

REVIEW

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Trends and hotspots in research on osteoporosis and nutrition from 2004 to 2024: a bibliometric analysis

Min Li¹, Binyang Yu², Haiyan Yang¹, Haiyan He¹, Ning Li¹, Aili Lv¹, Xiaoling Zhou³ and Rui Gao^{1*}

Abstract

Background The intricate association between nutrition and osteoporosis has garnered increasing attention, and approximately 3000 articles have been published in the past 20 years. However, there are currently very few comprehensive reviews on the development of this field. It is very necessary to retrospectively analyze the related articles and summarize the research hotspots, depth, and directions.

Objectives This study aimed to quantitatively analyze, visually review and comment on the articles published in the field of osteoporosis and nutrition based on the bibliometric methods, providing new insights for future research.

Methods The related articles published from 2004 to 2024 were retrieved from the Web of Science Core Collection (WOSCC). CiteSpace 6.1R2 software was used to conduct collaborative network analysis of annual publication volume, author patterns, country/region contributions, institutional affiliations, journal publications, highly cited literature, and keyword clustering.

Results A total of 2138 articles were assessed, revealing a consistent upward trend in published works in this domain, with the majority originating from the United States (564 papers). Seoul National University was identified as the most prolific institution (56 papers). Geng Bin was the most prolific author. Research hotspots included bone density, postmenopausal women, vitamin D, hip fractures, etc. Research subjects included physical activity, sarcopenia, calcium intake, machine learning, etc. Recent research trends indicate that cross-sectional study was more and the quality of life, muscle, and zinc are receiving attention in studies.

Conclusions Future research should continue to explore better methods for measuring bone density, investigating indicators for predicting fracture risk, exploring the relationship between various nutrients and substances with osteoporosis at a deeper level, and bolstering management strategies for male osteoporosis. Researchers should conduct longitudinal or interventional studies, and further improving the overall quality of life of patients with osteoporosis.

Keywords Bibliometric analysis, Osteoporosis, Nutrition, CiteSpace, Visualization

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Introduction

Osteoporosis is defined as reduced bone mineral density (BMD) and increased bone fragility [1]. In severe cases, fractures may occur, leading to elevated disability rates, depression, diminished quality of life, and even mortality [2]. It ranks among the most common ailments affecting middle-aged and elderly individuals [3]. With the continuous development of global aging, its prevalence is 18.3%, with a greater incidence in women than in men (23.1% and 11.7%, respectively) [4, 5]. In America, the incidence of osteoporosis is expected to increase by 32% to 17.2 million from 2010 to 2030 [6]. Previous studies have shown that more than one-third of middle-aged and elderly women (compared to one in five men) in the world suffer from fractures due to the effects of osteoporosis [7, 8]. Moreover, osteoporosis imposes a substantial economic burden worldwide. In the European Union alone, the estimated cost of preventing and managing osteoporosis is €37 billion, a figure set to increase by 25% by 2025 [9]. Therefore, osteoporosis has become a major public health problem worldwide [10].

Bone, as a living tissue, relies on a full spectrum of essential nutrients for growth and maintenance. It consists predominantly of protein, the principal component of connective tissue, which constitutes 50% of bone volume and 20% of bone weight. Good nutrition plays a pivotal role in maintaining optimal bone health. Consistent small benefits gained daily over the course of several decades can significantly impact one's fracture risk [11]. Nutrition, in particular, has emerged as a key determinant in mitigating bone loss and the risk of fractures. Several studies strongly recommend a diet rich in calcium, protein, vitamin C, and vitamin D as essential for preventing osteoporosis [12–14]. Previous research has substantiated the correlation between micronutrients and the prevention of osteoporosis, emphasizing the significance of dietary factors [15]. Conversely, poor nutrition has been identified as a contributing factor to osteoporosis and fractures [16].

Osteoporosis has emerged as a significant clinical challenge confronting the global human population. Understanding the intricate relationship between osteoporosis and nutrition is imperative for the development of effective preventive and therapeutic interventions. The relationship between osteoporosis and nutrition has received widespread attention, and approximately 3000 articles have been published in the past 20 years. However, there are currently very few comprehensive reviews on the development of this field. It is very necessary to retrospectively analyze the related articles and summarize the research hotspots, depth, and directions.

Bibliometrics, as a quantitative method, employs mathematical and statistical approaches to analyze scientific publications. CiteSpace, in particular, facilitates

the conceptualization of knowledge domains by generating and visualizing co-occurrence network maps of contributors and keywords as well as co-citation networks of cited authors and contributes to visualize research status, hotspots, and frontiers in a timely manner. Therefore, our study used data obtained from the Web of Science database to conduct bibliometric analysis on osteoporosis and nutrition studies published from 2004 to 2024. The comprehensive analysis might form the basis for evidence-based strategies aimed at promoting bone health and alleviating the substantial global burden caused by osteoporosis. It is hoped that this study will provide crucial insights and guidance for future researchers and decision makers, facilitating advancements in the field.

Materials and methods

Data source and search strategy

The research process is illustrated in Fig. 1. We collected the data from the Web of Science Core Collection database (WOSCC). The timespan covered from January 1, 2004, to March 1, 2024. The topic field was used to search for articles related to a specific research field. TS=(“Nutrition” or “Nutrients” or “Nutritional Supplements” or “Dietary Nutrients” or “Dietary Supplementations” or “Macronutrients” or “Micronutrients”) and (“Osteoporosis, Postmenopausal” or “Osteoporosis” or “Posttraumatic Osteoporosis” or “Senile Osteoporosis” or “Age Related Bone Loss” or “Age Related Osteoporosis”).

Inclusion/exclusion criteria

Inclusion criteria: (1) Original research articles related to osteoporosis and nutrition; (2) Studies published between 2004 and 2024; (3) Studies published in peer-reviewed journals; (4) The language of the article is English. Exclusion criteria: Review articles, conference abstracts, letters, and other non-empirical study types. Two researchers independently reviewed titles and abstracts and removed studies that were not related to osteoporosis and nutrition. A total of 2138 publications were retained after reviewing the titles and abstracts.

Data analysis and visualization

CiteSpace, developed by Chaomei Chen, is a Java application designed to visualize bibliographic databases effectively. It was chosen as our primary tool for bibliometric analysis due to its robust capabilities in identifying research trends, detecting emerging topics, and mapping intellectual structures within a scientific domain. The software is specifically designed to visualize patterns in bibliographic data, enabling us to highlight key turning points, influential authors, institutions, and geographic distributions in the field of osteoporosis and nutrition research. Its unique ability to detect and visualize co-citation networks, co-occurrence relationships, and

