

Global Trends and Current Status in Osteonecrosis of the Femoral Head: A Bibliometric Analysis of Publications in Recent 30 Years

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Abstract

Background: Osteonecrosis of the femoral head (ONFH) is a progressive and disabling disease with heavy socioeconomic burdens. The purpose of our study was to summarize the global trends and current status in ONFH.

Methods: Publications related to ONFH from 1991 to 2020 were searched from the Web of Science (WOS) core collection database. The data were analyzed with bibliometric methods. Microsoft Excel was used to statistical analysis and draw bar charts. SPSS was applied to perform linear regression analysis. VOSviewer was used to conduct bibliographic coupling analysis, co-authorship analysis, co-citation analysis, and co-occurrence analysis.

Results: A total of 5,523 publications were covered. The United States consistently ranked first in total publications, sum of times cited, average citations per item, and H-index. Kyushu University was the main contributor to ONFH. *Clinical Orthopaedics and Related Research* was the major publishing channels for ONFH-related articles. Takuaki Yamamoto published the most ONFH-related articles. Studies regarding ONFH could be divided into 5 clusters: mechanism study, treatment study, complication study, radiological study, and etiological study. Mechanism study might become the hot spot in the future.

Conclusions: This study identified the last 30 years' articles in ONFH and summarized their global trends and current status, which classified them by country, institution and author, publication, funding agency, and direction. This study will help researchers understand the research perspectives, hot spots, and trends of ONFH.

Introduction

Osteonecrosis of the femoral head (ONFH) is a progressive and disabling disease with heavy socioeconomic burdens [1]. Severe ONFH leads to the collapse of subchondral bone and eventually the damage of the hip joint, resulting in a loss of labor capacity [2]. Patients with advanced ONFH often do not respond well to medical treatment and require total hip arthroplasty (THA). However, THA, especially for young people, may cause a series of complications, including dislocation, periprosthetic fracture, infection, and prosthesis loosening [3]. The etiology of ONFH is various, among which the overuse of glucocorticoids (GCs), trauma, and alcohol are the most critical ones, while the pathogenesis of ONFH remains to be determined. A growing number of studies have focused on the pathogenesis and therapeutic approaches of ONFH worldwide. However, global trends and current status in ONFH have not been summarized yet.

Bibliometrics is a method to cognize the development tendency of a certain field and evaluate the contribution of a collection of research results such as all publications of the same scholar, institution or country by collecting literature metrology characteristics of the publications [4-6]. In addition, bibliometrics can also be used to guide policy formulation [7]. Nowadays, bibliometric analysis has been

used in a wide range of fields, including anesthesia, cancer, orthopedics and, neurology, to compare the contributions of different research findings [5, 8-10].

Therefore, the purpose of this study was to evaluate and summarize the global trends and current status in ONFH during the last 30 years, helping researchers understand the research perspectives, hot spots, and trends of ONFH.

Methods

Data sources

The search was conducted using the Web of Science (WOS) Core Collection database, including SCI-Expanded, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-Expanded, and IC. The journal impact factors (IF) came from the 2020 version Journal Citation Reports except for *Journal of Bone and Joint Surgery-British Volume* from the 2014 edition.

Search strategy

All the literature were retrieved in WOS on September 2, 2021. The search terms were: (TS=(Osteonecrosis of Femoral Head OR Necrosis of Femoral Head OR Femoral Head Necrosis OR Femur Head Necrosis)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article OR Review). For the time span, we chose the 30 years between 1991 and 2020.

Data collection

Full records and cited references were extracted from the retrieved literature for bibliometric analysis, such as titles, years of publications, authors, nationalities, institutions of authors, funding sources, journals of publications, abstracts, keywords, total number of publications, sum times of cited, average citations per item and H-index. The information based on bibliometric characteristics was downloaded from WOS and imported into Microsoft Excel 2017 and VOSviewer (v.1.6.17) for analysis.

Bibliometric analysis

Microsoft Excel 2017 was used for statistical analysis and the graphing of all the bar charts in the study. In addition, SPSS (v.26.0, IBM, New York, USA) was applied to perform linear regression analysis on the trends of total publications in the past 30 years. $P < 0.05$ is considered statistically significant. R^2 represents the degree to which the linear regression model explains the overall variance [11].

VOSviewer is a software for plotting maps based on network data. In the network visualization, items are represented by circles. The size of the circle is determined by the number of publications of the item. The distance between two circles approximately indicates the relatedness of the items. The color of an item is determined by the cluster to which the item belongs. In this study, VOSviewer was used for conducting bibliographic coupling analysis, co-authorship analysis, co-citation analysis, and co-occurrence analysis.

Results

Global trends of publications in ONFH

A total of 5,523 ONFH-related articles published between 1991 and 2020 was identified in our study. The total publications of ONFH generally increased over time ($R^2 = 0.872$, $P < 0.001$). The annual publications regarding ONFH have grown nearly sevenfold over the three decades from 61 in 1991 to 481 in 2020 (*Figure 1A*). A total of 98 countries or regions have published studies on ONFH (*Figure 1B*). Among them, the United States published the most articles (1,369, 24.787%), followed by China (1,246, 22.560%), Japan (544, 9.850%), Germany (303, 5.486%), England (283, 5.124%) and South Korea (281, 5.088%). The United States and China published more than twice as many articles as Japan ranking third. Moreover, the total number of ONFH publications in each country or region also increased over time: the United States ($R^2 = 0.732$, $P < 0.001$), China ($R^2 = 0.661$, $P < 0.001$), Japan ($R^2 = 0.525$, $P < 0.001$), Germany ($R^2 = 0.755$, $P < 0.001$), England ($R^2 = 0.679$, $P < 0.001$) and South Korea ($R^2 = 0.805$, $P < 0.001$) (*Figure 1C*). *Figure 1D* shows the number of publications from individual countries or regions visually in the heat map.

Quality analysis of global publications

Country

Figure 2A illustrates the sum of times cited, average citations per item, and H-index of the top ten countries with the most publications associated with ONFH. Among the ten countries, sum of times cited (45,314), average citations per item (33.1), and H-index (94) of the United States are all higher than the other nine countries. In terms of the total publications, China ranked second. However, China ranked ninth in average citations per item (11.33), just above India. Other developed countries, including Japan, Germany, England, South Korea, France, Canada, and Italy, all had high average citations per item and H-index despite the small number of publications.

