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WJO mainly publishes articles reporting research results and findings obtained in the field of orthopedics and covering a wide range of topics including arthroscopy, bone trauma, bone tumors, hand and foot surgery, joint surgery, orthopedic trauma, osteoarthropathy, osteoporosis, pediatric orthopedics, spinal diseases, spine surgery, and sports medicine.

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SCIENTOMETRICS

Research trends in exercise therapy for the treatment of pain in postmenopausal osteoporosis over the past decade: A bibliometric analysis

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Processing time: 84 Days and 22.8	BACKGROUND
Hours	Postmenopausal osteoporosis (PMOP) is the most common form of primary osteoporosis among women, and the associated pain often drives patients to seek
	clinical intervention. Numerous studies have highlighted the unique clinical be-

nefits of exercise therapy (ET) in alleviating PMOP-related pain. However, bibliometric analyses examining collaboration, development trends, and research frontiers in the field of ET for PMOP pain remain scarce.

AIM

To explore the research trends in ET for pain treatment in PMOP patients over the past decade.

METHODS

All scholarly works were meticulously sourced from the Science Citation Index-Expanded within the prominent Web of Science Core Collection. Utilizing the capabilities of CiteSpace 6.2.R5, we conducted a thorough analysis of publications,



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authors, frequently cited scholars, contributing nations, institutions, journals of significant citation, comprehensive references, and pivotal keywords. Additionally, our examination explored keyword cooccurrences, detailed timelines, and periods of heightened citation activity. This comprehensive search, from 2014 through 2023, was completed within a single day, on October 11, 2023.

RESULTS

In total, 2914 articles were ultimately included in the analysis. There was a rapid increase in annual publication output in 2015, followed by stable growth in subsequent years. Boninger, Michael L, is the most prolific author, whereas Ware JE has the most citations. The United States' global influence is significant, surpassing all other nations. The University of California System and Harvard University are the most influential academic institutions. J Bone Joint Surg Am is the most influential journal in this field. "Spinal cord injury" is the keyword that has garnered the most attention from researchers. The developmental pattern in this field is characterized by interdisciplinary fusion, with different disciplines converging to drive progress.

CONCLUSION

The academic development of the field of ET for pain in PMOP has matured and stabilized. Clinical management and rehabilitation strategies, along with the mechanisms underlying the relationship between ET and bone resorption analgesia, continue to be the current and future focal points of research in this field.

Key Words: Exercise therapy; Pain; Postmenopausal osteoporosis; CiteSpace; Bibliometric analysis; Web of Science

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Core Tip: This study presents a comprehensive analysis of research trends in exercise therapy for pain management in postmenopausal osteoporosis patients over the last decade. By utilizing CiteSpace and analyzing 2914 articles, this study highlights key authors, institutions, and nations contributing to this field. The findings emphasize the growing global influence of the United States and the pivotal role of interdisciplinary collaboration. With "spinal cord injury" as a major research focus, this study revealed that the role of exercise therapy in pain management and bone resorption analgesia will continue to drive future research on postmenopausal osteoporosis.

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INTRODUCTION

Postmenopausal osteoporosis (PMOP) represents the most prevalent form of primary osteoporosis among the female population [1,2], affecting more than 50% of women [3]. This condition is particularly noteworthy; as the global population ages, the incidence of PMOP steadily increases [4,5]. Clinical presentations of osteoporosis include the distress of pain, a reduction in stature, the emergence of a dowager's hump, heightened vulnerability to bone fractures, and potential constraints in respiratory function [6,7]. Among these factors, pain plays a prominent role, compelling individuals to seek clinical intervention^[8]. In addition to the physical and physiological consequences, PMOP has imposed a substantial financial burden upon health care systems worldwide. Thus, the endeavor to develop efficient clinical diagnostic and therapeutic strategies for PMOP has become a common aspiration owing to the efforts of physicians and their patients.