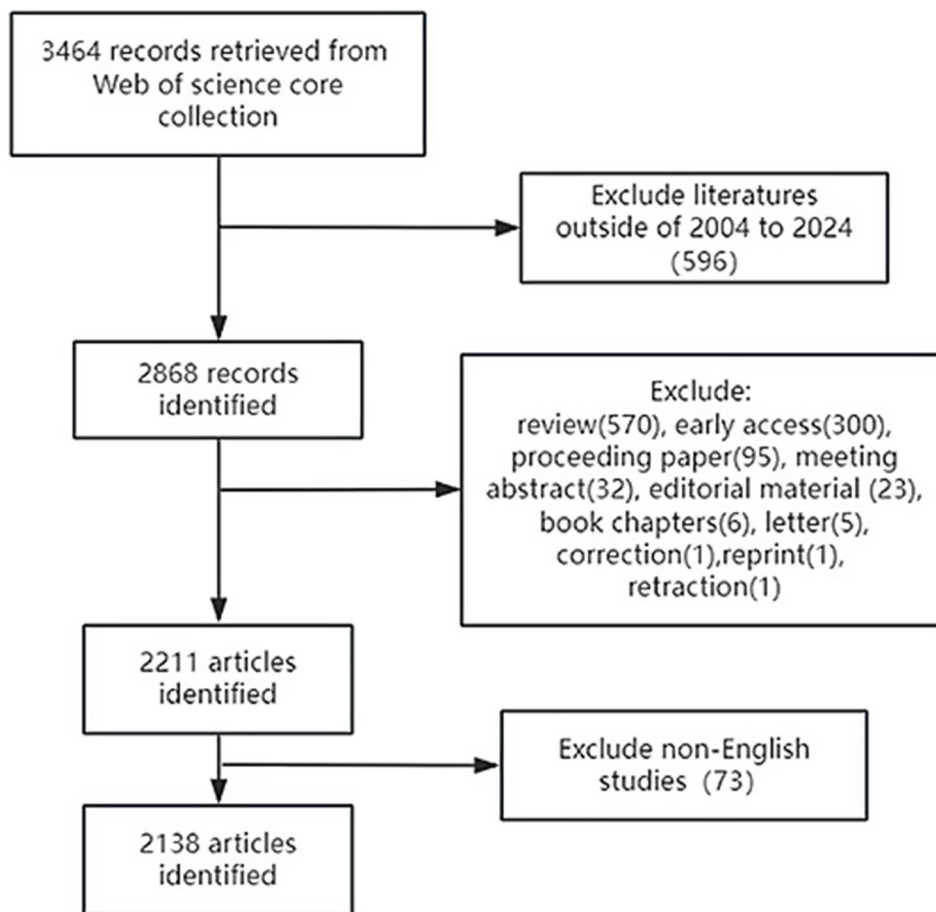


Fig. 1 Flow chart of the inclusion criteria

temporal patterns made it an ideal choice for our study. Firstly, we export the WOSCC database literature in “plain text file” format and then import it into CiteSpace 6.1 R2 software for literature visualization analysis. For the settings, we employed a time slicing range from 2004 to 2024, with one-year intervals. This fine-grained temporal slicing allows us to capture the evolution of the field on an annual basis, making it easier to identify significant changes in research activity over time. We selected author, institution, country, keyword, reference, cited author, and cited journal as term sources to ensure a comprehensive view of the various dimensions influencing the field. These parameters were chosen to provide insights into both the micro (individual authorship and institutional collaborations) and macro (geographical distribution and journal impact) aspects of the research landscape. Network pruning techniques, such as pathfinder and pruning sliced networks, were utilized to reduce redundancy in the visualized networks, enhancing clarity and ensuring that only the most significant connections between nodes were retained. This approach allows for a more precise identification of pivotal

studies and influential researchers. The trend maps generated through these settings include publication volume, authorship patterns, institutional and geographic collaboration, and keyword co-occurrence, which collectively offer a multidimensional view of the research landscape. CiteSpace also provides quantitative metrics, such as modularity (Q-values) and silhouette (S-values), to assess the structure and reliability of the visualized networks. A Q-value greater than 0.3 indicates that the network has a significant structure, meaning that the research topics are well-differentiated. S-values, which measure the coherence of clusters, are used to validate the quality of clustering, with values greater than 0.5 indicating reasonable clustering and values above 0.7 suggesting highly reliable clustering [17]. These metrics further ensure the robustness of the visualized results. Our study was reported in accordance with guidelines for bibliometrics [18].

Results

Analysis of annual publications

In this study, a comprehensive analysis was conducted on 2138 articles spanning the last two decades in the

field of osteoporosis and nutrition. As shown in Fig. 2, a steady increase in the number of publications related to osteoporosis and nutrition research can be observed, beginning with 46 publications in 2004 and culminating in a significant peak of 205 publications in 2023. Notably, starting around 2018, there is a marked acceleration in the publication rate, as evidenced by the sharp rise in publication numbers after a relatively stable period between 2009 and 2017. The apparent decline in publication count in 2024 (27 publications) is likely a reflection of incomplete data for that year. The sharp rise in recent years also indicates the presence of key research hotspots.

Analysis of countries and institutions

The global collaboration network (Fig. 3) visualizes the intricate relationships among countries involved in osteoporosis and nutrition research. The network consists of 86 nodes connected by 437 lines, indicating a moderate level of collaboration with a network density of 0.1196. This relatively dense network demonstrates that research in osteoporosis and nutrition is highly internationalized, with many countries engaging in joint studies. As indicated in Table 1, in the field of osteoporosis and nutrition, the United States, China, and South Korea stand out as central hubs of collaboration, with the United States exhibiting the most extensive connections. The dominance of the United States is further reinforced by its position as the country with the highest number of publications (564 papers, accounting for 21% of the total). China follows with 317 papers (11.8%), and South Korea ranks third with 285 articles. These three countries form a triad of collaboration that is critical to driving research

in osteoporosis and nutrition, reflecting their substantial resources and scientific influence in this field. Notably, universities emerge as the predominant institutions generating these publications, with Seoul National University, Harvard University, and the University of California System reigning supreme contributions. The respective publication counts for these institutions are 56, 49, and 48 in descending order. Several other influential research institutions include the United States Department of Agriculture, Catholic University of Korea, Harvard Medical School, and Yonsei University. Generally, these institutions predominantly hail from the United States, South Korea, and Canada.

Analysis of cited journals

Table 2 presents the top 10 journals in terms of citation volume, with the majority hailing from the United States, except for *Osteoporosis International* and *The Lancet*, which originated from Germany and England, respectively. The three leading journals in this ranking are *Osteoporosis International*, *Journal of Bone and Mineral Research*, and *The American Journal of Clinical Nutrition*. Their respective citation counts are 1449, 1366, and 1115, with corresponding impact factors of 4.0, 6.2, and 7.1, respectively. Notably, *The Lancet* and *The New England Journal of Medicine* had the highest impact factors at 168.9 and 158.5, respectively. Consequently, it can be inferred that this field boasts a selection of high-quality articles. Figure 4 illustrates the collaboration among cited journals and reveals 826 nodes connected by 4310 lines, generating a network density of 0.0126. In this visualization, the journals ranked at the top exhibit larger nodes,

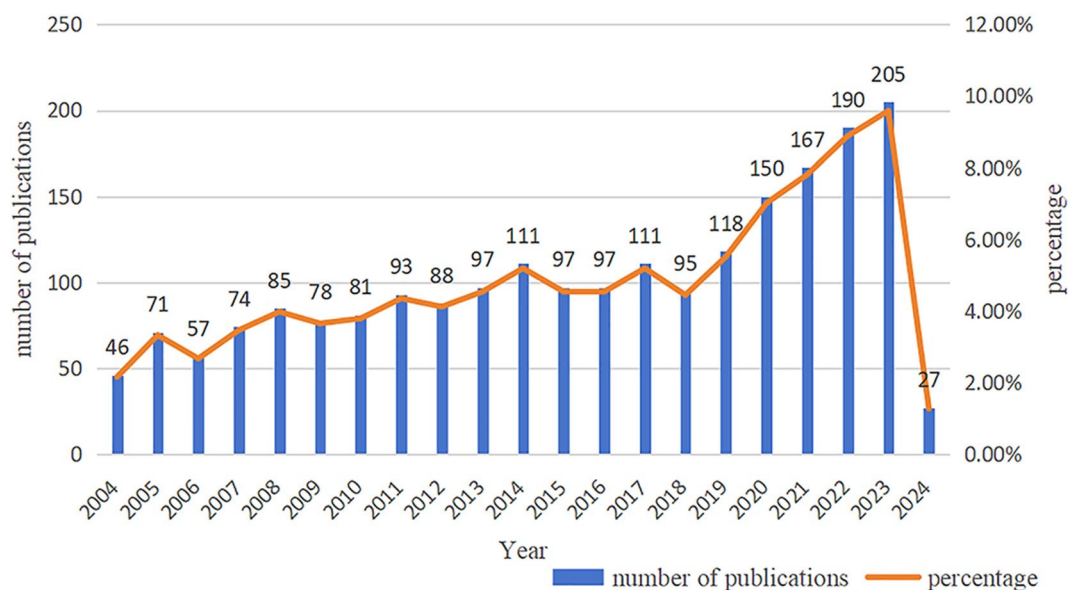


Fig. 2 Trend of annual publications from 2004 to 2024

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 Nodes Labeled: 1.0%
 Pruning: None

