisted navigation in cell therapy, highlighting technological innovations in surgical precision[66]. Finally, Ng's[77] analysis of joint-preserving procedures trends emphasizes the growing preference for methods that delay or prevent arthroplasty, signifying a shift toward more conservative, preservation-oriented treatment strategies in ONFH. These studies collectively contribute to a comprehensive understanding of core decompression as a treatment for ONFH,

Table 4

Top 10 co-cited references on research of core decompression in ONFH

Rank	Co-cited reference	Citations
1	Ficat RP, 1985, *Journal of Bone and Joint Surgery—British Volume*, Volume 67, Page 3, DOI: 10.1302/0301-620X.67B1.3155745	254
2	Mont MA, 1996, *Clinical Orthopaedics and Related Research*, Page 169, DOI: 10.1097/00003086-199 603 000-00020	198
3	Mont MA, 1995, *Journal of Bone and Joint Surgery—American Volume*, Volume 77A, Page 459, DOI: 10.2106/00004623-199 503 000-00018	181
4	Steinberg ME, 1995, *Journal of Bone and Joint Surgery—British Volume*, Volume 77B, Page 34, DOI: 10.1302/0301-620X.77B1.7822393	179
5	Hernigou P, 2002, *Clinical Orthopaedics and Related Research*, Page 14, DOI: 10.1097/01.BLO.0000038472.05771.79	147
6	Harris WH, 1969, *Journal of Bone and Joint Surgery—American Volume*, Volume 51, Page 737, DOI: 10.2106/00004623-196 951 040-00012	125
7	Mont MA, 2006, *Journal of Bone and Joint Surgery—American Volume*, Volume 88A, Page 1117, DOI: 10.2106/JBJS.E.01041	120
8	Urbaniak Jr, 1995, *Journal of Bone and Joint Surgery—American Volume*, Volume 77A, Page 681, DOI: 10.2106/00004623-199 505 000-00004	118
9	Scully SP, 1998, *Journal of Bone and Joint Surgery—American Volume*, Volume 80A, Page 1270, DOI: 10.2106/00004623-199 809 000-00004	115
10	Koo KH, 1995, *Journal of Bone and Joint Surgery—British Volume*, Volume 77B, Page 870, DOI: 10.1302/0301-620X.77B6.7593097	109

focusing on surgical techniques, outcomes, preclinical insights, technological advancements, quantitative assessments, and the underlying causes of the disease.

Hotspots and frontiers: MSCs

References with citation bursts indicate emerging research topics, marked by their increased citation in recent years[78]. Analysis of references showing significant citation bursts (Table 5) indicates MSCs as the focal point in ONFH research, especially within core decompression studies. Besides references with citation bursts, keywords facilitate rapid identification of trends and hotspots in the research field of core decompression in ONFH. Excluding keywords like osteonecrosis, core decompression, hip, and femoral head, Table 6 primarily features keywords such as bone marrow, MSCs, cell therapy, stem cells, treatment, and angiogenesis. According to keyword clustering analysis and trend topic analysis (Fig. 10), we concluded that the research of core decompression in ONFH predominantly focuses on the clinical outcomes and mechanisms involving MSCs.

The use of MSCs in core decompression has become a promising approach for treating ONFH. Recent research has