In clinical practice, multimodal pharmacological regimens, such as romosozumab[9], denosumab[10], and bisphosphonates[11], are typically employed to alleviate the pain resulting from osteoporosis. However, long-term administration of these medications continues to raise varying concerns regarding side effects and medical expenses for patients. For example, romosozumab may induce cardiovascular disease or trigger allergic reactions[12]. Denosumab exhibits a notable decline in its antiresorptive effects starting approximately seven months after the last injection, which can lead to vertebral fracture rebound^[13]. Bisphosphonates are associated with a risk of jaw necrosis, delayed tooth eruption, atypical femur fractures, and disruptions in the bone growth system[14]. Hence, with the extended duration of treatment, many patients have become more inclined toward alternative therapies.

Exercise therapy (ET) has emerged as a fundamental rehabilitation strategy, guided by professional physicians and requiring active patient participation [15]. Compared to other treatment modalities, ET's greatest advantage lies in its lack of side effects and cost-effectiveness, making it more accessible and acceptable to a broader range of patients. Numerous studies have already explored the clinical benefits of ET in alleviating pain for PMOP patients from various perspectives [16-19]. However, to the best of our knowledge, there has been no bibliometric research directly addressing this area to date.



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CiteSpace, developed by Professor Chao-Mei Chen, is a bibliometric analysis tool primarily used for visualizing trends and patterns in scientific research, especially in areas such as co-citation analysis, co-occurrence analysis, and burst term detection[20,21]. By constructing knowledge maps, it assists researchers in identifying hotspots, frontiers, and emerging trends within a given field. Compared to other bibliometric tools, CiteSpace's main advantage lies in its emphasis on temporal evolution and its sensitivity to detecting burst terms, making it particularly effective in uncovering research frontiers and predicting future trends[22-24]. Additionally, CiteSpace offers more comprehensive visualization capabilities, producing complex yet intuitive maps.

MATERIALS AND METHODS

Data sources and search strategy

Every piece of data for this investigation was meticulously extracted from the Science Citation Index-Expanded of the Thomson Reuters' Web of Science Core Collection (WoSCC), which is widely acknowledged as the most authoritative scholarly online database. The data retrieval strategy was designed to cover the critical topics of "postmenopausal osteoporosis", "pain", and "exercise therapy". This comprehensive search, from 2014 to 2023, was executed within a single day on October 11, 2023. The criteria for inclusion were stringent, encompassing only those papers published in English and classified as articles, without any limitations on the country of publication or the nature of the study. The search methodologies and their corresponding results are described in detail in Table 1. A total of 2914 articles were gathered, and after their import into CiteSpace for the purpose of deduplication, it was determined that there were no instances of duplicate entries.

Statistical analysis

The intricate map crafted using CiteSpace 6.2.R5 features an array of citation tree rings and interconnecting lines. The citation tree rings serve as a visual representation, illuminating both the occurrence and frequency of citations in the scrutinized documents. The color of the rings reflects the chronological timeline of citations, while their thickness indicates the citation volume within a specific timeframe. Similarly, the color of the lines that interlink various points relates to the initial co-occurrence timing of a given node, with the line thickness symbolizing the robustness of this co-occurrence relationship. In this network, nodes are ranked according to their prominence, utilizing the betweenness centrality index as the measure. CiteSpace harnesses this metric to identify and evaluate the significance of scholarly works, denoted by purple circles representing key publications, authors, journals, and institutions. Nodes distinguished by substantial centrality and frequent appearances offer invaluable insights, facilitating the exploration of essential queries and research domains, specifically in the context of ET for pain in patients with PMOP.

For the parameter settings in CiteSpace, we referred to the latest high-impact studies[25-28] using this software version to facilitate subsequent comparisons and validations of similar research. The specific parameters are as follows: The time span is set from 2014 to 2023, divided into annual intervals. To ensure comprehensive inclusion of terms, we considered "Title", "Abstract", "Author Keywords", and "Keywords Plus". A total of 50 entities were included for each time interval, and the analysis employed the enhanced pathfinder tree algorithm.