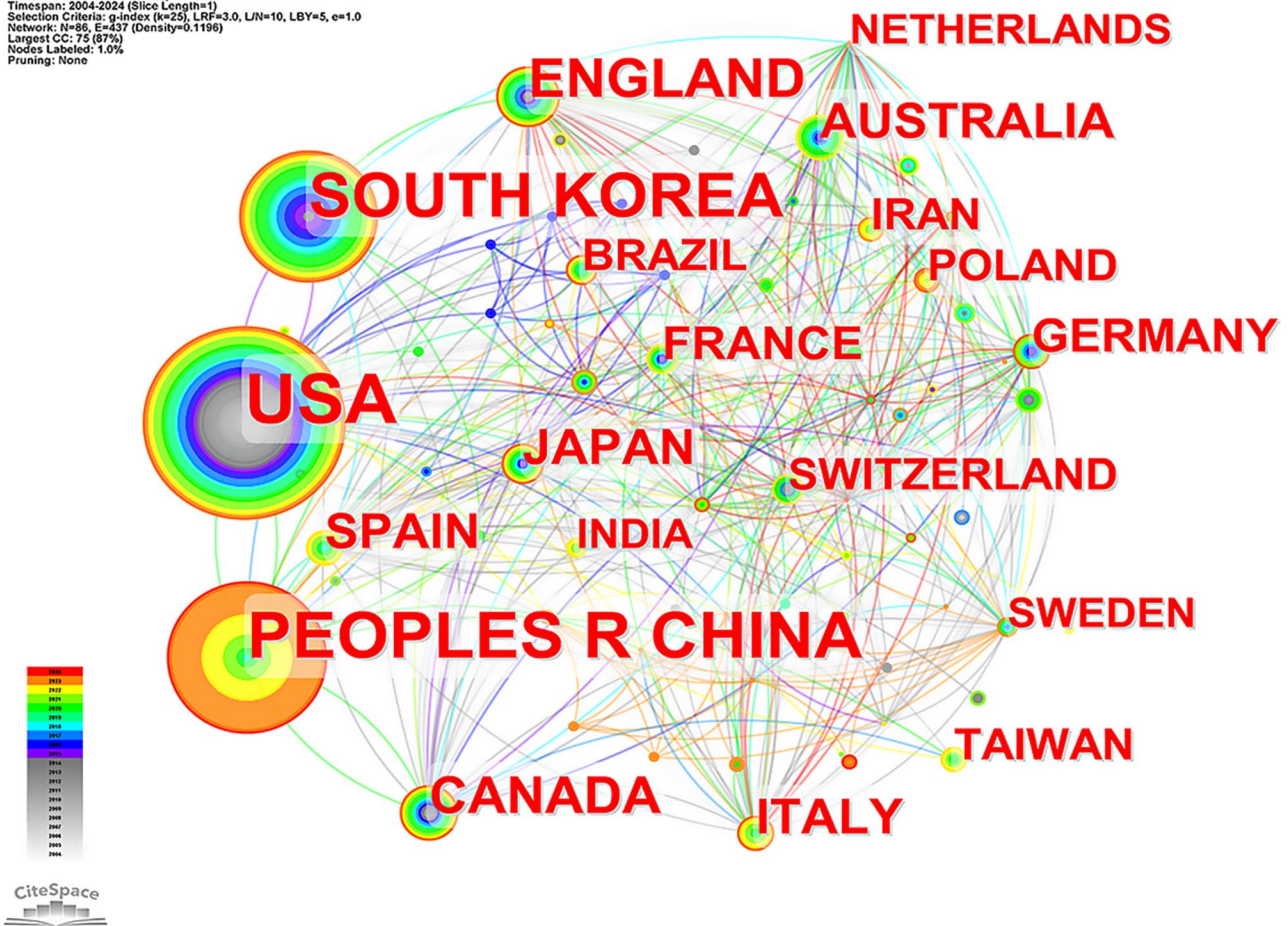


Fig. 3 Country/region collaboration chart

Table 1 Top 10 countries and institutions by the number of publications

Rank	Country/Region	Publicatons	Rank	Institutions	Publicatons
1	United States	564	1	Seoul National University	56
2	China	317	2	Harvard University	49
3	South Korea	285	3	University of California System	48
4	England	148	4	United States Department of Agriculture	35
5	Canada	114	4	Catholic University of Korea	35
6	Japan	86	5	Harvard Medical School	32
7	Italy	83	6	Yonsei University	28
8	Spain	82	6	Centers for Disease Control & Prevention - USA	28
9	Australia	79	6	Tufts University	28
10	Germany	62	7	University of Toronto	26

indicating their prominence in terms of collaboration and citation impact.

Analysis of authors

The collaboration network among authors (Fig. 5) highlights the intricate relationships between prolific researchers in osteoporosis and nutrition. The network consists of 318 nodes and 528 connected lines, resulting in a relatively low network density of 0.0105, which

suggests that there is still room for enhancing collaborative efforts within this research field. The data in Table 3 show that the majority of the top 10 authors based on publication volume are from China, with others from the United States and South Korea. Geng Bin, from the Department of Orthopedics at Lanzhou University Second Hospital, leads the field with 12 publications. This is followed closely by Looker A C from the National Center for Health Statistics (CDC), Rhee Yumie from Yonsei

Table 2 Top 10 journals by citations

Rank	Cited journals	Citations	Country	Category zone	IF(2023)
1	<i>Osteoporosis International</i>	1449	Germany	Q2	4.0
2	<i>Journal of Bone and Mineral Research</i>	1366	United States	Q1	6.2
3	<i>The American Journal of Clinical Nutrition</i>	1115	United States	Q1	7.1
4	<i>Bone</i>	1032	United States	Q2	4.398
5	<i>The Journal of Clinical Endocrinology and Metabolism</i>	983	United States	Q1	5.8
6	<i>Calcified Tissue International</i>	739	United States	Q3	4
7	<i>The New England Journal of Medicine</i>	682	United States	Q1	158.5
8	<i>The Lancet</i>	681	England	Q1	168.9
9	<i>Journal of Nutrition</i>	663	United States	Q2	4.687
10	<i>JAMA-Journal of the American Medical Directors Association</i>	635	United States	Q1	7.6

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 Nodes Labeled: 1.0%
 Pruning: Pathfinder