Institution

Over the past three decades, approximately 3,721 institutions worldwide have published ONFH-related literature. *Figure 2B* details the top ten most contributing institutions all over the world. Of the ten institutions, five were in China (Shanghai Jiao Tong University, Dalian University, Guangzhou University of Chinese Medicine, Huazhong University of Science and Technology and Xi'an Jiaotong University), two were in Japan (Kyushu University and Osaka University), two were in the United States (Hospital for Special Surgery and Duke University) and the last one was in South Korea (Seoul National University). The institution that has made the greatest contribution to ONFH research is Kyushu University with 115 publications, 2,675 citations, 23.26 average citations and an H-index of 27. Shanghai Jiao Tong

University came in the second (107 publications, 1,676 citations, 15.66 average citations and H-index of 20), followed by Osaka University (74 publications, 1,982 citations, 26.78 average citations and H-index of 27), Seoul National University (66 publications, 1,381 citations, 20.92 average citations and H-index of 22) and Dalian University (61 publications, 992 citations, 16.26 average citations and H-index of 16).

Author

Analyzing quality of publications by the author, the top ten contributors to ONFH are presented in *Figure 2C*. Of the ten authors, five were from Japan (Takuaki Yamamoto, Yukihide Iwamoto, Goro Motomura, Nobuhiko Sugano and Yasuharu Nakashima), two were from China (Dewei Zhao and Changqing Zhang), two were from the United States (Michael A Mont and Harry K W Kim), and the remaining one was from South Korea (Kyung-Hoi Koo). Moreover, eight of these authors were from the top ten institutions, four were from Kyushu University (Takuaki Yamamoto, Yukihide Iwamoto, Goro Motomura and Yasuharu Nakashima), Nobuhiko Sugano was from Osaka University, Dewei Zhao was from Dalian University, Changqing Zhang was from Shanghai Jiao Tong University and Kyung-Hoi Koo was from Seoul National University. The greatest contributor was Takuaki Yamamoto with 94 publications, 2,379 citations, 25.31 average citations, and an H-index of 29. While Michael A Mont, who ranked second in publications, had the highest citations, average citations and H-index among the top ten authors (79 publications, 4,927 citations, 62.37 average citations and H-index of 36).

Analysis of journal and funding agencies

Journal

The top ten journals publishing the most ONFH-related articles are shown in *Figure 3A*. *Clinical Orthopaedics and Related Research* (IF = 4.176, 2020) was the most active journal on ONFH research with 348 articles, followed by the *International Orthopaedics* (IF = 3.075, 2020) with 186 articles, *Journal of Bone and Joint Surgery-American Volume* (IF = 5.284, 2020) with 183 articles, *Journal of Arthroplasty* (IF = 4.757, 2020) with 154 articles, *Journal of Pediatric Orthopaedics* (IF = 2.324, 2020) with 132 articles and *Archives of Orthopaedic and Trauma Surgery* (IF = 3.067, 2020) with 129 articles. Of the ten journals, *Clinical Orthopaedics and Related Research* had the most total citations (13,092 citations, 37.62 average citations and H-index of 58). In contrast, *Journal of Bone and Joint Surgery American Volume* had the highest average citations and H-index (13,072 citations, 76.9 average citations and H-index of 71).

Funding agency

Figure 3B presents the top ten funding agencies with the most ONFH-related articles. Globally, the National Natural Science Foundation of China (NSFC, China) funded the most articles with the maximum number of citations (528 publications, 6,739 citations, 12.69 average citations and H-index of 37). United

States Department of Health Human Services (the United States) ranked second (168 publications, 6,712 citations, 39.95 average citations and H-index of 43), followed by National Institutes of Health (NIH, the United States) (165 publications, 6,338 citations, 38.41 average citations and H-index of 43), Ministry of Education Culture Sports Science and Technology (Japan) (99 publications, 1,216 citations, 11.92 average citations and H-index of 19), Japan Society for the Promotion of Science (Japan) (92 publications, 1,156 citations, 12.17 average citations and H-index of 18), and National Institute of Arthritis Musculoskeletal Skin Diseases (NIAMS, the United States) (72 publications, 2,613 citations, 36.29 average citations and H-index of 28).

Bibliographic coupling analysis

Country

Bibliographic coupling analysis is a method exhibiting the relatedness of items based on the number of references they share. *Figure 4A* shows the relationship of 59 identified countries (the minimum number of documents of a country is over five) in total link strength using VOSviewer. The top six countries by total link strength were as followed: the United States (total link strength = 1,066,241 times), China (total link strength = 737,151 times), Japan (total link strength = 427,254 times), South Korea (total link strength = 280,129 times), Germany (total link strength = 273,705 times) and England (total link strength = 214,591 times).

Institution

Figure 4B details the relationship of 405 identified institutions (the minimum number of documents of an institution is over five) in total link strength using VOSviewer. The top six institutions by total link strength were as followed: Kyushu University (total link strength = 137,084 times), Johns Hopkins University (total link strength = 130,922 times), Sinai Hospital (total link strength = 108,755 times), Shanghai Jiao Tong University (total link strength = 94,142 times), Dalian University (total link strength = 91,473 times) and Seoul National University (total link strength = 84,178 times).

Journal

Figure 4C presents the relationship of 189 identified journals (the minimum number of documents of a journal is over five) in total link strength using VOSviewer. The top six journals by total link strength were as followed: *Clinical Orthopaedics and Related Research* (total link strength = 308,010 times), *Journal of Bone and Joint Surgery-American Volume* (total link strength = 208,262 times), *International Orthopaedics* (total link strength = 135,281 times), *Journal of Arthroplasty* (total link strength = 132,289 times), *Journal of Bone and Joint Surgery-British Volume* (total link strength = 119,992 times) and *Archives of Orthopaedics and Trauma Surgery* (total link strength = 96,174 times).

Co-authorship analysis

Country

Co-authorship analysis is a measure to determine the connectivity of items based on the number of co-authored publications. *Figure 5A* shows the relationship of 59 identified countries (the minimum number of documents of a country is over five) in total link strength using VOSviewer. The top six countries by total link strength were as followed: the United States (total link strength = 353 times), England (total link strength = 179 times), Germany (total link strength = 149 times), China (total link strength = 144 times), France (total link strength = 112 times) and Italy (total link strength = 86 times).