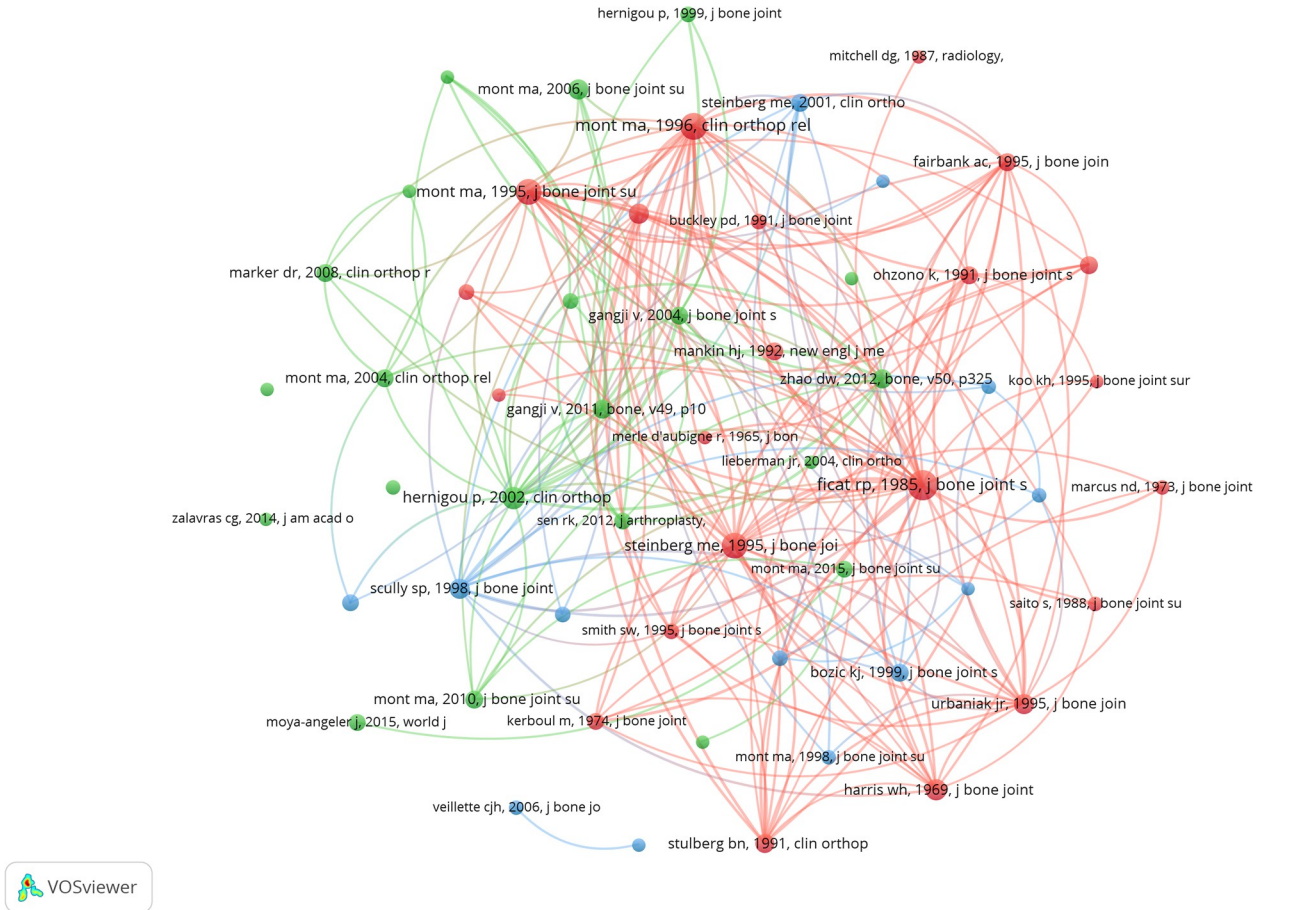

Figure 8. The visualization of co-cited references on research of core decompression in ONFH.

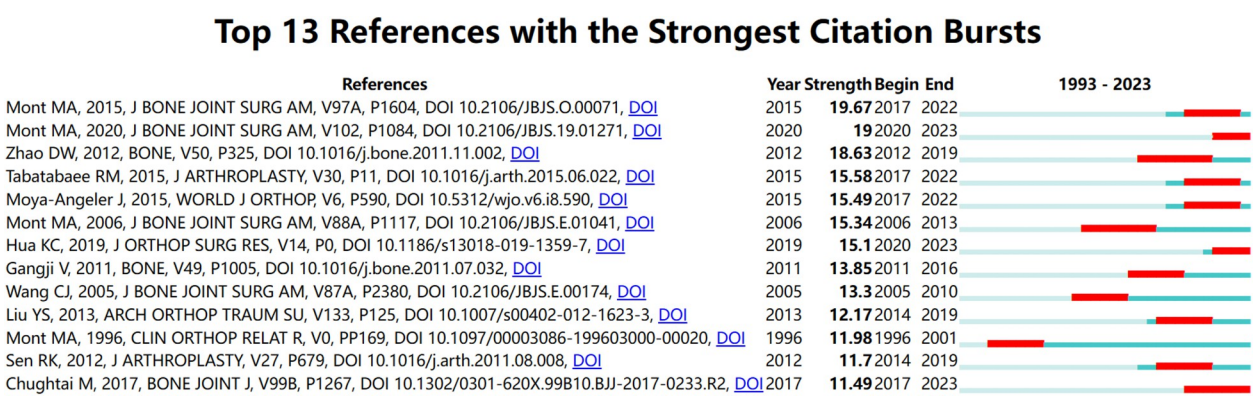

Figure 9. Top 13 references with strong citation bursts. A red bar indicates high citations in that year.

elucidated its effectiveness and underlying mechanisms. Addressing ONFH effectively requires a thorough understanding of its physiological and pathological dimensions, especially the role of MSCs.