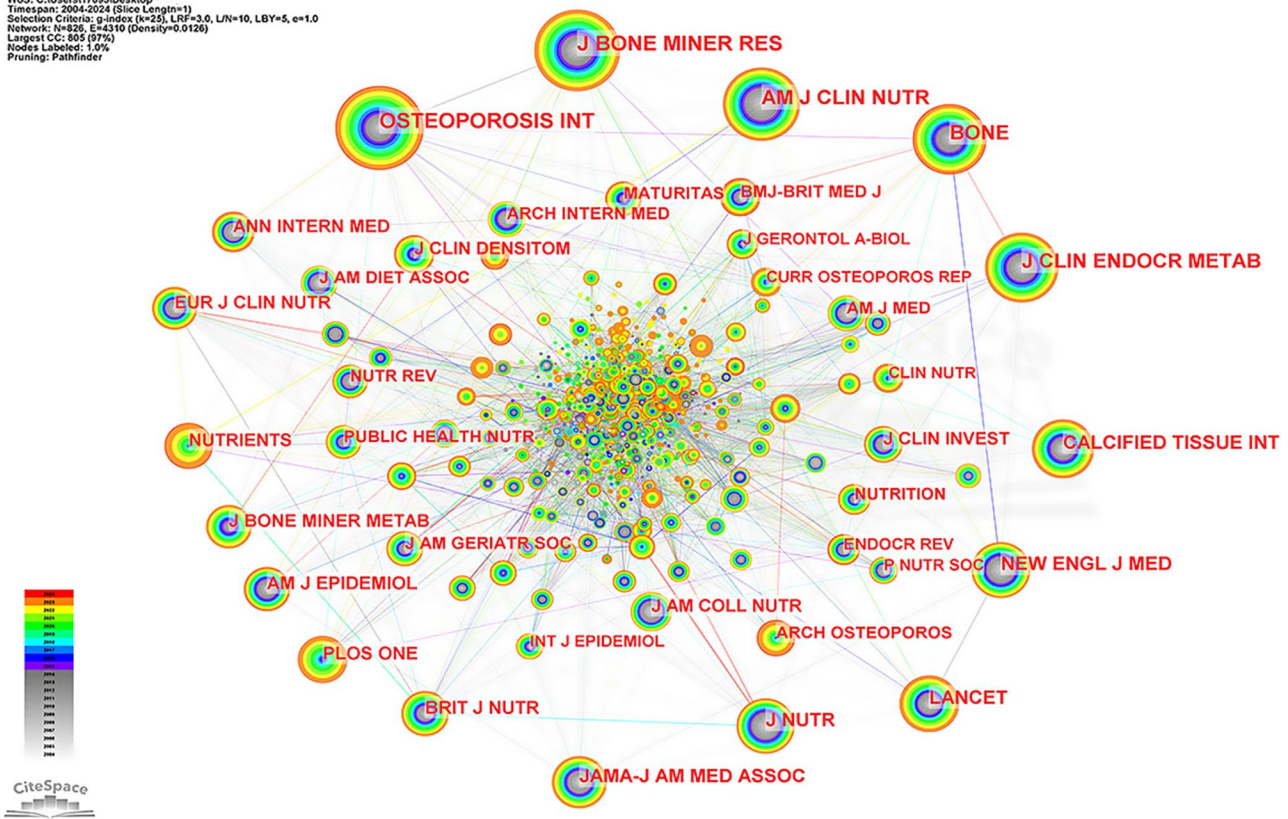


Fig. 4 Collaboration chart of cited journals

University in South Korea, and several Chinese researchers, including Xia Yayi, Tang Yuchen, and Liu Mingjiang. In Fig. 5, several close-knit collaborative clusters can be observed, particularly those involving authors from the same institutions or geographic regions. For example, Liu Mingjiang, Zhang Ya, and Xie Ruijie from the Nanhua Hospital at Hengyang Medical School (University of South China) exhibit close collaborations, as evidenced by the multiple lines connecting these authors. Similarly, Geng Bin and Xia Yayi from Lanzhou University

show strong collaboration ties, particularly in the areas of orthopedics and osteoporosis-related research.

Analysis of co-cited references

Table 4 provides a comprehensive summary of the main information pertaining to the top 10 most co-cited references. The most frequently co-cited reference is the article “Osteoporosis”. Authored by Compston, J.E. from the Department of Medicine at Cambridge Biomedical Campus in England, this article was published in *Lancet* in 2019 and has garnered 48 citations. It is worth

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 Largest CC: 38 (5%)
 Nodes Labeled: 1.0%
 Pruning: None

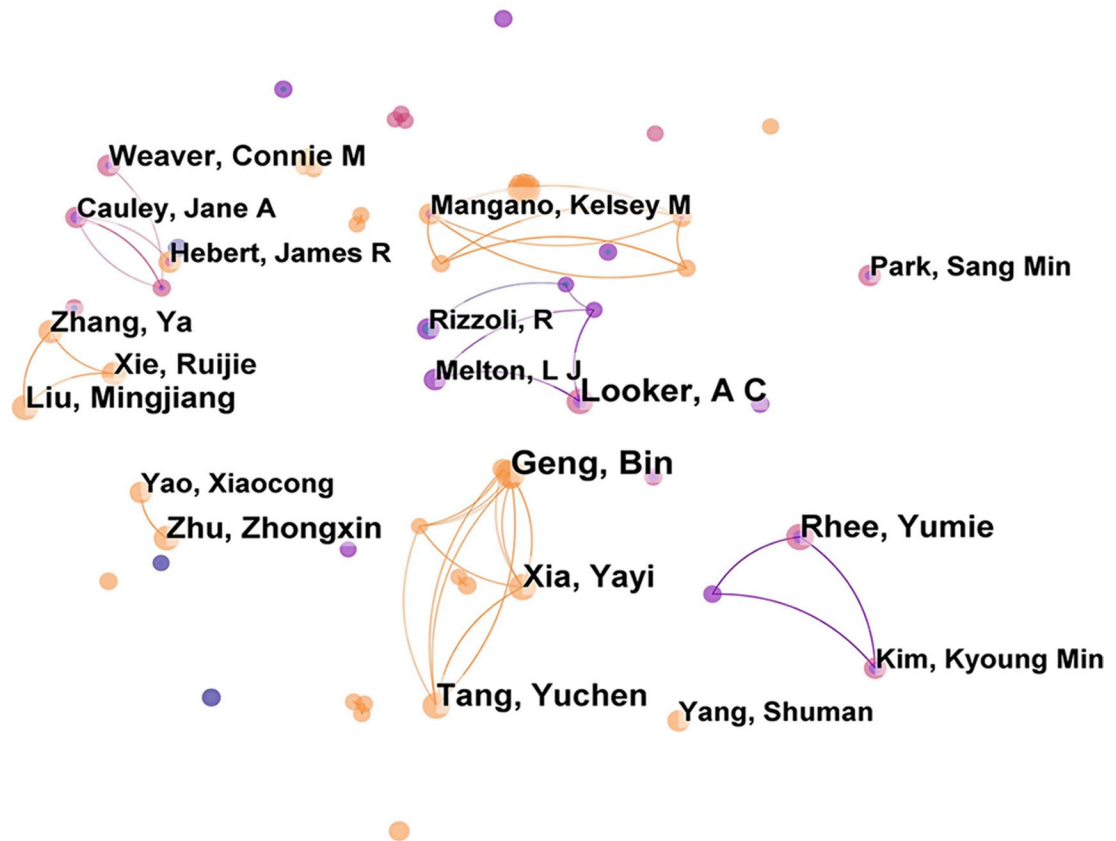


Fig. 5 Author collaboration chart

Table 3 Top 10 active authors in the research

Rank	Author	Publications	Country	Affiliation
1	Geng, Bin	12	China	Department of Orthopedics, Lanzhou University Second Hospital
2	Looker, A C	11	United States	Division of Health and Nutrition Examination Surveys, National Center for Health Statistics, Centers for Disease Control and Prevention
3	Rhee, Yumie	10	Korea	Department of Internal Medicine, Yonsei University College of Medicine
3	Xia, Yayi	10	China	Department of Orthopedics, Lanzhou University Second Hospital
3	Tang, Yuchen	10	China	Chongqing Medical University
4	Liu, Mingjiang	9	China	Nanhua Hospital, Hengyang Medical School, University of South China
4	Zhu, Zhongxin	9	China	Hospital of Wenzhou Medical University
5	Zhang, Ya	8	China	Nanhua Hospital, Hengyang Medical School, University of South China
5	Weaver, Connie M	8	United States	Department of Nutrition and Food Studies, George Mason University
5	Xie, Ruijie	8	China	Nanhua Hospital, Hengyang Medical School, University of South China

mentioning that a majority of the authors of these highly cited articles are from the United States, with the remaining contributors hailing from England, Spain, and Taiwan, China. Among the top 10 cited articles, the second and third positions are from *Osteoporosis International*,

and the fourth and last positions belong to *The New England Journal of Medicine*. Additionally, the sixth and ninth positions are from the *Journal of Bone and Mineral Research*. Figure 6 presents the co-cited reference network, which consists of references with higher centrality

Table 4 Top 10 co-cited references in the research

Rank	Co-cited reference	Author	Year	Frequency	Country	Source
1	Osteoporosis	Compston, J.E.[19]	2019	48	England	Lancet
2	The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations.	Weaver, C.M.[20]	2016	34	United States	Osteoporosis International
3	European guidance for the diagnosis and management of osteoporosis in postmenopausal women	Kanis, J.A.[21]	2020	31	England	Osteoporosis International
4	Vitamin D deficiency	Holick, M.F.[22]	2007	25	United States	The New England Journal of Medicine
5	Sarcopenia: revised European consensus on definition and diagnosis	Cruz-Jentoft, A.J.[23]	2019	23	Spain	Age Aging
5	The recent prevalence of osteoporosis and low bone mass in the United States based on bone mineral density at the femoral neck or lumbar spine	Wright, N.C.[6]	2014	23	United States	Journal of Bone and Mineral Research
6	Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment	Chen, L.K.[24]	2020	21	Taiwan, China	Journal of the American Medical Directors Association
6	Trends in osteoporosis and low bone mass in older US adults, 2005–2006 through 2013–2014	Looker, A.C.[25]	2017	21	United States	Osteoporosis International
7	Incidence and economic burden of osteoporosis-related fractures in the United States, 2005–2025	Burge, R.[26]	2007	19	United States	Journal of Bone and Mineral Research
7	Calcium plus vitamin D supplementation and the risk of fractures	Jackson, R.D.[27]	2006	19	United States	The New England Journal of Medicine