Institution

Figure 5B details the relationship of 405 identified institutions (the minimum number of documents of an institution is over five) in total link strength using VOSviewer. The top six institutions by total link strength were as followed: Seoul National University (total link strength = 125 times), Kyungpook National University (total link strength = 104 times), Stanford University (total link strength = 97 times), Osaka University (total link strength = 95 times), Fukuoka University (total link strength = 91 times) and John Hopkins University (total link strength = 88 times).

Author

Figure 5C exhibits the relationship of 629 identified authors (the minimum number of documents of an author is over five) in total link strength using VOSviewer. The top six authors by total link strength were as followed: Goro Motomura (total link strength = 328 times), Takuaki Yamamoto (total link strength = 272 times), Satoshi Ikemura (total link strength = 226 times), Yukihide Iwamoto (total link strength = 272 times), Yasuharu Nakashima (total link strength = 218 times) and Dewei Zhao (total link strength = 186 times).

Co-citation analysis

Journal

Co-citation analysis refers to a method presenting the relatedness of items based upon the number of times they are cited together. *Figure 6A* displays the relationship of 841 identified journals (the minimum number of citations of a journal is over 20) in total link strength using VOSviewer. The top six journals by total link strength were as followed: *Clinical Orthopaedics and Related Research* (total link strength = 625,944 times), *Journal of Bone and Joint Surgery-American Volume* (total link strength = 582,344 times),

Journal of Bone and Joint Surgery-British Volume (total link strength = 415,827 times), *Journal of Arthroplasty* (total link strength = 162,360 times), *Journal of Pediatric Orthopaedics* (total link strength = 125,262 times) and *Radiology* (total link strength = 114,859 times).

Publication

Figure 6B reveals the relationship of 1,184 identified publications (the minimum number of citations of a publication is over 20) in total link strength using VOSviewer. The top six publications by total link strength were as followed: Mont et al. [12] (total link strength = 10,027 times), Ficat [13] (total link strength = 9,686 times), Steinberg et al. [14] (total link strength = 7,134 times), Harris [15] (total link strength = 6,067 times), Mont et al. [16] (total link strength = 5,983 times) and Mankin [17] (total link strength = 5,523 times).

Co-occurrence analysis

The relatedness of items is determined by the number of documents in which they occur together. The aim is to determine hot research directions and topics critical for tracking the development of science [18]. As illustrated in *Figure 7A*, 515 identified keywords (the minimum number of occurrences of a keyword in titles and abstracts is over ten) are classified into 5 clusters: “Mechanism study”, “Treatment study”, “Complication study”, “Radiological study”, and “Etiological study”. In the “Mechanism study” cluster, the most used keywords were nontraumatic osteonecrosis, steroid-induced osteonecrosis of the femoral head, mesenchymal stem cell, and apoptosis. For the “Treatment study” cluster, the frequently used keywords were core decompressing, follow-up, total hip arthroplasty, and replacement. In the “Complication study” cluster, the most used keywords were children, femoral neck fracture, complication, and management. For the “Radiological study” cluster, the major keywords were MRI, diagnosis, bone marrow edema, and transient osteoporosis. In the “Etiological study” cluster, the main keywords were risk-factor, natural-history, systemic lupus erythematosus, and bone mineral density. These results demonstrated the distribution of research areas on ONFH in the last 30 years.

The overlay visualization is identical to the network visualization except for the colors of items. As presented in *Figure 7B*, keywords are colored differently depending on the average time they appear in the publications. The blue color keyword appeared earlier while the yellow color keyword appeared later. Before 2010, most studies focused on the “Complication study” and “Radiological study”. The results of co-occurrence analysis indicated that “Mechanism study” may become the hot spot of future ONFH research.

Discussion

Global trends in ONFH research

Bibliometric analysis could be used to evaluate the current status and forecast the future directions [18]. Therefore, our study was conducted to evaluate and summarize the global trends and current status about ONFH in the last 30 years. As demonstrated in this study, the number of ONFH-related publications has increased significantly over the past three decades from 1991 to 2020. And we can predict that ONFH-related publications will continue to increase over time in the coming years. Researchers worldwide participated in ONFH research, especially in North America, East Asia, and Europe from the heat map. Not only the relatively high morbidity rate, the degrees of economic growth might also explain this result. China's contribution was lower than that of the United States before 2013, and gradually surpassed that of the United States after 2013, even though the total number of publications of the United States was still more than that of China. The reasonable explanation may attribute to the rapid national development and the corresponding annually increased research funding for ONFH.

Quality of global publications

In terms of total publications, sum of times cited, average citations per item, and H-index, the United States ranked first in the world, identified as the leading country on ONFH. China was in the second place by the number of total publications and sum of times cited, ranked third in H-index, while only surpassed India in average citations per item among the top ten countries. That means China has held a leading position in ONFH research among developing countries. However, there is still a significant gap between China and developed countries with regard to the academic level of ONFH research. The top ten institutions contributing the most to ONFH were from China, Japan, the United States, and South Korea, all of which belong to the top ten countries, indicating that the establishment of outstanding institutions is the prerequisite to improve the academic level of a country. The top ten authors who contributed most to ONFH were also from the top ten countries, and eight of them worked for top 10 institutions. It demonstrated the complementary role between excellent scientific platforms and first-class scholars. The excellent scientific platforms provided sufficient scientific funds and advanced experimental equipment for top scholars, who made great contributions to the further development of the platforms. Among the top ten journals, *Clinical Orthopaedics and Related Research* published the most ONFH-related articles, nearly twice as many as the publications of the second-ranked journal. Also, *Clinical Orthopaedics and Related Research* had the most total citations, though the average citations per item were relatively low. *Journal of Bone and Joint Surgery-American Volume* and *Journal of Bone and Joint Surgery-British Volume* both had relatively high average citations per item and H-index, which indicated the high quality of their publications. From above, we could track the latest advances of ONFH by monitoring the latest research of these institutions, authors, and journals.