The femoral head, like all bones, constitutes a dynamic tissue comprised of bone cells, marrow, and an intricate network of blood vessels[79]. Within this context, bone marrow MSCs emerge as versatile stem cells that play a pivotal role in bone regeneration and repair. These cells possess the unique capacity to differentiate into various cell types, including osteoblasts responsible for bone formation, thereby contributing significantly to the maintenance and restoration of bone health[80].

The blood supply to the femoral head primarily depends on the medial and lateral circumflex femoral arteries[81]. Any disruption to this blood supply can result in avascular necrosis, a condition characterized by the deterioration of bone tissue due to inadequate oxygen and nutrient delivery[82]. The pathological basis of ONFH often arises from compromised blood flow to the femoral head, triggered by factors like traumatic injuries, steroid usage, or alcohol abuse[83]. This ischemic condition leads to the demise of bone and marrow cells, eventually culminating in the structural collapse of the femoral head. In response to this damage, an inflammatory reaction and a natural reparative process are initiated[84].

Table 5

The main research contents of the 13 references with strong citations bursts

Rank	Strength	Main research content
1	19.67	This study underscores the critical role of early intervention and joint-preserving procedures in managing osteonecrosis of the femoral head, while also recognizing total joint arthroplasty as essential for advanced cases[2].
2	19.00	Highlighting the necessity of early detection and joint-preserving techniques in osteonecrosis of the femoral head, this study also points to the adjunctive benefits of cell-based therapies[35].
3	18.63	This research compares bone marrow mesenchymal stem cells (MSCs) treatment to core decompression in early-stage ONFH, demonstrating MSCs' effectiveness in preventing femoral head collapse and obviating the need for total hip replacement[36].
4	15.58	Comparing core decompression with and without bone marrow MSCs injection in early-stage ONFH, this study underscores MSCs therapy's potential in enhancing patient-reported outcomes and MRI results[37].
5	15.49	This article offers an overview of ONFH, covering risk factors, diagnosis, treatment options, and discussing femoral head sparing and replacement procedures[4].
6	15.34	This research stresses early diagnosis and intervention in joint-preserving procedures for ONFH, noting total hip arthroplasty's effectiveness for collapsed femoral heads[38].
7	15.10	A comprehensive analysis reveals core decompression as a viable and safe treatment for ONFH, especially when combined with autologous bone or bone marrow, showing improved success rates[39].
8	13.85	A blind comparative study shows that autologous bone marrow cell implantation in the femoral head's necrotic lesion effectively treats early-stage osteonecrosis, significantly improving pain, joint symptoms, and slowing disease progression[40].
9	13.30	A randomized comparison indicates that extracorporeal shock wave treatment outperforms core decompression and nonvascularized fibular grafting in early-stage ONFH, enhancing pain scores and hip function[41].
10	12.17	Core decompression, both with and without MSCs implantation, effectively treats ONFH. Yet, combining core decompression with MSCs implantation and porous hydroxyapatite bone filler may enhance its efficacy[42].
11	11.98	An extensive literature review on ONFH treatment shows core decompression achieving satisfactory outcomes in 63.5% of cases, compared to a 22.7% success rate with nonoperative management, underscoring core decompression's potential in early-stage disease[43].
12	11.7	Analyzing 51 osteonecrotic hips, this study found that core decompression combined with autologous bone marrow MSCs instillation led to superior clinical outcomes and hip survival compared to core decompression alone, especially in patients with initially unfavorable prognostic features[44].
13	11.49	This review offers an evidence-based management guide for non-traumatic ONFH, taking into account patient demographics, study methodologies, and outcomes[45].

Table 6

Top 20 keywords on research of core decompression in ONFH

Rank	Keywords	Counts	Rank	Keywords	Counts
1	osteonecrosis	212	11	osteonecrosis of femoral head	19
2	core decompression	189	12	meta-analysis	18
3	avascular necrosis	94	13	magnetic resonance imaging	17
4	osteonecrosis of the femoral head	92	14	sickle cell disease	17
5	femoral head	80	15	femoral head osteonecrosis	17
6	hip	59	16	cell therapy	16
7	total hip arthroplasty	39	17	bone graft	15
8	femoral head necrosis	30	18	stem cells	15
9	bone marrow	20	19	treatment	15
10	mesenchymal stem cells	19	20	angiogenesis	14

However, in cases of ONFH, the repair mechanism involving the participation of MSCs often falls short of fully restoring the structural integrity of the femoral head[85]. Consequently, therapeutic strategies like core decompression combined with MSCs therapy have been explored.