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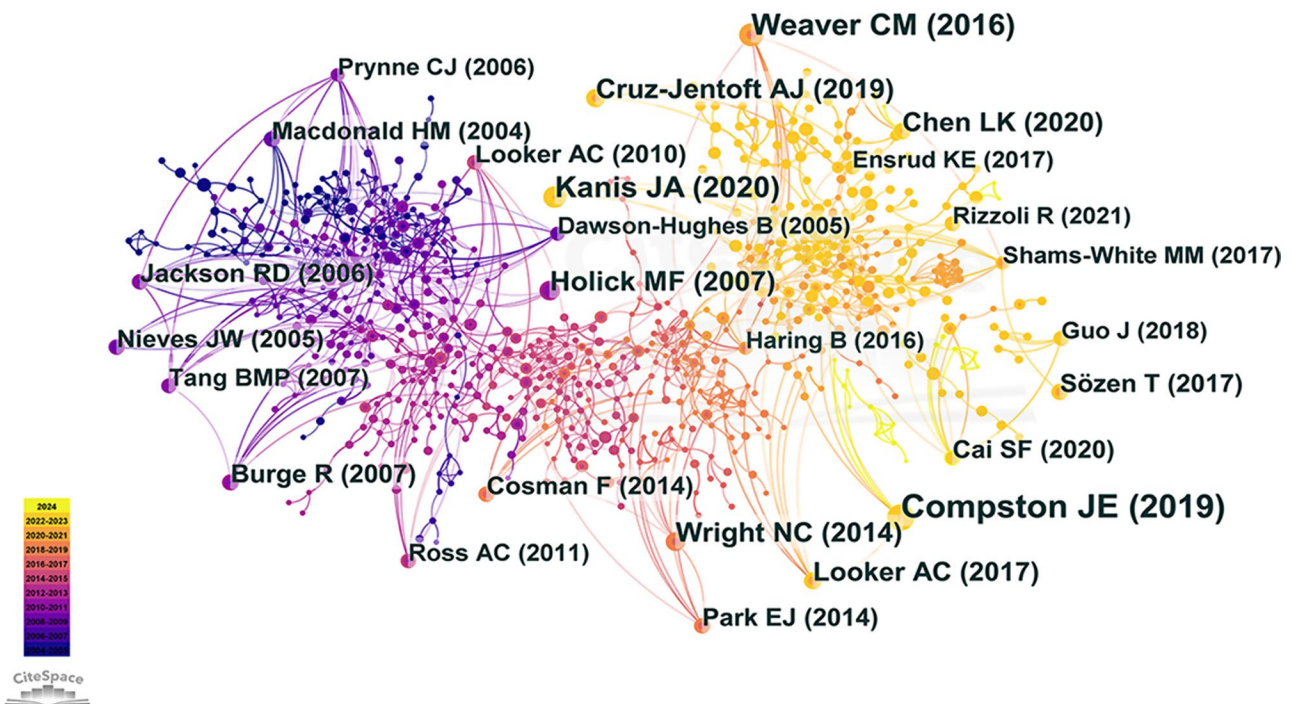


Fig. 6 The collaboration chart of co-cited references

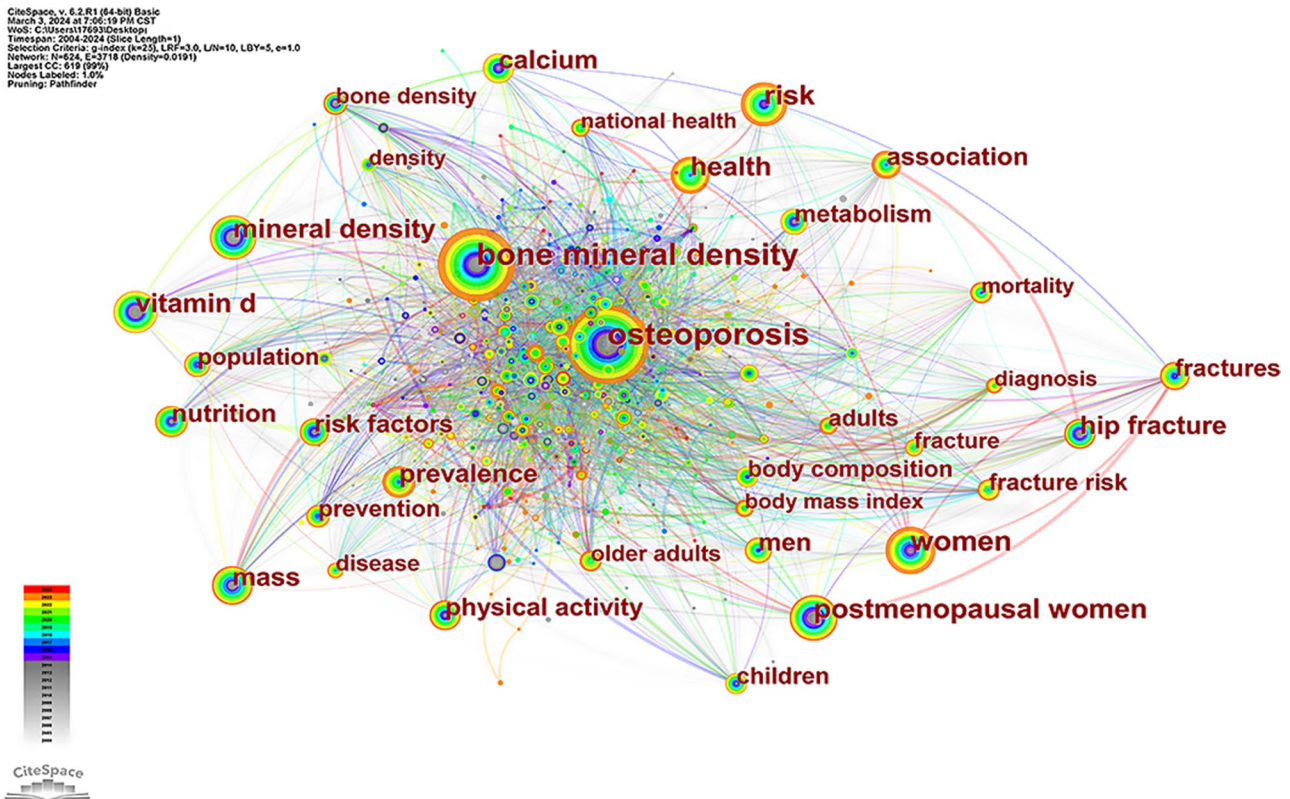


Fig. 7 Keyword co-occurrence knowledge map

Table 5 Co-occurrence frequency of the top 10 keywords

Rank	Keywords	Number of occurrences	Centrality
1	osteoporosis	788	0
2	bone mineral density	731	0
3	women	387	0.01
4	postmenopausal women	335	0.02
5	risk	318	0.02
6	vitamin D	290	0.01
7	mineral density	284	0.01
8	health	259	0.02
9	mass	236	0.01
10	hip fracture	214	0.03

and citation counts. The lighter the color of the nodes in the graph, indicating the article was published later. This network aids in identifying the pivotal knowledge base within the field, offering convenience in determining crucial research contributions.

Analysis of keywords

Keyword co-occurrence analysis

To identify the hotspots and frontiers of publications spanning from 2004 to 2024, a comprehensive analysis of keyword co-occurrence is imperative. CiteSpace was subsequently employed to construct a keyword knowledge co-occurrence map, as shown in Fig. 7. The time slice was set to 1 year, resulting in 624 nodes connected by 3718

links, with a network density of 0.0191. The size of each node corresponds to the significance of the respective keyword. To provide a more insightful understanding of these keywords, we present the ten most frequently occurring terms, along with their frequencies in Table 5. The top ten keywords identified were osteoporosis, bone mineral density, women, postmenopausal women, risk, vitamin D, mineral density, health, mass, and hip fracture. Hip fracture had the highest centrality at 0.03. These keywords offer valuable insights into the prevailing themes and concerns within the research field.