Bibliographic coupling analysis was used in this study to establish the similarity relationship among publications from three dimensions of country, institution, and journal. Bibliographic coupling was established when two items cited the same article, determining the relatedness between two items. To some extent, the total link strength of a particular item could also explain its influence worldwide. The United States, Kyushu University, and *Clinical Orthopaedics and Related Research* were the leading

country/institution/journal on ONFH globally. Co-authorship analysis was used to evaluate the cooperation between items by counting the number of co-authored publications. Items with higher total link strength indicated that the countries/institutions/authors were more willing to cooperate with others. Therefore, the United States, Seoul National University, and Goro Motomura were more cooperative than others. Co-citation analysis was established when two items were cited by another article together. Compared with bibliographic coupling analysis, co-citation analysis could more scientifically highlight the influence of items worldwide. We could conclude that *Clinical Orthopaedics and Related Research* and Mont et al. were the most influential journal/publication on ONFH globally.

Keywords of ONFH study

The co-occurrence network visualization was created by analyzing the number of articles in which keywords occurred together in the titles or abstracts. Our results suggested that nontraumatic osteonecrosis drew the most attention worldwide, in line with the reality. Other keywords with the highest total link strength were of great significance in their respective fields. The combination of the concluded directions with keywords could provide new thoughts to the research contents of ONFH. And further attention and high-quality studies were needed in these fields. In overlay visualization, items were colored differently from network visualization to highlight their average appearing time. This kind of visualization was pivotal in identifying the hotspot directions related to ONFH in the future. In accordance with our results, mechanism study might become the next prevailing direction. Several frontier keywords related to the pathogenesis of ONFH were listed in the overlay visualization, such as mesenchymal stem cell, apoptosis, oxidative stress, adipogenesis, osteogenic differentiation, and endothelial progenitor cell [3, 19-22]. The balance between osteogenic and adipogenic differentiation of mesenchymal stem cells, angiogenic differentiation of endothelial progenitor cells, and oxidative stress and apoptosis of endothelial cells and osteoblasts were critical impact factors in the pathogenesis of ONFH. Therefore, these directions deserve more time and funds for more in-depth and comprehensive research in the future. Moreover, our research results also provided some help for several countries or funding agencies to make more scientific and reasonable investment plans and talent introduction plans.

Strengths and limitations

Our study gave a novel insight into the global trends and current status of ONFH-related publications by using bibliometric methods. However, there are some limitations to the study that have to be pointed out. Due to the differences in the publications covered by the major databases, including WOS, Pubmed and Cochrane library, we may omit several publications from analysis, leading to database bias. In addition, we only analyzed English publications and excluded non-English publications, which may result in language bias. Moreover, the effect of publication time on the sum of times cited has not been considered. Several latest articles with high quality might not attract our attention because of the low sum of times cited.

Conclusions

This study identified the ONFH-related publications in the last 30 years and presented their global trends and current status. The total publications of ONFH generally increased over time in the last three decades. The United States consistently ranked first in total publications, sum of times cited, average citations per item, and H-index. Kyushu University, Osaka University, Hospital for Special Surgery, and Duke University were the main contributing institutions to ONFH. *Clinical Orthopaedics and Related Research*, *Journal of Bone and Joint Surgery-American Volume*, and *Journal of Bone and Joint Surgery-British Volume* were the major publishing channels for ONFH-related articles. Takuaki Yamamoto and Michael A Mont were the main contributors to ONFH. Furthermore, mechanism study about ONFH including mesenchymal stem cells, apoptosis, oxidative stress, adipogenesis, osteogenic differentiation, and endothelial progenitor cell has attracted more attention and will become the hot spot in the future.

Abbreviations

ONFH, osteonecrosis of the femoral head; WOS, Web of Science; THA, total hip arthroplasty; GCs, glucocorticoids.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

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Author Contributions

WX, CH and RD: conceived and designed the experiments, authored or reviewed drafts of the paper. ZW, YL and ZC: performed the experiments and analyzed the data. MF and JW: prepared figures and wrote the paper. All authors read and approved the final manuscript.