RESULTS

Annual publications and trends

Our search results indicate that a total of 2914 publications were included in the analysis. To facilitate a more intuitive understanding of the annual publication trends, we have illustrated the data in Figure 1A. Between 2014 and 2015, there was an exponential surge in activity, with the annual publication count increasing from 34 to 284 articles, a remarkable 735% increase. This indicates that the domain of ET for pain in PMOP patients has garnered extensive scholarly attention. From 2015 to 2019, the annual publication count was relatively stable, with minor fluctuations. However, from 2019 to the present day, there has been a consistent upsurge, with an annual growth rate ranging from 6% to 14%. In 2022, it reached its zenith at 397 publications. As of October 2023, 283 articles had been published. By following the prevailing trajectory, we anticipate that this year's number of publications will exceed 400 articles, maintaining its stable growth trend. In summary, there has been a surge of scholarly attention to ET for PMOP pain since 2015, followed by stable growth.

Analysis of authors and cited authors

To analyze the core authors, we constructed an author co-occurrence network (Figure 1B) based on the 2914 publications. The network comprises 5611 nodes and 17061 links, representing the number of authors and their collaborative relationships, respectively. Among them, Michael L Boninger stands out with the highest number of publications (12), asserting a central influence in this field. He is followed by the researchers David Ring (9), Mark P Jensen (6), Kevin C Chung (6), Armin Curt (6), Kristin R Archer (6), Rasmus Elsoe (6), Peter Larsen (6), Hiroaki Nakamura (6), and Shiro Imagama (6), as documented in Table 2. Importantly, Michael L Boninger is the most prolific author, having contributed a substantive body of work encompassing a dozen articles. Mr. Boninger is affiliated with the Department of Physical Medicine and Rehabilitation at the University of Pittsburgh. The top four scholars are located in the United States, which claims half of the top ten positions in this scholarly domain.

Tab	Table 1 Topic search query					
Set	Results	Search query				
#1	276350	TS = ((perimenopausal woman) or (climacteric women) or (menopause women) or (postmenopausal women) or (menopausal women and bone) or (osteoporosis) or (fracture) or (osteoporotic) or (osteopenia) or (spinal cord injury))				
#2	2008447	TS = ((Exercise) OR (Physical activity) OR (Aerobic) OR (Resistance) OR (Strength) OR (Endurance) OR (Yoga) OR (Pilates) OR (Tai Chi) OR (Physiotherapy) OR (Physical therapy) OR (Kinesiology) OR (Feldenkrais) OR (Motor control) OR (Hydrotherapy) OR (Training))				
#3	239147	TS = ((Analgesia) OR (Anesthesia and Analgesia) OR (Pain) OR (Acute Pain) OR (Pain Measurement) OR (Breakthrough Pain) OR (Pelvic Girdle Pain) OR (Musculoskeletal Pain) OR (Chronic Pain) OR (Patellofemoral Pain Syndrome) OR (Flank Pain) OR (Complex Regional Pain Syndromes) OR (Shoulder Pain) OR (Neck Pain) OR (Pelvic Pain) OR (Back Pain))				
#4	2913	#1 AND #2 AND #3				

Web of Science Core Collection: October 11, 2014 to October 10, 2023.

Table 2 Top 10 authors of publications on exercise therapy for pain in postmenopausal osteoporosis							
Rank	Author	Frequency	Year	Country			
1	Boninger Michael L	12	2015	United States			
2	Ring David	9	2016	United States			
3	Jensen Mark P	6	2014	United States			
4	Chung Kevin C	6	2015	United States			
5	Curt Armin	6	2015	Switzerland			
6	Archer Kristin R	6	2015	United States			
7	Elsoe Rasmus	6	2016	Denmark			
8	Larsen Peter	6	2016	Denmark			
9	Nakamura Hiroaki	6	2017	Japan			
10	Imagama Shiro	6	2019	Japan			

The comprehensive map detailing the cited authors encompasses 1403 nodes and 5113 links, as depicted in Figure 2A. The author Ware JE emerged as the most cited author, with 107 citations, closely followed by Macdermid JC (86 citations), Finnerup NB (86), Siddall PJ (83), and Jensen MP (72), as outlined in Table 3. The top ten authors in terms of centrality included Chen Y (0.11), Melzack R (0.09), Colloca L (0.09), Finnerup NB (0.08), Chaplan SR (0.08), Sluka KA (0.08), Macdermid JC (0.07), Beaton DE (0.07), Melton LJ (0.06), and Arora R (0.04), as further detailed in Table 3.

