

# Global Research Trends and Hotspots on Percutaneous Kyphoplasty and Osteoporotic Vertebral Body Compression Fractures: A Bibliometric Analysis

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**Purpose:** Osteoporotic vertebral compression fractures (OVCFs) pose significant challenges in healthcare, and percutaneous kyphoplasty (PKP) has emerged as a key treatment option. This study aimed to identify and analyze research trends on PKP and OVCFs through a comprehensive bibliometric analysis.

**Patients and Methods:** A literature search on PKP and OVCFs was conducted using the Web of Science Core Collection, finalized on March 21, 2025. The analysis employed bibliometric tools including VOSviewer, CiteSpace, and the R package “bibliometrix”.

**Results:** A total of 381 articles published from 2002 to 2025 were included in this study. These publications were authored by 1739 researchers affiliated with 486 institutions across 28 countries. The journals *Spine* and *European Spine Journal* were prominent in terms of citations. China emerged as the leading contributor, ranking first in both total publications (265) and citations (3599). Soochow University was identified as the most productive institution. Yang HL was the most influential author, ranking first in total publications (22) and accumulating the highest total citation count of 483. The keyword “bone cement” was a frequently occurring term. The keywords “bone cement distribution” (2022–2025) and “volume” (2023–2025) were observed to undergo significant bursts of activity.

**Conclusion:** This bibliometric study highlighted the growing global interest in PKP and OVCFs research, with China as a leading contributor. The research focus has evolved to emphasize procedural safety, material optimization, and patient-centered outcomes. These findings provide valuable insights for guiding future research and informing evidence-based treatment strategies.

**Keywords:** kyphoplasty, osteoporosis, fracture, compression, bibliometrics, trend, hotspot

## Introduction

Osteoporotic vertebral compression fractures (OVCFs), the most common complication of osteoporosis, affect approximately 1.4 million patients annually, with an incidence rate of 10.7 per 1000 person-years in women and 5.7 in men.<sup>1</sup> These fractures result from reduced bone mineral density (BMD) and trabecular microarchitecture deterioration, leading to pain, deformity, and reduced quality of life.<sup>2</sup> Clinical presentations include midline back pain, height loss, kyphosis, and mobility impairment.<sup>3</sup> The pathogenesis of OVCFs involves compromised vertebral strength due to the loss of trabecular connectivity and decreased BMD, which predisposes vertebrae to fracture under minimal trauma.<sup>2</sup> Diagnosis relies on clinical evaluation supported by imaging techniques such as X-rays, MRI, and bone densitometry, with standardized methods like the Genant semiquantitative approach improving fracture detection and risk stratification.<sup>4</sup> Treatment strategies range from conservative approaches to minimally invasive procedures like PKP and vertebroplasty, aimed at pain relief, vertebral height restoration, and kyphosis correction.<sup>5,6</sup>

PKP is a minimally invasive procedure used to treat OVCFs, offering rapid pain relief and restoration of vertebral height through balloon expansion and bone cement injection.<sup>7</sup> Despite its benefits, PKP is associated with complications such as cement leakage and recompression of the treated vertebrae, which can lead to recurrent back pain and new fractures.<sup>8</sup> Cement leakage not only limits the effectiveness of vertebral height restoration and kyphosis correction but also increases the risk of adjacent vertebral fractures and vertebral recompression.<sup>9</sup> Moreover, patient-related factors such as advanced age, diabetes, and poor bone quality further contribute to the incidence of new fractures after PKP. Bian et al identified low Hounsfield unit values, cement leakage, and fractures at the thoracolumbar junction as risk factors for new vertebral compression fractures after PKP.<sup>10</sup> Current research is limited by small sample sizes, retrospective designs, and heterogeneity in study populations and outcome measures, which restricts the generalizability of findings. Additionally, many studies lack long-term follow-up to fully assess durability and late complications. Current research highlights the necessity for a view to synthesize existing trend and guide future studies towards enhancing the safety and efficacy of PKP for OVCFs patients.

Bibliometric analysis, a quantitative method for evaluating scientific literature, provides insights into research trends, collaborations, and impacts across various domains.<sup>11</sup> The published bibliometric analysis on kyphoplasty and vertebroplasty in 2020 has primarily delineated the research landscape by identifying the top 100 most-cited articles, revealing key contributors, evolving research hotspots, and geographic distribution patterns.<sup>12</sup> Currently, no bibliometric analysis has been dedicated to exploring research trends in PKP for OVCFs. Therefore, this study aims to perform a thorough bibliometric analysis of publications related to PKP for OVCFs, offering a detailed overview of publication patterns, research hotspots, and future directions in this field.