Keyword clustering and citation bursts analysis

In order to thoroughly explore the current research hotspots within the field, CiteSpace was used to generate a keyword clustering map (Fig. 8). The clustering quality is supported by a modularity (Q) value of 0.3351, reflecting a satisfactory clustering effect, and a silhouette (S) value of 0.6812, which signifies high homogeneity among the clusters and reasonable outcomes. The identified clusters encompass a wide range of topics, including #0 physical activity, #1 sarcopenia, #2 machine learning, #3 vitamin D, #4 metabolism, #5 body mass index, #6 nutrition examination survey, #7 trabecular bone, and #8 quality of life. Each cluster represents a specific domain, reflecting the research trends and the current focus of the academic community. The significant clusters that

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Selection Criteria: q=0.95, LRF=3.0, L/N=10, LBY=5, e=1.0
Network: N=624, E=7345 (Density=0.0378)
Largest CC: 519 (92%)
Nodes Labeled: 1.0%
Pruning: Pathfinder
Modularity Q=0.335
Weighted Mean Silhouette S=0.6512
Harmonic Mean(Q, S)=0.4492
    
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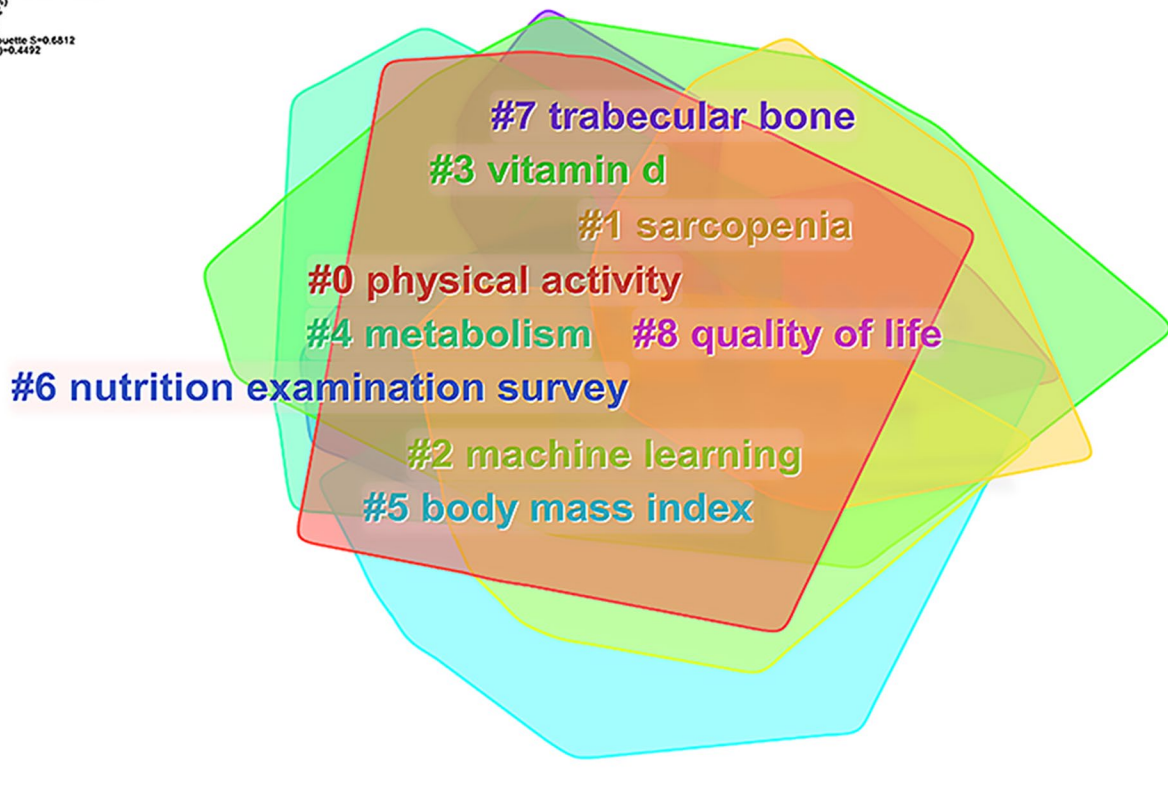


Fig. 8 Keyword clustering map

emerged are closely related, with overlaps indicating interconnections between fields such as sarcopenia and osteoporosis, both of which impact bone and muscle health in older adults. Physical activity (#0) and sarcopenia (#1) have emerged as central themes, emphasizing their role in healthy aging and prevention of age-related conditions. Machine learning (#2) has been increasingly applied in biomedical research to unravel complex gene-environment interactions. Clusters such as metabolism (#4) and body mass index (#5) align with broader public health concerns, while trabecular bone (#7) and quality of life (#8) highlight specific outcomes of bone health research. Additionally, keyword analysis was conducted using citation burst detection to uncover emerging trends within the field. Figure 9 presents the top 20 keywords with the strongest citation bursts from 2004 to 2024. Keywords such as elderly women, calcium supplementation, and third national health showed high burst strengths in the earlier periods, while more recent bursts highlight keywords such as osteoporotic fractures, sarcopenia, quality of life, cross-sectional study, muscle, and zinc. These latter keywords remain influential through 2024, indicating ongoing research attention. The red line

in Fig. 9 indicates the period of significant citation bursts, emphasizing the rise in importance of these terms.

Discussion

Principal findings

This research employed CiteSpace software to conduct bibliometric analysis of published articles pertaining to osteoporosis and nutrition studies from 2004 to 2024. The authors, institutions, journals, countries, references, and keywords associated with osteoporosis and nutrition were examined to determine the current status and development trends. The analysis revealed a consistent and significant increase in the number of publications over time. This upward trend highlights the growing recognition of the importance of osteoporosis and nutrition as research fields, particularly in addressing public health concerns associated with aging populations and dietary influences on bone health. Several factors contribute to this upsurge in interest. First, during this period, advancements in understanding the role of specific nutrients, genetics, and lifestyle factors in bone health gained prominence in the literature. Furthermore, public health organizations worldwide may have prioritized osteoporosis prevention strategies, leading to increased research