These data highlight the significant scholarly impact of the works authored by these researchers. However, the relatively modest variance in citation counts across articles by different authors is intriguing. This pattern suggests that many research teams have been deeply and persistently working on ET for pain management in PMOP. This finding also mirrors the extensive clinical integration of ET as a primary therapeutic strategy for alleviating pain in patients with PMOP.

Analysis of countries and institutions

Through the country co-occurrence network (Figure 1C), we identified 96 countries that have contributed to research in this field. The countries with the highest centrality are the United States (0.32), England (0.17), and Spain (0.13). Notably, the United States takes the lead on a global scale in terms of publication output, boasting 931 articles, surpassing the second-ranked country by an impressive 132%. Furthermore, the centrality of the United States significantly outpaces that of other nations. In the Asian context, China, with 402 articles, and Japan, with 162 articles, also emerged as strong contenders with internationally competitive publication volumes in this field (Table 4).

Further analysis of the academic collaboration network (Figure 2B) revealed that 356 institutions worldwide have made scientific contributions to the research on ET treatment for PMOP-related pain. The top 10 academic institutions by number of publications are the University of California System (87 articles), Harvard University (86), Pennsylvania Commonwealth System of Higher Education (56), Harvard Medical School (53), Veterans Health Administration (50), United States Department of Veterans Affairs (50), University of Toronto (48), University of Texas System (48), Mayo Clinic (45), and University of London (42), as detailed in Table 5. These visual representations affirm the presence of well-established academic institutions and collaborative networks on a global scale, illustrating the extensive engagement and collaborative exchange among these academic entities.

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Table 3 Frequency and centrality of top 10 cited authors for publications related to exercise therapy for pain in postmenopausal osteoporosis							
Rank	Frequency	Author	Rank	Centrality	Author		
1	107	Ware JE	1	0.11	Chen Y		
2	86	Macdermid JC	2	0.09	Melzack R		
3	86	Finnerup NB	3	0.09	Colloca L		
4	83	Siddall PJ	4	0.08	Finnerup NB		
5	72	Jensen MP	5	0.08	Chaplan SR		
6	67	Cohen J	6	0.08	Sluka KA		
7	65	Kanis JA	7	0.07	Macdermid JC		
8	63	Hudak PL	8	0.07	Beaton DE		
9	61	Basso DM	9	0.06	Melton LJ		
10	57	Court-Brown CM	10	0.04	Arora R		

Table 4 Frequency and centrality of top 10 countries related to publications on exercise therapy for pain in postmenopausal osteoporosis

Rank	Frequency	Countries	Rank	Centrality	Countries
1	931	United States	1	0.32	United States
2	402	Peoples R China	2	0.17	England
3	184	Canada	3	0.13	Spain
4	177	England	4	0.10	Germany
5	162	Japan	5	0.09	Australia
6	151	Germany	6	0.09	Switzerland
7	137	Australia	7	0.07	Sweden
8	124	Italy	8	0.06	Canada
9	121	South Korea	9	0.05	Italy
10	102	Spain	10	0.05	Portugal

Table 5 Top 10 institutions by number of publications on exercise therapy for pain in postmenopausal osteoporosis

Rank	Frequency	Year	Institutions
1	87	2015	University of California System
2	86	2014	Harvard University
3	56	2015	Pennsylvania Commonwealth System of Higher Education
4	53	2014	Harvard Medical School
5	50	2014	Veterans Health Administration
6	50	2014	United States Department of Veterans Affairs
7	48	2015	University of Toronto
8	48	2016	University of Texas System
9	45	2015	Mayo Clinic
10	42	2015	University of London

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Analysis of cited journals

Figure 2C and Table 6 provide a comprehensive overview of the journals cited for research on ET for pain in patients with PMOP over the past decade. Notably, J Bone Joint Surg Am and Clin Orthop Relat R garnered the highest citation frequency, establishing them as pivotal journals and significant references for ET for pain in PMOP. Furthermore, Arthritis Res Ther and Clin J Sport Med exhibited the highest centrality, underscoring their influence of publishing articles concerning ET for pain in PMOP patients over the past decade.