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Figures

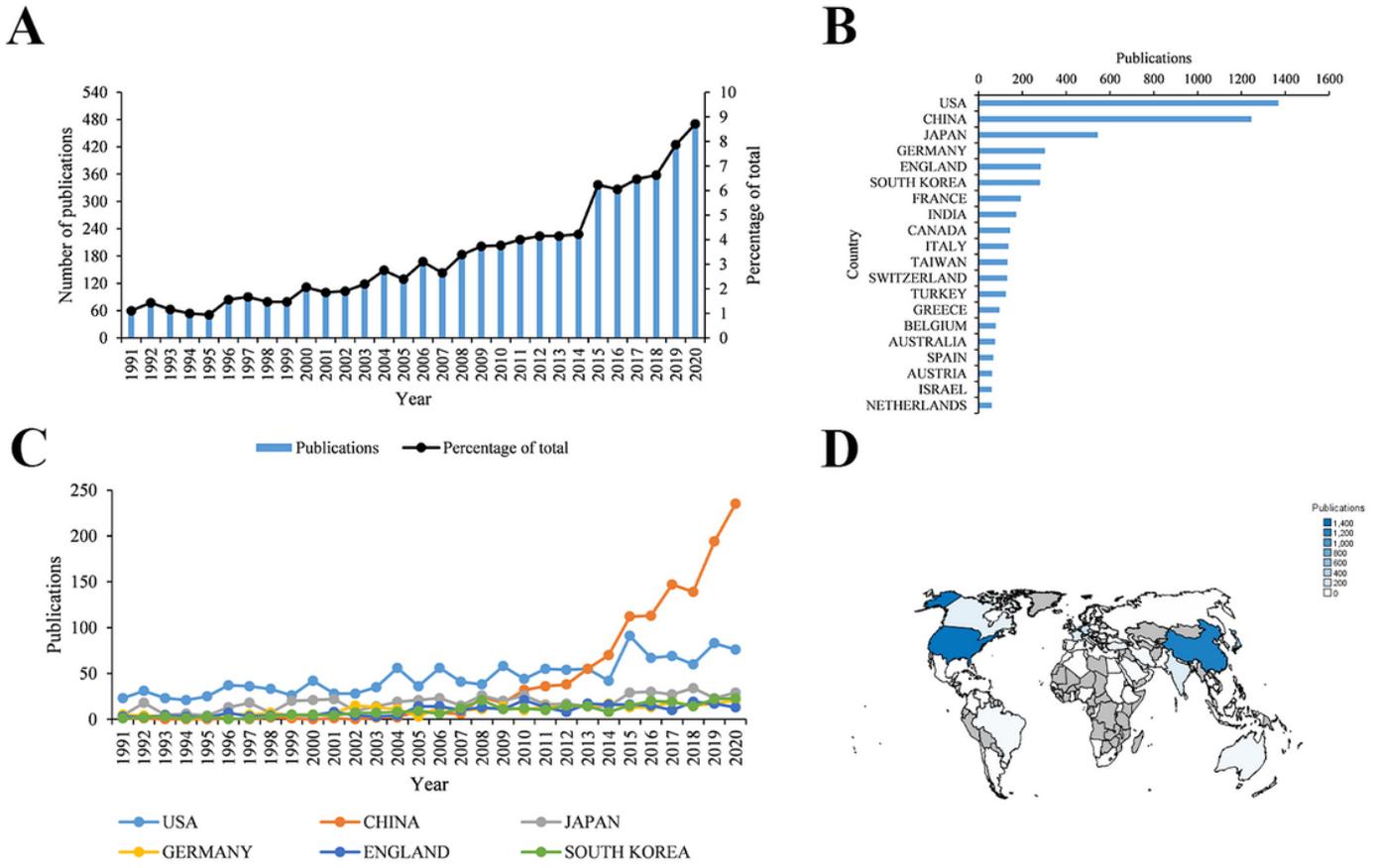


Figure 1

Global trends of publications on osteonecrosis of the femoral head (ONFH) in recent 30 years. (A) Annual ONFH-related publications worldwide. (B) The total number of ONFH-related publications from the top 20 countries/regions. (C) ONFH-related publications of top six countries/regions over time. (D) Heat map displaying the distribution of ONFH-related publications globally.