Top 20 Keywords with the Strongest Citation Bursts

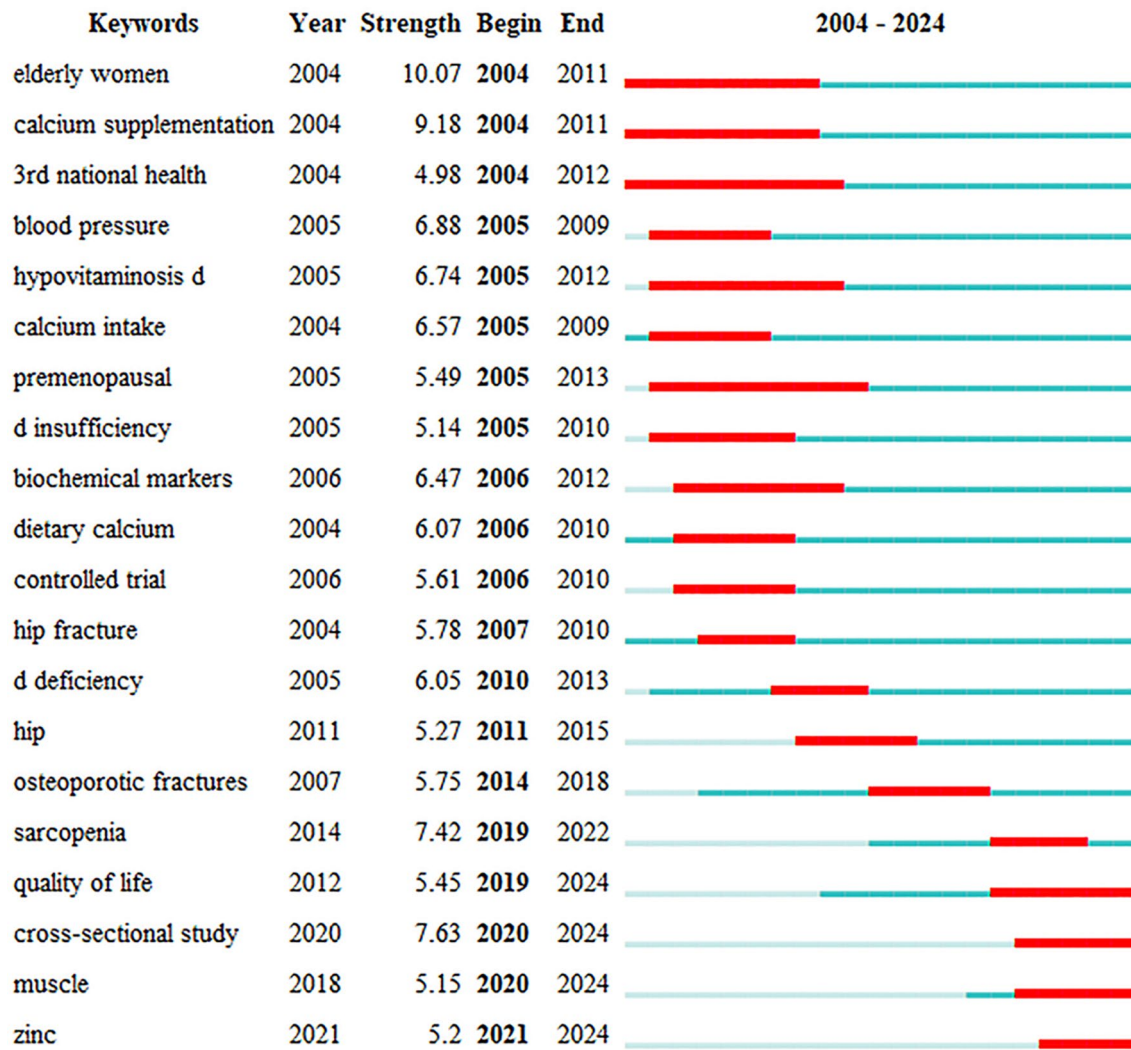


Fig. 9 Keywords citation bursts

funding and publication output [7, 10, 28]. The sharp rise in recent years also indicates the presence of key research hotspots. This could encompass the study of new pharmacological treatments, advancements in early diagnosis, and the impact of nutrition on fracture prevention [29]. The increasing trend may also suggest greater international collaboration among researchers, as more diverse institutions and countries contribute to the global understanding of osteoporosis and nutrition. In light of this trend, it is advisable to encourage large-scale, long-term tracking studies to acquire more robust data and definitive conclusions. Additionally, it is crucial to strengthen the popularization of scientific knowledge and raise public awareness regarding the intricate interplay between osteoporosis and nutrition.

The collaboration network of country and institution reveals several implications for advancing research in osteoporosis and nutrition. Firstly, the United States' central position in the network underscores its leadership in this field, facilitated by institutions like Harvard University, the University of California System, and the United States Department of Agriculture. These institutions have not only contributed the largest number of publications but also have strong collaborative ties with other global research centers. Such collaborations foster innovation and accelerate scientific advancements by providing access to diverse datasets, cutting-edge methodologies, and expertise from a wide range of disciplines. Secondly, China's significant presence in the network reflects its rapid ascent in osteoporosis research. In recent years, Chinese institutions have been increasingly

collaborating with other global leaders, particularly the United States and South Korea. This growing collaboration suggests that China is becoming a critical player in the global research landscape, likely driven by its increasing investment in healthcare research, government policies promoting scientific innovation, and a growing focus on the aging population. Thirdly, South Korea's position as the third-largest contributor of publications highlights the country's commitment to osteoporosis and nutrition research. Seoul National University, the top institution in terms of publication output (56 papers), exemplifies South Korea's prominence in this domain. The country's collaborations with the United States, China, and other global players are critical to advancing knowledge, sharing resources, and fostering international research initiatives. Additionally, countries like England, Canada, Japan, and Australia are also significant contributors to the field, with notable institutions such as the University of Toronto and the Catholic University of Korea driving research output. These countries are becoming increasingly involved in collaborative efforts, which indicates a growing global interest in osteoporosis and nutrition. The involvement of multiple regions suggests that research is becoming more diversified and that innovations are benefiting from a broader set of perspectives and expertise. The extensive international collaboration suggests that tackling global health issues such as osteoporosis requires coordinated efforts across borders. Collaborative research allows for the pooling of financial resources, technical expertise, and patient populations, which are essential for conducting large-scale studies and clinical trials that can yield more generalizable results. As a result, countries with lower publication counts, such as Iran and Poland, can still contribute significantly through collaborative partnerships.

Osteoporosis International holds the top position in terms of citation volume, exemplifying its profound academic advantage and influence in the field of osteoporosis and nutrition. The second and third-highest-ranked journals, namely *Journal of Bone and Mineral Research* and *American Journal of Clinical Nutrition*, belonging to the fields of orthopedics and nutrition respectively, implying a close interconnection between osteoporosis and nutrition. Moreover, *The Lancet* and *The New England Journal of Medicine*, both of which rank among the top 10 cited journals in this field, are renowned members of the four major medical journals and have immense influence in the medical domain. This clear evidence underscores the criticality of research on osteoporosis and nutrition in advancing human society.

The research field's individual scholars and their collaborations are clearly displayed through the author's collaborative mapping, providing a more visual representation for prolific authors [30]. The majority of top

authors in the field are concentrated in China, which suggests that Chinese institutions are playing a leading role in advancing research in osteoporosis and nutrition. However, the collaboration network is largely regional, with clusters formed around specific institutions like Lanzhou University and Nanhua Hospital. While this regional collaboration has produced a significant number of publications, expanding international collaborations could enhance the global impact of the research. The relatively low density of the author network indicates that many researchers work in silos. This fragmentation represents an opportunity to foster stronger ties between researchers, particularly between leading institutions in the United States, China, and South Korea. For example, researchers like Looker A C from the United States, who focuses on nutritional surveys, could collaborate with orthopedic researchers like Geng Bin to create interdisciplinary approaches that combine clinical, nutritional, and epidemiological data to better understand osteoporosis. Geng Bin's studies, primarily focusing on joint surgery, sports medicine, and osteoporosis, have delved into various nutritional factors such as dietary fiber intake [31], fibrinogen [32], blood mercury levels [33], high-density lipoprotein cholesterol (HDL-C) [34], BMI [35], and their correlation with osteoporosis. The current structure of the collaboration network indicates that future research efforts could be significantly enhanced through strategic partnerships. By fostering collaborations between leading researchers across different fields, such as nutrition, orthopedic surgery, and epidemiology, it may be possible to develop more comprehensive strategies for addressing osteoporosis and its relationship with nutrition. For example, further research into the relationship between nutritional indicators (such as BMI, HDL-C, and dietary fiber) and bone health could be enhanced through multidisciplinary approaches that bring together clinical expertise and population-level data analysis. Although there is a strong presence of researchers from China, the relatively low number of connections between Chinese authors and their international counterparts suggests that there is potential to enhance global collaboration.

Citation frequency plays a critical role in assessing the influence and quality of papers, serving as an indicator to evaluate the influence status and scientific research quality across different countries, institutions, or individuals [36]. An exemplary article in terms of citation frequency is "Osteoporosis" [19], which serves as a pivotal reference for understanding osteoporosis, a chronic disease that requires long-term management. The fracture risk assessment algorithm introduced in this paper has become instrumental in clinical practice, as it combines bone density with clinical risk factors to guide treatment strategies for high-risk populations. Additionally, the paper's exploration of key regulatory pathways in bone

resorption and formation has opened new avenues for therapeutic interventions, suggesting potential research directions in the discovery of novel treatment strategies with distinct mechanisms of action. Given the increasing prevalence of osteoporosis, the article also addresses critical gaps in care, particularly the treatment gap for high-risk populations. The future direction of research could focus on implementing fracture liaison services and improving patient compliance, both of which are essential to reducing the disease burden. In addition, the highly cited articles “European guidance for the diagnosis and management of osteoporosis in postmenopausal women” [21] and “Vitamin D deficiency” [22] deserve the attention of researchers. The close relationship between osteoporosis and postmenopausal women discussed in the paper paves the way for future research focused on improving disease management guidelines, increasing awareness, and developing more targeted therapies. The relationship between vitamin D supplementation and fracture prevention remains a controversial yet critical area of research. Future studies should aim to clarify the optimal levels of vitamin D required for bone health and explore the broader implications of vitamin D on musculoskeletal diseases. Sarcopenia is increasingly recognized as a comorbidity in individuals with osteoporosis, as demonstrated by Cruz-Jentoft et al.’s “Sarcopenia: revised European consensus on definition and diagnosis” [23]. Sarcopenia, characterized by a decline in muscle mass and strength, compounds the risk of fractures and further complicates osteoporosis management. This co-cited work highlights the need for an integrated approach to the diagnosis and treatment of osteoporosis and sarcopenia, with future research likely to explore combined therapeutic strategies addressing both muscle and bone health. The implications of these references suggest that future research directions should focus on improving fracture risk prediction models, optimizing treatment compliance, and enhancing the understanding of the interplay between nutrition, sarcopenia, and osteoporosis. Moreover, the development of novel therapeutic approaches targeting both bone and muscle health will be critical in addressing the complex needs of aging populations at risk for osteoporosis-related fractures.