Core decompression is a surgical technique aimed at alleviating bone pressure and fostering the growth of new blood vessels. By creating a channel in the femoral head, core decompression enhances blood flow, reduces pain, and promotes the body's natural healing processes[86]. When complemented with MSCs transplantation, this approach holds the potential to enhance the healing process. Transplanted MSCs can differentiate into osteoblasts and facilitate the restoration of blood supply by promoting angiogenesis[87].

Clinical outcomes

The synergistic application of MSCs transplantation and core decompression has emerged as a pivotal advancement in the treatment of ONFH, as evidenced by a collection of seminal studies. MSCs in core decompression have been found to have promising effects in early stage ONFH in terms of symptomatic relief and preventing femoral head collapse[88,89]. The introduction of MSCs has shown a significant increase in Harris hip score, indicating improved functionality and pain relief in early stages of ONFH[90]. Wang's meta-analysis highlights the effectiveness of this combination therapy in reducing pain and enhancing joint function, potentially slowing disease progression[91]. Chang documented a significant reduction in the femoral head's necrotic area in patients receiving combined MSCs transplantation and core decompression versus core decompression alone[92]. Li's 10-year follow-up results further support the combined therapy's superiority over core decompression alone in long-term effectiveness[93]. Wang also noted the promising role of MSCs alongside core decompression in improving outcomes through angiogenesis and bone formation in necrotic zones, adding translational relevance[94]. In conclusion, studies report pain relief, slowed necrosis progression, and a delayed need for total hip arthroplasty, suggesting MSCs may enhance natural healing and potentially reverse osteonecrosis.

Mechanisms

The complexity of signaling pathways in MSCs-mediated treatment has unveiled multiple targets to enhance core decompression therapy's effectiveness in ONFH. The Notch-RBPJ pathway, a crucial regulator of MSCs differentiation, influences femoral head necrosis progression through its impact on osteogenic and chondrogenic differentiation[95]. Similarly, the PPARγ signaling pathway, modulated by C/EBPα, plays a key role in balancing adipogenic and osteogenic differentiation, crucial for steroid-induced avascular necrosis[96]. Moreover, the PI3K/AKT pathway, through extracellular vesicles from human umbilical cord MSCs, protects against steroid-induced necrosis by enhancing osteoblast survival and angiogenesis[97]. Furthermore, VCAM-1 regulation of the Apelin/CCN2 pathway suggests a novel angiogenic mechanism in trauma-induced osteonecrosis[98]. Notably, exosomes from hypoxia-preconditioned MSCs enhance angiogenesis, presenting a new therapeutic avenue[99]. It is also significant that the role of miR-21-5p in promoting angiogenesis and osteogenesis offers insights into microRNA-mediated bone repair regulation[100]. Researchers have further illuminated that the delivery of microRNA-210 into bone microvascular endothelial cells via MSC-derived exosomes opens up new treatment possibilities[101]. Lastly, the silencing of miR-137-3p targets critical genes for osteogenesis and angiogenesis, offering a promising strategy for the treatment of steroid-induced osteonecrosis[102]. These papers collectively advance our understanding of the signaling pathways involved in the treatment of ONFH through core decompression combined with MSCs.

Building on the complex signaling pathways, this research delves into the genetic and molecular aspects of MSCs' role in treating ONFH. Song identified the potential of LRRC17 in modulating bone metabolism via the Wnt signaling pathway, suggesting targeting its low expression in femoral head necrosis could rebalance MSCs' osteogenic and adipogenic differentiation[103]. Additionally, research on VEGF and BMP-2 reveals their synergistic effects in promoting vascularization and bone repair, thus enhancing MSCs' osteogenic capacity[104]. Furthermore, introducing genetically modified MSCs that overexpress PDGF-BB presents a promising supplementary treatment to core decompression, optimizing bone regeneration and preventing disease progression[105]. Moreover, the study on PARK7 highlights its role in shielding MSCs from stress-induced apoptosis via the Nrf2 signaling pathway, thus enhancing MSC transplant survival and effectiveness[106]. Lastly, using recombinant adenovirus to carry the HGF gene highlights the critical balance of cellular activities for MSC proliferation and differentiation, with pathways such as WNT and PI3K/AKT as potential targets to improve treatment outcomes[107]. These insights collectively pave the way for a comprehensive gene-based strategy to enhance MSCs' reparative potential in ONFH.