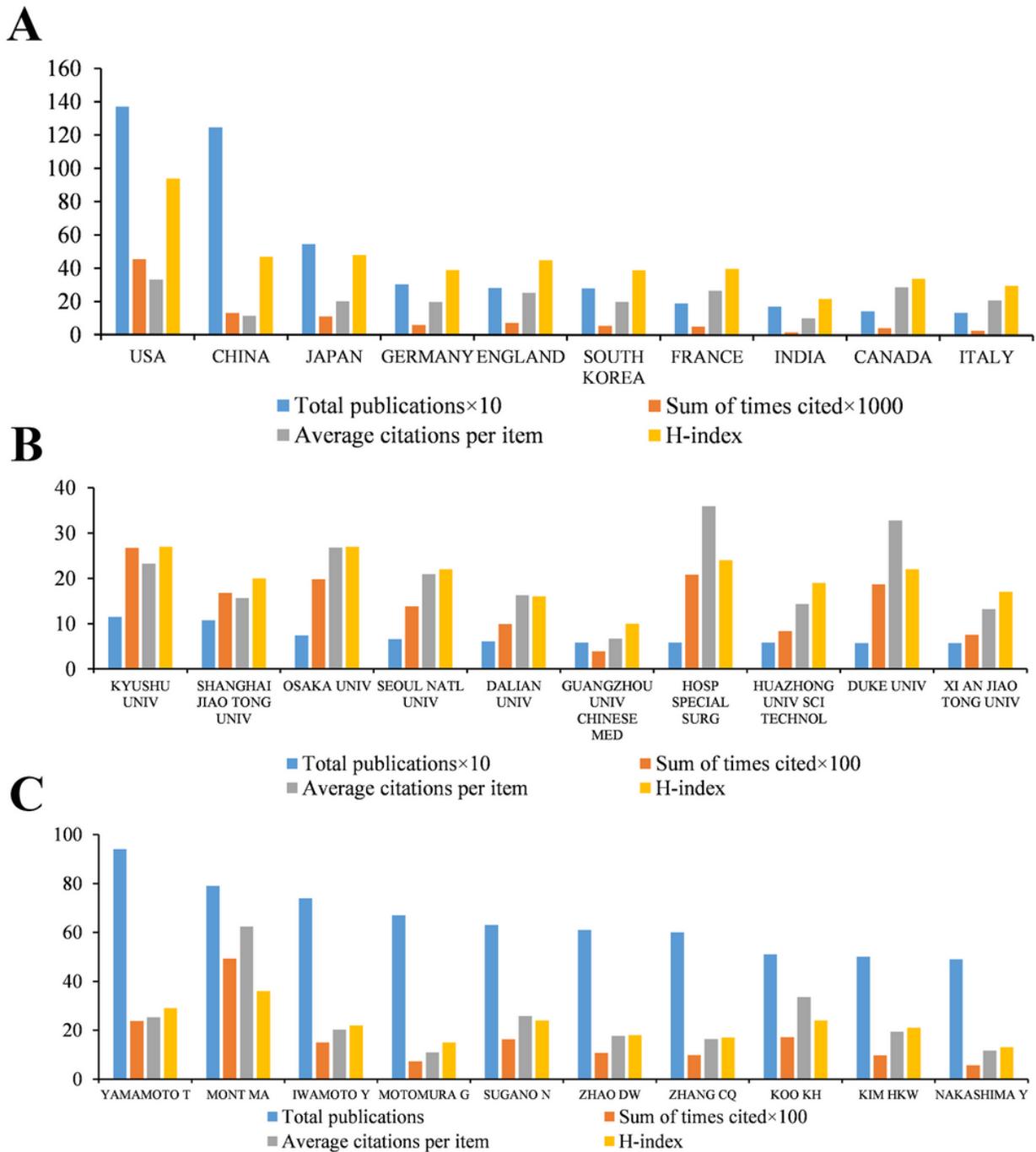
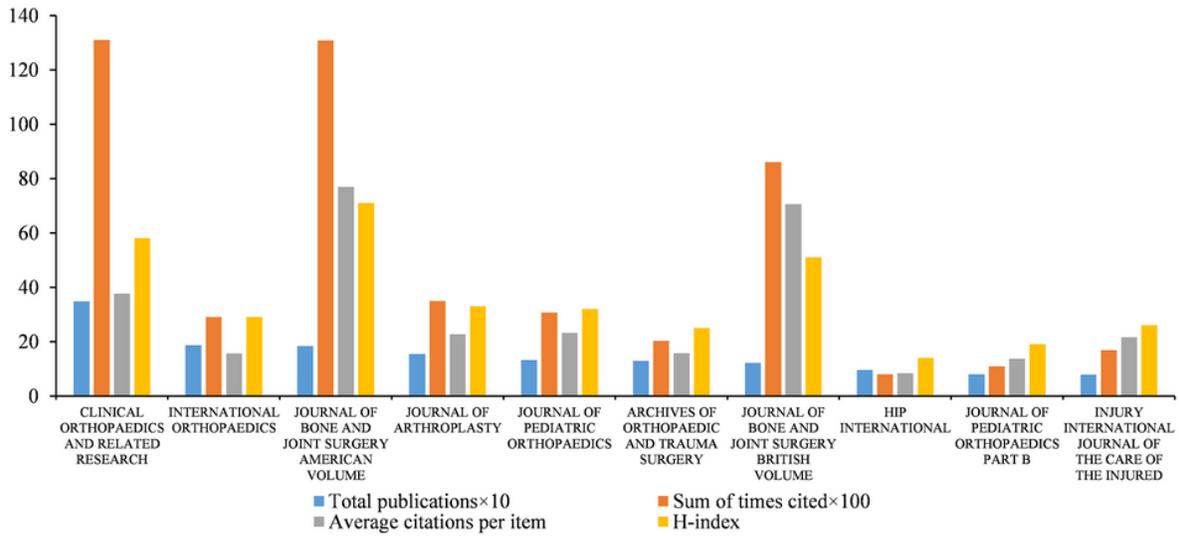
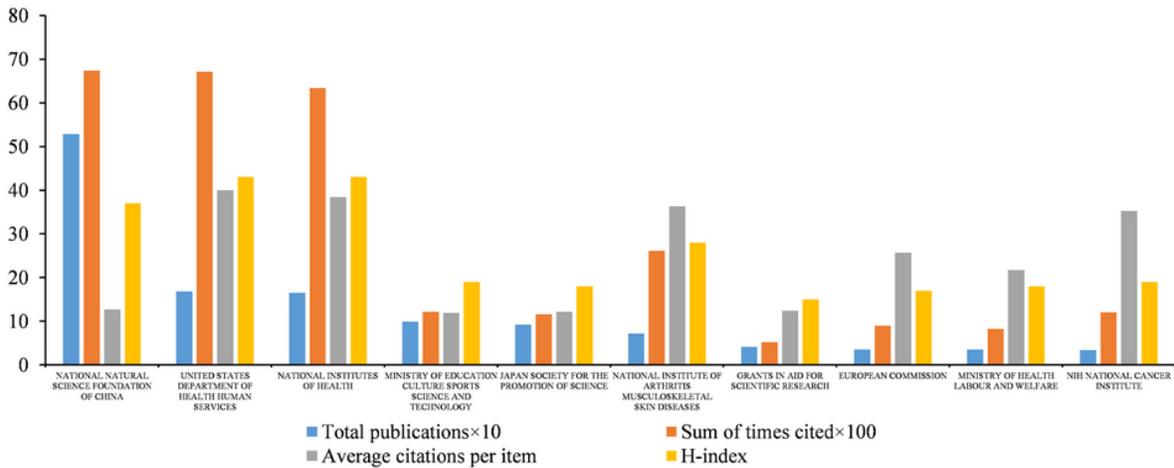
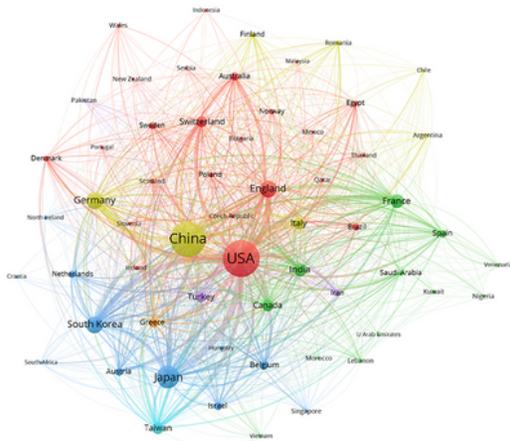
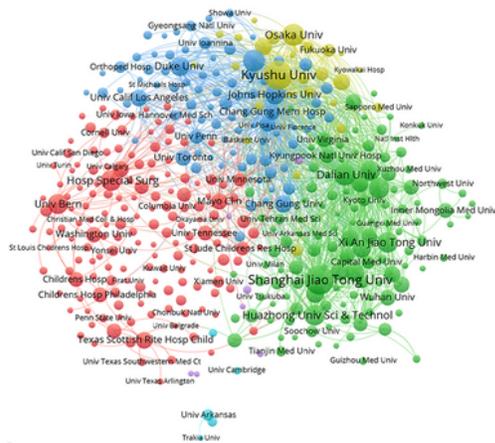
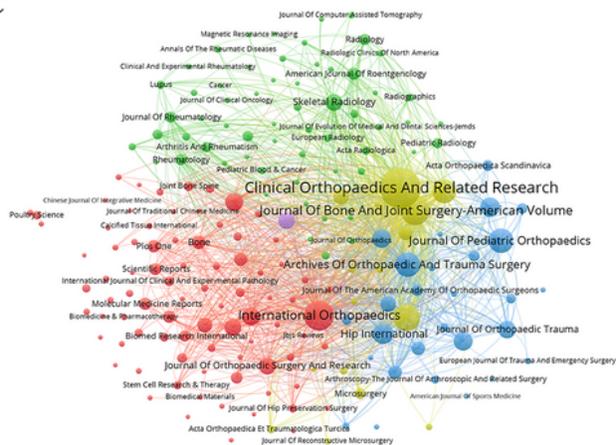


Figure 2

Quality analysis of global publications on ONFH in recent 30 years. (A) Total publications, sum of times cited, average citations per item, and H-index of top ten countries by contributions. (B) Total publications, sum of times cited, average citations per item, and H-index of top ten institutions by contributions. (C) Total publications, sum of times cited, average citations per item, and H-index of top ten authors by contributions.

A**B****Figure 3**

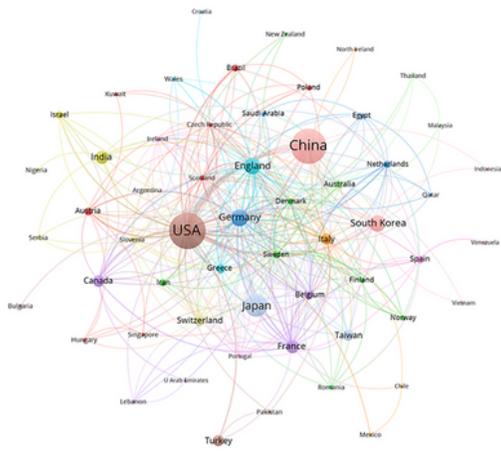
Analysis of highly contributing journals and funding agencies on ONFH in recent 30 years. (A) Total publications, sum of times cited, average citations per item, and H-index of top ten journals. (B) Total publications, sum of times cited, average citations per item, and H-index of top ten funding agencies.