Figure 3 presents a dual map overlay illustrating the references in the field of ET for pain in PMOP. The left side of the map displays the citing journals, whereas the right side shows the journals that are referenced. The journals on the right are connected to those on the left through reference links, with the academic discipline of each source denoted by the color of these links. On the map's elliptical representation, the vertical axis signifies the number of papers, whereas the horizontal axis reflects the number of contributing authors. As demonstrated in this dual map, a notable green mainline emerges from the integration of three distinct academic domains, whereas a striking pink mainline originates from the union of four domains. This particular configuration indicates that research on ET for pain in PMOP is predominantly characterized by an interdisciplinary evolution.

Keyword co-occurrence and citation burst analysis

The analysis of keywords displaying both high centrality and frequency, as shown in Figure 1D, revealed 489 nodes and 1936 lines. The frequency and centrality data revealed that the most prevalent keywords were "spinal cord injury", "pain", "quality of life", "neuropathic pain", "hip", "functional recovery", and "exercise", as detailed in Table 7.

Additionally, we have illustrated the most frequently cited major keywords from 2014 to 2023 in Figure 4. This visualization not only sheds light on developmental patterns and the research frontier but also pinpoints the current research hotspots and priorities in this field. The commencement and culmination of each burst are indicated by "begin" and "end", respectively, with the "intensity" value signifying the magnitude of the impact. The light blue area delineates the study period, whereas the red regions mark the inception and conclusion of a burst. A close examination of the keywords with the strongest citation bursts over the past decade reveals a fascinating evolution. Initially, terms such as "functional recovery", "spinal cord injury", and "osteoporotic fractures" captured significant academic attention. More recently, keywords such as "case reports" and "walking" have emerged as central themes in research. This trend illustrates the emphasis in the field of ET for patient pain in PMOP on health management and the improvement of patients' quality of life.

Keywords timeline and landscape analysis

Figure 2D displays a timeline review map featuring nine distinct co-citation clusters, numerically designated from 0 to 8, along with their interrelated dynamics. This timeline, progressing from left to right, chronicles the emergence and eventual fading of research keywords from 2014 to 2023 while also revealing the structural composition of each cluster.

The timeline view revealed that the first cluster (#0), "neuropathic pain", focused on neuropathic pain, chronic pain recovery, spinal cord injury, hyperalgesia, and central sensitization. The second cluster (#1), termed "distal radius fracture", focused on outcome, management, disability, fractures, stress fracture, surgery, distal radius, osteoporosis, and clinically significant differences. The third cluster (#2) on "spinal cord injuries" emphasized validity, therapy, individuals, reliability, validation, adults, participation, fitness, and menopause. Cluster #3, labeled "osteoporosis", included low back pain, prevalence, strength, quality of life, population demographics, muscle strength, falls, and older adults. The fifth cluster (#4), identified as "analgesics", explored topics related to osteoarthritis, fracture, analgesia, instability, and knee conditions. Cluster #5, named "vertebroplasty", focused on diagnosis, pain management, efficacy, guidelines, spine health, kyphoplasty, and behavioral aspects. The sixth cluster (#6), "breast cancer", focused on adjuvant endocrine therapy, postmenopausal women, grip strength, and physical activity. Cluster #7, designated "running", investigated exercise, pain, shoulder injuries, risk factors, and foot-related issues. Finally, cluster #8, labeled "electrical stimulation", revolves around arthritis, electrical stimulation techniques, quality concerns, and motor imagery practices. To provide a more direct and lucid representation of the relationship between keywords and their evolution in ET for PMOP pain, as well as clustering information, we transformed the keyword timeline chart into a keyword landscape chart (Figure 2E).