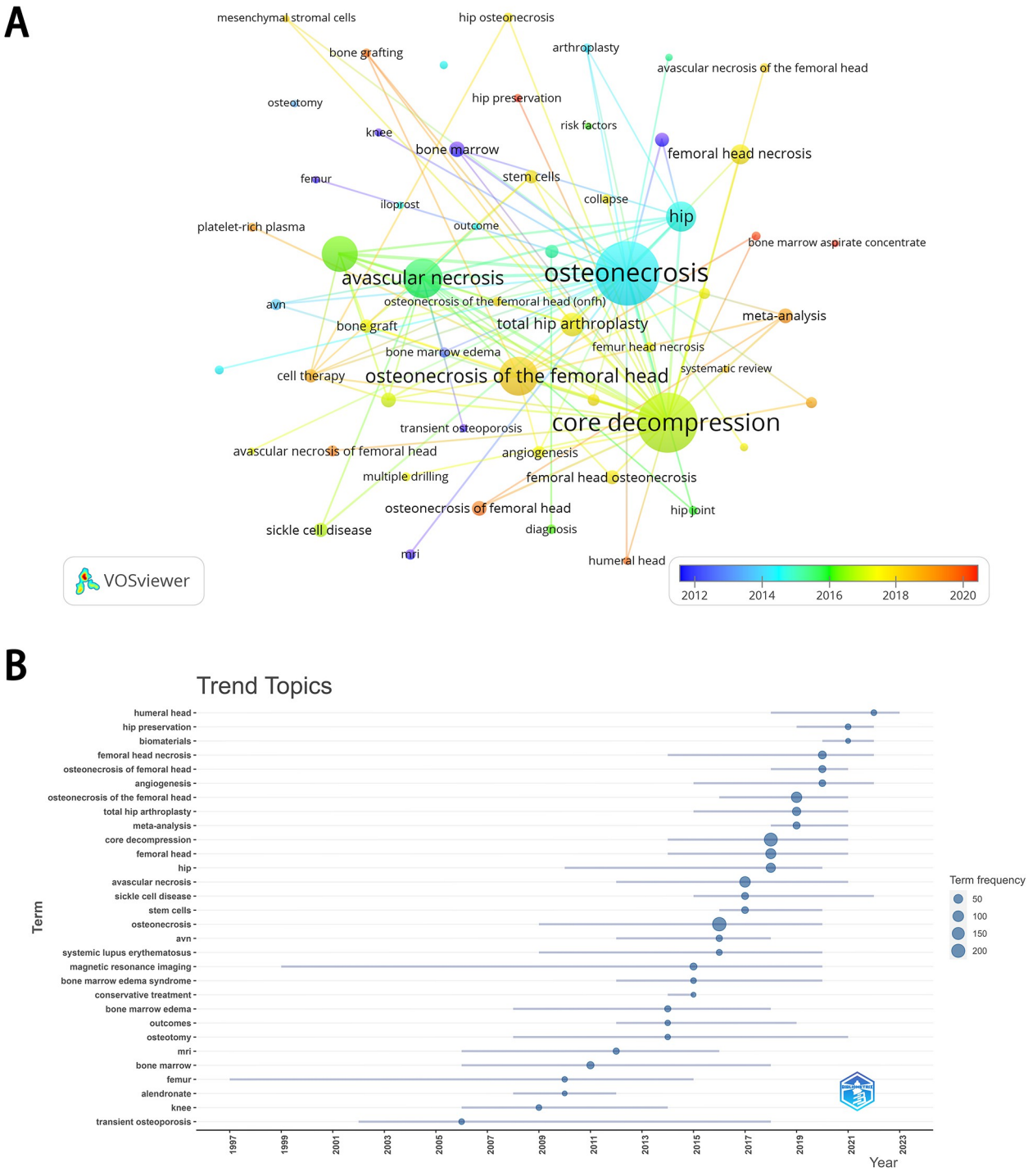

Figure 10. Keyword cluster analysis (A) and trend topic analysis (B).

Challenges and future directions

Treating ONFH with MSCs and core decompression therapy presents multiple challenges. First, patient response variability highlights the necessity for personalized treatments due to differences in MSCs potency, disease severity, and genetic backgrounds. Additionally, identifying the optimal source, dose, and timing of MSCs requires further research for standardization. Second, the long-term safety and efficacy of these therapies remain uncertain, with concerns about benefit durability and potential adverse effects, such as the rare risk of tumorigenesis from MSCs[108,109]. Lastly, the complex mechanisms behind MSCs therapeutic effects, particularly in angiogenesis and osteogenesis, are not fully understood, underscoring the need for further investigation into their regenerative capabilities.