A**B****C****Figure 4**

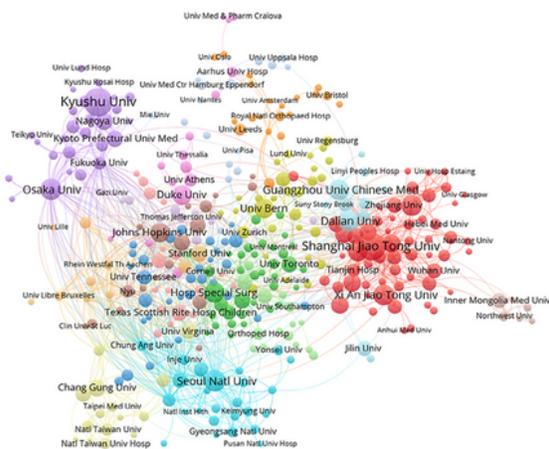
Bibliographic coupling analysis of global publications on ONFH in recent 30 years. (A) Network visualization of the 59 identified countries on ONFH. (B) Network visualization of the 405 identified institutions on ONFH. (C) Network visualization of the 189 identified journals on ONFH. In the visualized network, each item is represented by a circle. The size of the circle is determined by the number of

publications of the item. The distance between two circles approximately indicates the relatedness of the items. The color of an item is determined by the cluster to which the item belongs.

A



B



C

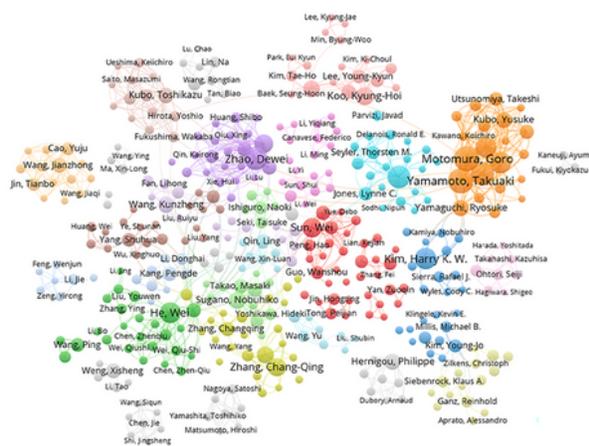
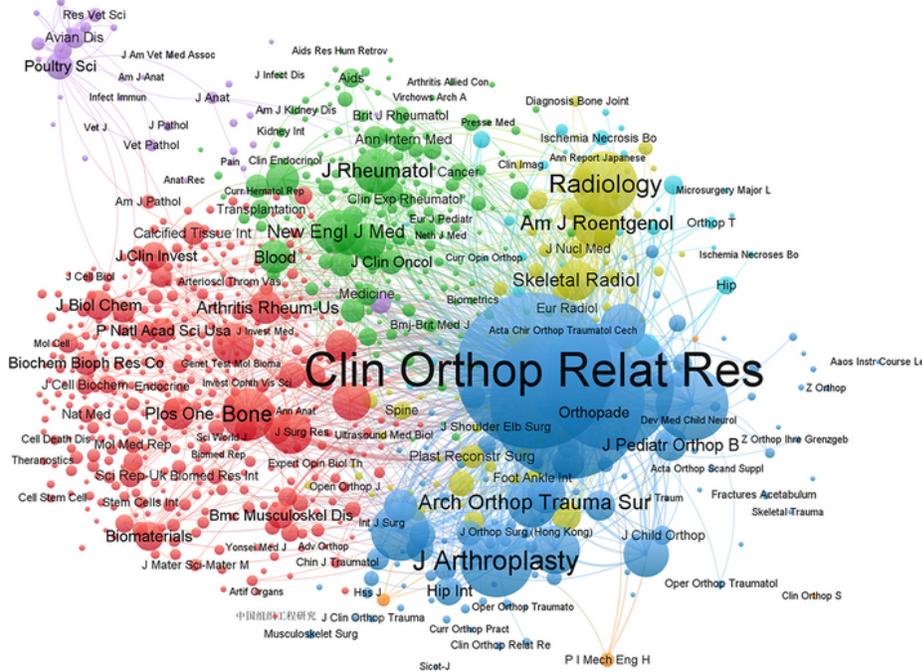


Figure 5

Co-authorship analysis of global publications on ONFH in recent 30 years. (A) Network visualization of the 59 identified countries on ONFH. (B) Network visualization of the 405 identified institutions on ONFH.

(C) Network visualization of the 629 identified authors on ONFH. In the visualized network, each item is represented by a circle. The size of the circle is determined by the number of publications of the item. The distance between two circles approximately indicates the relatedness of the items. Item color is determined by the cluster to which the item belongs.