Cluster dependencies of reference

To further explore the disciplinary development patterns in this field, we constructed a clustered dependency diagram based on the references and used arrows to indicate their developmental relationships (Figure 1E). Specifically, the arrow tails indicate the most recent knowledge frontiers, whereas the arrowheads represent the sources of foundational literature. Figure 1E shows that within the field of ET for pain in patients with PMOP, the predominant development pattern is interdisciplinary fusion. For example, #0 spinal cord injury is formed by the fusion of #5 muscle strength, #6 voxel-based morphometry, and #10 neurorehabilitation. Similarly, #1 sprouting results from the fusion of #4 transcranial direct current stimulation, #5 muscle strength, and #6 voxel-based morphometry.

DISCUSSION

CiteSpace was utilized to conduct a bibliometric analysis of publications on ET for pain management in patients with PMOP from 2014 to 2023. This analysis provides a detailed summary of the significant data, research focuses, and



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Table 6 Frequency and centrality of top 10 cited journals related to exercise therapy for pain in postmenopausal osteoporosis							
Rank	Frequency	Cited Journals	Rank	Centrality	Cited Journals		
1	870	J Bone Joint Surg Am	1	0.08	Arthritis Res Ther		
2	707	Clin Orthop Relat R	2	0.05	Clin J Sport Med		
3	691	Arch Phys Med Rehab	3	0.04	Spinal Cord		
4	677	Pain	4	0.04	Cochrane Db Syst Rev		
5	608	Plos One	5	0.04	Med Sci Sport Exer		
6	561	J Bone Joint Surg Br	6	0.04	Brain		
7	507	Injury	7	0.04	PM & R		
8	484	Spine	8	0.04	Stroke		
9	454	Lancet	9	0.04	Ann Oncol		
10	452	BMC Musculoskel Dis	10	0.04	Biomaterials		

Table 7 Frequency and centrality of top 10 keywords related to exercise therapy for pain in postmenopausal osteoporosis

Rank	Frequency	Keywords	Rank	Centrality	Keywords
1	352	Spinal cord injury	1	0.08	Hip
2	344	Pain	2	0.07	Functional recovery
3	281	Quality of life	3	0.06	Classification
4	267	Management	4	0.06	Efficacy
5	240	Neuropathic pain	5	0.06	Mechanisms
6	168	Exercise	6	0.05	Neuropathic pain
7	166	Outcome	7	0.05	Injury
8	158	Prevalence	8	0.05	Recovery
9	147	Strength	9	0.05	Meta-analysis
10	146	Risk	10	0.05	Association

emerging trends within this field, offering insights into the current state and future directions of ET for pain in patients with PMOP.

General information

This study revealed that 2914 articles related to ET for pain in patients with PMOP were published over the past decade. Since 2015, the field has demonstrated not only a high baseline of annual publications but also a consistent upward trajectory, suggesting its academic maturity and growing stability. This sustained output underscores the prominence of ET in the broader context of pain management and medical research.

An analysis of author collaboration networks and institutional affiliations indicates that multiple countries have developed competent research teams contributing significantly to high-impact journals. Notably, the United States and China have emerged as leaders in the field, with strong potential to shape future advancements. The global collaboration network between these research teams highlights the field's interdisciplinary nature, emphasizing the importance of integrating resources and fostering innovation through cross-disciplinary exchange. This trend is likely to accelerate the discovery of more effective interventions for PMOP.

However, despite these promising developments, significant disparities remain between research capabilities across regions and institutions. For instance, the United States holds a leading position due to its advanced technologies and well-established academic infrastructure. Chinese growing research output, particularly in randomized controlled trials, is expected to further increase global contributions, given the country's large population of PMOP patients. As China continues to expand its research in this area, it may play an increasingly important role in driving innovation.

In the future, strengthening international collaboration, enhancing data sharing, and prioritizing interdisciplinary research are imperative. Such efforts will not only improve research efficiency but also facilitate the discovery of highquality, effective interventions for PMOP patients. With this in mind, significant advancements in ET for PMOP are anticipated in the near future, contributing to improved patient outcomes.