Addressing the current therapeutic challenges in ONFH requires a comprehensive research approach. Future research

should prioritize personalized treatment strategies, utilizing genomics and biomarker discovery to customize therapies according to individual patient profiles. Extended follow-up studies are critically needed to assess the long-term safety and efficacy of MSCs and core decompression therapies. Optimizing MSCs therapy entails refining source, preparation, and delivery methods, including preconditioning, scaffolding, and genetic modifications, to enhance therapeutic outcomes. Additionally, elucidating the mechanisms of action of MSCs at the molecular level could yield novel treatments that either mimic or amplify these effects. Investigating combination therapies, including the use of bioactive scaffolds and gene therapy, could further improve treatment outcomes.

Advantages and shortcomings

This is the first study to systematically analyze core decompression research in ONFH through bibliometric analysis, thereby offering comprehensive insights for scholars interested in this field. Additionally, we utilized three bibliometric tools – VOSviewer and CiteSpace among them – which are widely recognized in bibliometric research[29]. Consequently, our data analysis process is expected to be more objective. Lastly, bibliometric analysis provides a more comprehensive overview of current trends and frontiers than traditional reviews do. However, this study's data were exclusively sourced from the WoSCC database, potentially omitting relevant studies from other databases. Furthermore, by focusing solely on English-language publications, our study may underestimate the contributions of non-English papers.

Conclusions

This comprehensive bibliometric analysis marks a pivotal advancement in understanding the evolution, key contributors, and research trends in core decompression for ONFH. Despite the growing interest and contributions, this study highlights a significant gap in international collaboration and communication, which remains a major challenge for advancing the development of effective treatments. Although progress has been made in the field, there is still a need for more concerted efforts across institutions and countries. The emphasis on personalized and advanced therapeutic strategies, such as MSCs use and innovative surgical techniques, highlights the field's shift toward targeted and effective interventions. Future research should prioritize addressing these gaps, focusing on optimizing these approaches and ensuring their long-term efficacy and safety for patients with ONFH.

Ethical approval

This study is a bibliometric analysis of the literature on core decompression for ONFH and does not involve experimental research on patients. Therefore, ethical approval is not required.

Consent

Since this research does not involve studies on patients or volunteers, there is no need to obtain written informed consent, and no patient or volunteer information is used.

Sources of funding

This work was supported by the Traditional Chinese Medicine Clinical Evidence-Based Research Project of the High-Level Traditional Chinese Medicine Hospital Construction Project of Wangjing Hospital, China Academy of Chinese Medical Sciences (grant number WJYY-XZKT-2023-28).

Author's contribution

Conceptualization, data curation, formal analysis, visualization, writing – original draft: T.-j.Y.; conceptualization, data curation, formal analysis, visualization, writing – original draft: P.-p. W.; conceptualization, data curation, formal analysis, visualization, writing – original draft: T.-x.C.; investigation, resources, writing – review and editing: G.-y.Z.; investigation, resources, writing – review and editing: Y.-w.D.; investigation, resources, writing – review and editing: Y.-f.S.; investigation, resources, writing – review and editing: Z.-j.H.; investigation, resources, writing – review and editing: R.G.; investigation, resources, writing – review and editing: P.-c.D; conceptualization, supervision, project administration, funding acquisition, writing – review and editing: H.-j.H.

Conflicts of interest disclosure

The authors declare that there are no conflicts of interest to disclose. There are no financial or personal relationships with other parties that could have influenced the work.

Research registration unique identifying number (UIN)

This bibliometric analysis does not involve human subjects in a manner that requires research registration, and thus no UIN is applicable.

Guarantor

Hai-jun He is the guarantor. He accepts full responsibility for the work and the conduct of the study. He had access to all the data and controlled the decision to publish.

Provenance and peer review

This paper was not invited and is submitted independently. It will be subject to external peer-review.

Data availability statement

In this bibliometric analysis, all data used were obtained from publicly available sources, specifically the Web of Science Core Collection (WoSCC) database. The datasets analyzed during the current study are publicly available through the WoSCC database with appropriate access permissions. The search strategies and criteria used to retrieve the literature are described in detail in the "Methods" section of the manuscript. Therefore, other researchers can replicate the study by following the same procedures.

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