Keyword co-occurrence refers to the presence of different keywords within the same literature [37]. A high frequency of keyword occurrences indicates research hotspots and developmental trends in the field [38]. Our findings demonstrate that studies focusing on osteoporosis and nutrition prioritize bone density, women (including postmenopausal women), vitamin D, body mass index, risk, and hip fractures. Osteoporosis is characterized by a reduction in bone mass and deterioration of bone tissue microarchitecture, which increases susceptibility to bone fragility and fractures [39]. In patients

without fragility fractures, low BMD is often utilized to diagnose osteoporosis. However, measuring BMD via dual-emission X-ray absorptiometry (DXA) is an imperfect predictor of fracture risk, as it identifies less than half of individuals who subsequently experience an osteoporotic fracture. Therefore, further exploration is needed in future research to determine whether there are better methods for measuring bone density and predictive indicators for fracture risk. A decrease in estrogen appears to be a prominent mechanism in the development of osteoporosis, particularly during menopause [40]. These findings align with our own research. Currently, there is limited research specifically addressing osteoporosis in males, despite evidence indicating their vulnerability to brittle fractures, with higher postfracture mortality rates in males than in females. Similar risk factors for fractures exist between genders, necessitating recommendations on appropriate dietary intake (including calcium, protein, and vitamin D), regular exercise, and the avoidance of smoking and excessive alcohol consumption [41]. However, due to insufficient published studies, the effectiveness of fracture prevention therapies and osteoporosis treatments in men remains inadequately supported.

In addition, the investigation of “risk factors” holds substantial significance within these studies. Osteoporotic fractures are associated with several risk factors, encompassing a range of characteristics. These factors include but are not limited to advancing age, female sex, postmenopausal status, reduced gonadal function or premature ovarian failure, low body weight, a familial history of hip fractures, racial background (with a higher risk observed among individuals of white ethnicity compared to black ethnicity), prior occurrences of clinical or morphometric spinal fractures, previous fractures resulting from minor trauma (referred to as osteoporotic fractures), rheumatoid arthritis, current tobacco use, alcohol consumption (at least 3 cups per day), low BMD, inadequate vitamin D levels, insufficient calcium intake, overweight, susceptibility to falls, and fixation procedures [42]. These risk factors all include the keyword hotspots we are exploring, so they are still worthy of attention in future research. One study showed that calcium plus vitamin D3 reduced the risk for fracture among elderly women but not elderly men [43]. There is still controversy over the evidence that vitamin D and calcium supplementation reduce the risk of osteoporosis. While osteoporosis can affect any bone, certain sites, such as the hip, spine, and wrist, are especially susceptible to osteoporosis [39]. Fractures represent a significant public health concern due to their association with morbidity, functional impairment, reduced quality of life, and even mortality [44]. Consequently, comprehensive and extensive research to address the numerous problems associated with osteoporosis is crucial.

The keyword clustering map has highlighted key areas of ongoing and future research, offering valuable insights into the evolving landscape of this field. Clusters such as physical activity, machine learning, sarcopenia, and nutrition emphasize the interdisciplinary nature of current studies, where clinical, biological, and computational research converge. Notably, the #0 physical activity cluster points to the increasing emphasis on exercise as a non-pharmacological intervention for mitigating the adverse effects of aging-related musculoskeletal conditions. Studies have consistently demonstrated the benefits of resistance and aerobic exercises in preventing osteoporosis and sarcopenia, especially in older populations, where reduced bone density and muscle strength pose significant health risks [45–49]. Sarcopenia, a condition closely associated with osteoporosis, is particularly concerning for older adults, and its presence in the keyword clustering map underscores its importance as an emerging research priority. The interaction between bone and muscle health, as represented by keywords such as “muscle” and “quality of life,” reveals the increasing focus on improving functional outcomes for aging individuals. Furthermore, machine learning has gained prominence (#2 cluster), providing novel analytical tools for exploring the genetic and environmental factors that underlie bone and muscle degeneration [50, 51]. These tools offer promising directions for future research, especially in developing personalized treatment strategies based on genetic and lifestyle factors. The emergence of the #3 vitamin D and #5 body mass index clusters reflects ongoing debates in the field of nutrition and bone health. While vitamin D and calcium are well-established in the prevention of osteoporosis, conflicting findings from recent meta-analyses [52] and randomized controlled trials [53] raise important questions regarding the effectiveness of supplementation. The presence of keywords such as “zinc” and “cross-sectional study” in the citation burst analysis further suggests that nutritional factors beyond vitamin D and calcium are gaining attention as researchers explore their roles in musculoskeletal health. Lastly, the continuous citation bursts for keywords such as “quality of life,” “muscle,” “cross-sectional study,” and “zinc” indicate that the field is moving towards more patient-centered research, with an emphasis on improving overall well-being rather than focusing solely on disease prevention. This shift highlights the importance of integrating interventions that address both physical and psychological aspects of aging, particularly in populations at risk for sarcopenia and osteoporosis. The findings from the keyword clustering and citation burst analyses suggest several potential research directions. First, future studies should aim to clarify the relationship between different nutrients, such as zinc, and musculoskeletal health. As the understanding of sarcopenia and

osteoporosis deepens, it will be essential to explore how dietary interventions and nutritional supplementation influence both muscle and bone integrity. Second, the role of machine learning in identifying predictive biomarkers and genetic risk factors warrants further exploration, as it offers potential for personalized treatment strategies. Lastly, the continuous citation bursts for quality of life and cross-sectional studies point to the need for longitudinal and interventional studies that assess the long-term effects of lifestyle changes, exercise, and nutritional interventions on aging-related diseases.

Limitations

This study has several limitations that warrant acknowledgment. First, the bibliometric analysis focused exclusively on publications extracted from the WOSCC database, potentially overlooking influential documents. Hence, future research could enhance the comprehensiveness of the analysis by supplementing it with additional databases. Second, to present the bibliometric characteristics of the original articles, we intentionally excluded reviews from the studies that inadvertently obscured some emerging trends in the field. Additionally, we confined our search to articles published between January 2004 and February 2024, excluding those published outside this timeframe. Finally, the pool of recruited manuscripts may feature weaker or peripheral works, potentially distorting the analysis to some extent.

Conclusions

We used CiteSpace to analyze osteoporosis and nutrition-related articles published from 2004 to 2024 from the WOSCC database, aiming to identify publication patterns, contributors, and recent research hotspots and trends. The analysis revealed a consistent annual increase in productivity, particularly since 2018, indicating a predicted continuation of this upward trend. The United States was the country with the most published journals, with Seoul National University emerging as the most productive institution. Research hotspots include bone density, postmenopausal women, vitamin D, hip fractures, etc. Research subjects include physical activity, sarcopenia, calcium intake, body mass index, etc. Recent research trends indicate that quality of life, muscle, and zinc are receiving attention in studies related to nutrition and osteoporosis. Future studies should further explore improved methods to measure bone density and predictive indicators of fracture risk. Additionally, insufficient evidence exists regarding the effectiveness of therapies aimed at preventing fractures or treating osteoporosis in men. Controversies persist regarding the relationships among various nutrients, nutritional supplements, and osteoporosis, necessitating further investigation. Strengthening the clinical management of osteoporosis

patients and improving their quality of life remain important in the future. Longitudinal or interventional research should be conducted to promote the development of this field in the future. Finally, as osteoporosis poses a significant clinical challenge to the global population, undertaking comprehensive and extensive research is crucial to address the numerous complexities associated with this condition.

Abbreviations

BMD	Bone mineral density
BMI	Body mass index
DXA	Dual-emission X-ray Absorptiometry
HDL-C	High-density lipoprotein cholesterol
IF	Impact factor
RCTs	Randomized controlled trials
WoSCC	Web of Science Core Collection
WHO	World Health Organization

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Author contributions

LM and YB contributed to the conceptualization, methodology, resources, software, visualization, original draft preparation, and review and editing. YH and HH contributed to the data curation, investigation, validation, and original draft preparation. GR, LN, LA, and ZX contributed to the formal analysis, project administration, and supervision. GR made contributions to the funding acquisition.

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Data availability

All data generated or analyzed during this study are included in this published article and its additional information files. Further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

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