A



B

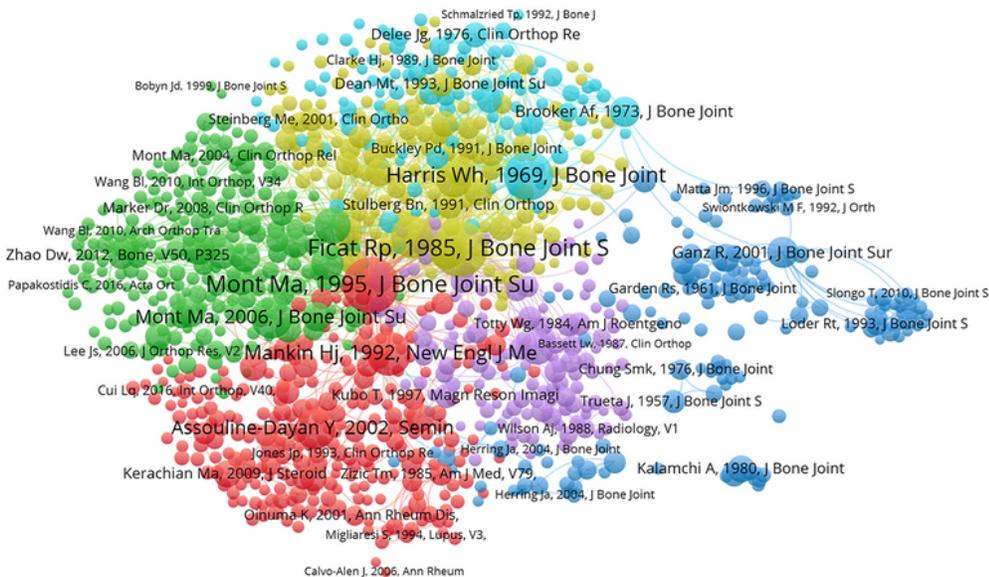


Figure 6

Co-citation analysis of global publications on ONFH in recent 30 years. (A) Network visualization of the 841 identified journals on ONFH. (B) Network visualization of the 1,184 identified publications on ONFH. In the visualized network, each item is represented by a circle. The size of the circle is determined by the number of publications of the item. The distance between two circles approximately indicates the relatedness of the items. Item color is determined by the cluster to which the item belongs.

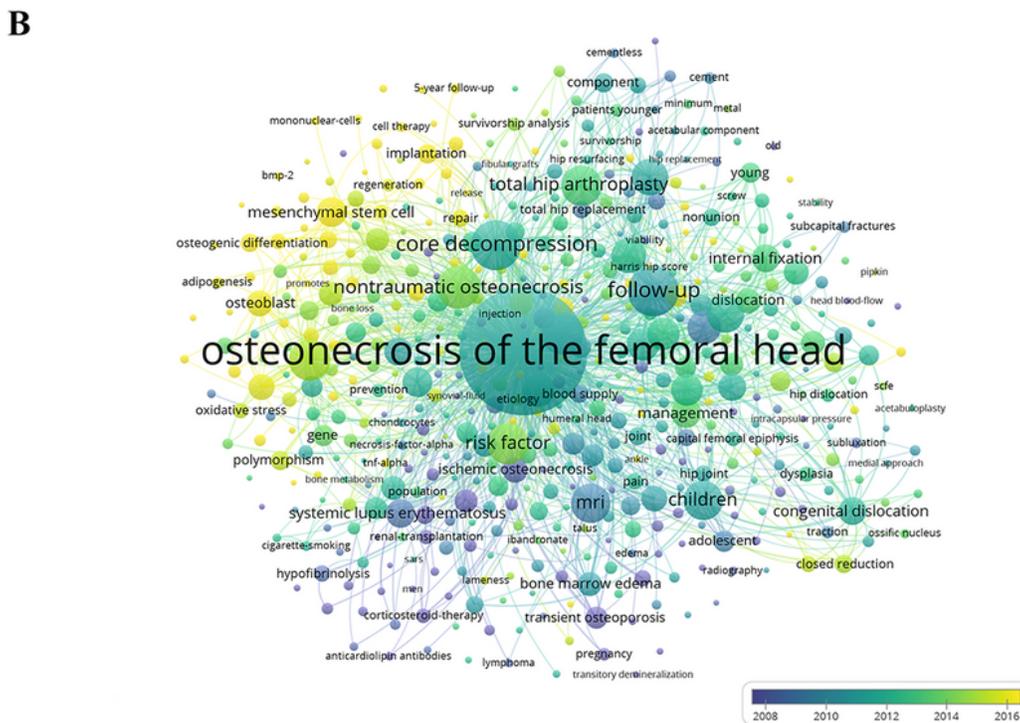
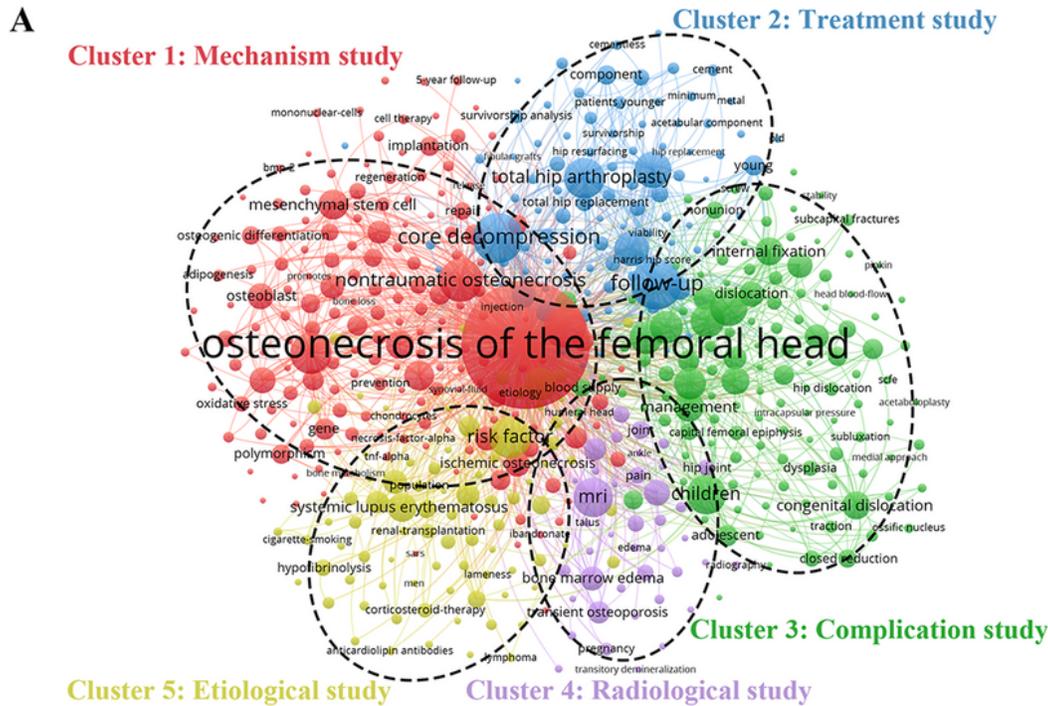


Figure 7

Co-occurrence analysis of global publications on ONFH in recent 30 years. (A) Network visualization of 515 identified keywords on ONFH. All the keywords are divided into 5 clusters: "Mechanism study", "Treatment study", "Complication study", "Radiological study" and "Etiological study". (B) Overlay visualization of the 515 identified keywords on ONFH based on the average time they appeared in the publications. The blue color keyword appeared earlier while the yellow color keyword appeared later.