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Figure 1 Map of annual publications, authors of articles, countries related to publications, keywords in publications, and reference cluster dependencies of publications on exercise therapy for pain in postmenopausal osteoporosis patients. A: Map of annual publications on exercise therapy for pain in postmenopausal osteoporosis patients; B: Map of authors of articles on exercise therapy for pain in postmenopausal osteoporosis patients; C: Map of countries related to publications on exercise therapy for pain in postmenopausal osteoporosis patients; D: Map of keywords in publications on exercise therapy for pain in postmenopausal osteoporosis patients; E: Map of reference cluster dependencies of publications on exercise therapy for pain in postmenopausal osteoporosis patients.

Research hotspots

Through a detailed analysis of keyword hotspots, we identified two main research focuses in the field of ET for treating pain in PMOP patients: Clinical management and rehabilitation strategies, as well as mechanisms between ET and bone resorption analgesia.

Clinical management and rehabilitative strategies

One of the primary areas of research [29] in the field of ET for pain in patients with PMOP lies in clinical management and rehabilitative strategies. ET is widely regarded as a safe and effective rehabilitation modality distinct from pharmacological treatments[15-19,30-32]. Two critical questions drive research in this area: (1) What is the optimal ET regimen? and









Figure 2 Map of cited authors, institutions, cited journals, the keyword timeline, and the keyword landscape related to exercise therapy for pain in postmenopausal osteoporosis patients. A: Map of cited authors related to exercise therapy for pain in postmenopausal osteoporosis patients; B: Map of institutions related to exercise therapy for pain in postmenopausal osteoporosis patients; C: Map of cited journals related to exercise therapy for pain in postmenopausal osteoporosis patients; D: Map of the keyword timeline related to exercise therapy for pain in postmenopausal osteoporosis patients; E: Map of the keyword landscape related to exercise therapy for pain in postmenopausal osteoporosis patients.

(2) How can patient adherence to ET improve? Numerous studies[33,34] have explored the effectiveness of various exercise regimens. The findings generally support that [19,35,36], under appropriate conditions of intensity, diverse exercise modalities yield satisfactory therapeutic outcomes, with marginal differences in efficacy between them. For example, Watson *et al*[17] reported that high-intensity resistance and impact training can significantly improve bone mineral density and physical function in postmenopausal women with osteopenia or osteoporosis. These findings

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Figure 3 Dual map overlays related to exercise therapy for pain in postmenopausal osteoporosis patients.

Тор	20	keywords	with	the	strongest	citation	bursts
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Keywords	Year	Strength Begin	End	2014 - 2023
Functional recovery	2014	3.87 2014	2015	
Spinal-cord-injury	2015	6.08 2015	2018	_
Osteoporotic fractures	2015	4.84 2015	2016	-
Neck	2015	4.7 2015	2016	-
Rats	2015	4.49 2015	2018	_
Sensory neurons	2015	4.36 2015	2016	_
Kinematics	2015	4 2015	2016	_
Rat	2015	3.87 2015	2016	_
Transcranial magnetic stimulation	2016	5.73 2016	2018	_
Motor cortex stimulation	2016	4.66 2016	2018	
Deformity	2016	4.35 2016	2017	
Cells	2017	4.43 2017	2020	
Elderly-patients	2017	4.27 2017	2018	
Trial	2015	4.11 2017	2018	
Peripheral nerve injury	2015	3.97 2017	2019	
Older-adults	2018	5.46 2018	2020	
Predictors	2018	4.79 2018	2019	
Reorganization	2019	4.31 2019	2021	
Case report	2020	7.4 2020	2023	
Walking	2017	4 41 2020	2023	

Figure 4 Top 20 keywords with the strongest citation bursts.

indicate that while there may not be a single "optimal" exercise regimen, individual customization on the basis of patient needs and physical capacity is essential for maximizing benefits. Improving patient adherence to ET presents another challenge. Despite the known benefits of exercise, a subset of patients struggle to maintain long-term commitment. Several studies have identified education and supervised guidance as key factors in boosting adherence[37-39]. By fostering a better understanding of the benefits of ET and providing consistent support, health care professionals can help ensure that patients stay engaged with their prescribed regimens.

Mechanisms between ET and bone resorption analgesia

In recent years, interest in understanding how ET alleviates pain in patients with PMOP has increased, particularly its impact on bone resorption. As researchers have delved deeper into this area, various mechanisms have been proposed, many of which highlight the complex interaction between ET and the biological pathways involved in bone metabolism.

One key finding by Shi et al[40] demonstrated that ET promotes the production of muscle-derived kynurenic acid, which alleviates pain through the Gpr35/NFkB p65 pathway. Wang et al[41] suggested that ET inhibits TRAP activation through the Fos/Fosb pathway, thereby reducing bone resorption and pain. Similarly, Li et al[42] reported that ET enhances bone mass in animal models of PMOP by simultaneously inhibiting bone resorption and stimulating bone formation. These studies suggest that the effects of ET on pain relief are not merely symptomatic but may involve deeper changes in bone metabolism.

In addition to these biochemical pathways, other studies have pointed to the role of epigenetic mechanisms. Zhang et al [18], for example, suggested that ET may influence noncoding RNA and DNA methylation, thereby affecting bone metabolism at the genetic level. While these mechanisms are still being explored, they offer a promising avenue for future

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research aimed at optimizing ET for pain management in PMOP patients.

Critical assessment and future directions

Although the body of research on ET for PMOP has expanded substantially in recent years, several gaps remain. First, while existing studies offer valuable insights into the general efficacy of various ET regimens, there is a need for more rigorous, large-scale clinical trials that can better define standardized protocols. Furthermore, the issue of patient adherence warrants more focused attention. Understanding the psychological, social, and environmental factors that influence long-term adherence to ET could provide more tailored interventions, particularly for patients who struggle to maintain consistent participation.

Additionally, while the emerging understanding of the mechanisms underlying the impact of ET on pain and bone metabolism is promising, much remains unknown. Future research should aim to elucidate the exact molecular pathways involved, especially with respect to how ET can be optimized for individual patient profiles on the basis of genetic and epigenetic factors. This precision-based approach could significantly enhance therapeutic outcomes and minimize variability in response to ET.

CONCLUSION

In conclusion, while substantial progress has been made in the field of ET for pain in patients with PMOP, there is considerable room for further exploration. By strengthening collaboration, deepening mechanistic understanding, and addressing patient adherence issues, future research holds the potential to revolutionize how PMOP is managed, ultimately leading to more effective and personalized therapeutic strategies.

Limitations

This study has several limitations that should be acknowledged. First, the analysis was conducted using data exclusively from the WoSCC database. While the WoSCC provides a comprehensive dataset for bibliometric analysis, it may not capture all relevant literature, particularly those indexed in other major databases such as Scopus, PubMed, or Google Scholar. The selection of only publications in WoSCC may introduce some publication bias, as research published in nonindexed journals or regional publications could have been overlooked. Additionally, the time frame for data extraction was restricted to the available range in WoSCC at the time of analysis, which may have limited our ability to track longer-term trends or recent developments.

Second, while CiteSpace is a valuable tool for detecting and visualizing emerging trends, its reliance on citation data limits its ability to integrate data from multiple sources or databases. As such, citation analysis cannot be conducted on publications outside the WoSCC database, which may limit the scope of this study. Moreover, although CiteSpace excels at identifying key research patterns, it does not provide an in-depth exploration of the fundamental mechanisms behind ET for pain in patients with PMOP. This limits the ability of this study to offer a comprehensive understanding of the biological and clinical processes involved.

Future research could address these limitations by broadening the scope of database selection to include multiple databases, such as Scopus or PubMed, and extending the time frame for analysis to include more recent publications. Incorporating data from additional sources could provide a more holistic view of research trends and improve the robustness of the findings. Additionally, combining bibliometric analysis with more detailed mechanistic reviews or experimental studies could yield deeper insights into the underlying processes of ET for pain in PMOP, offering a more complete understanding of the field. Despite these limitations, this study utilized CiteSpace to present an overview of the latest research trends in ET for pain in patients with PMOP, providing valuable insights for future studies and clinical applications.

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FOOTNOTES

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