## Materials and Methods

### Search Strategies and Data Collection

A literature search concerning PKP and OVCFs was performed by Wang HB and Cao XJ using the Web of Science Core Collection (WoSCC). The WoSCC is recognized as a reputable and comprehensive database, providing access to high-quality academic publications across various disciplines. Besides, this database offers comprehensive citation indexing and compatibility with bibliometric tools such as VOSviewer and CiteSpace.<sup>13</sup> The search strategy utilized was: (TS= (“percutaneous kyphoplasty” OR “PKP” OR “balloon kyphoplasty”)) AND TS=(“osteoporotic vertebral body compression fractures” OR “osteoporotic vertebral compression fractures” OR “OVCFs” OR “osteoporotic spinal compression fractures”). Only English-language articles were selected. Literature retrieval was finalized on March 21, 2025, to ensure consistency and minimize discrepancies resulting from database updates. During the filtering process, bibliographic data were exported in both “Full record and cited references” and “plain text” formats. The exported textual data for bibliometric analysis encompassed publication and citation counts, titles, author affiliations, institutions, geographic regions, keywords, and journal sources.

### Statistical Analysis

VOSviewer (1.6.20, Leiden University, the Netherlands), CiteSpace (6.3.R1, Drexel University, USA), and the R package “bibliometrix” (4.3.3, University of Naples Federico II, Italy) were utilized for academic data visualization and analysis. VOSviewer played a crucial role in mapping co-occurrence and coupling networks of authors, institutions, countries, journals, and keywords.<sup>14</sup> This tool enabled the visualization of complex academic collaboration networks, thereby elucidating relationships among various metrics within the research domain.

CiteSpace was utilized to identify keyword bursts, thereby facilitating the comprehension of emerging trends. The parameters were configured using time slicing from January 2002 to March 2025, with keywords designated as the node type. A keyword node threshold of 5 was applied to each fragment, and pruning was performed using pathfinder and clip merge network methods. These parameters enabled the conduct of visualization analysis and the generation of a keyword timeline.

A comprehensive bibliometric analysis was performed using the R package “bibliometrix”. The package enabled the mapping of global research distribution, identification of key trends, and assessment of author, journal, and country

influence. The academic impact of researchers and journals was assessed using the h-index, a balanced indicator of scholarly influence.<sup>15,16</sup> Furthermore, the g-index and m-index were also considered. The g-index provides a more nuanced evaluation of a researcher's citation impact by assigning greater weight to frequently cited publications.<sup>17</sup> The m-index normalizes the h-index by accounting for the years since a researcher's first publication, thereby providing an indicator of academic consistency and sustainability.<sup>18</sup> Journal prestige and citation impact were evaluated using Journal Citation Reports (JCR) quartiles and the Impact Factor (IF) in 2023–2024. JCR quartiles categorize journals into four tiers, with Q1 representing the highest academic impact, whereas the IF reflects the average citations per article over the preceding two years. To ensure an updated evaluation of journal prestige and citation impact, the most recent JCR and IF data were utilized.

## Results

### Overview of Publications

This analysis included a total of 381 publications, all of which were articles. These works were published in 121 journals and spanned the period from 2002 to 2025. Contributions were made by 1739 authors affiliated with 486 institutions across 28 countries or regions. Collectively, these studies cited 5077 references. The average number of co-authors per article was 6.09, with 9.449% of the publications resulting from international collaborations. The average age of the documents was 7.12 years, while the average number of citations per article was 19.62. The annual growth rate of publications in this field was calculated to be 6.76% (Figure 1).

The annual number of publications related to PKP and OVCFs demonstrated a clear upward trend over the years. Starting with two publications in 2002, the field experienced modest growth in the early years. Specifically, the annual publication count remained below 5 per year until 2007, when it reached 10, and then fluctuated between 7 and 18 from 2008 to 2016. From 2017 onward, annual publications consistently exceeded 15, with notable surges to 27 in 2017, 30 in both 2019 and 2021, and a record high of 43 in 2024. The cumulative number of publications also increased steadily, rising from 2 in 2002 to 381 by 2025 (Figure 2).

The most cited article in this field, titled “An in vivo comparison of the potential for extravertebral cement leak after vertebroplasty and kyphoplasty”, was published in *Spine* in 2002, which had an IF of 2.7 at that time, and has since garnered 224 citations.<sup>19</sup> The second highest cited work, “Early radiographic and clinical results of balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures”, also appeared in *Spine* in 2003 (IF=2.7), accumulating 207 citations.<sup>20</sup> The third most cited publication, “Balloon kyphoplasty is effective in deformity correction of osteoporotic vertebral compression fractures”, was published in *Spine* in 2005 (IF=2.7) and has been cited 185 times.<sup>21</sup>

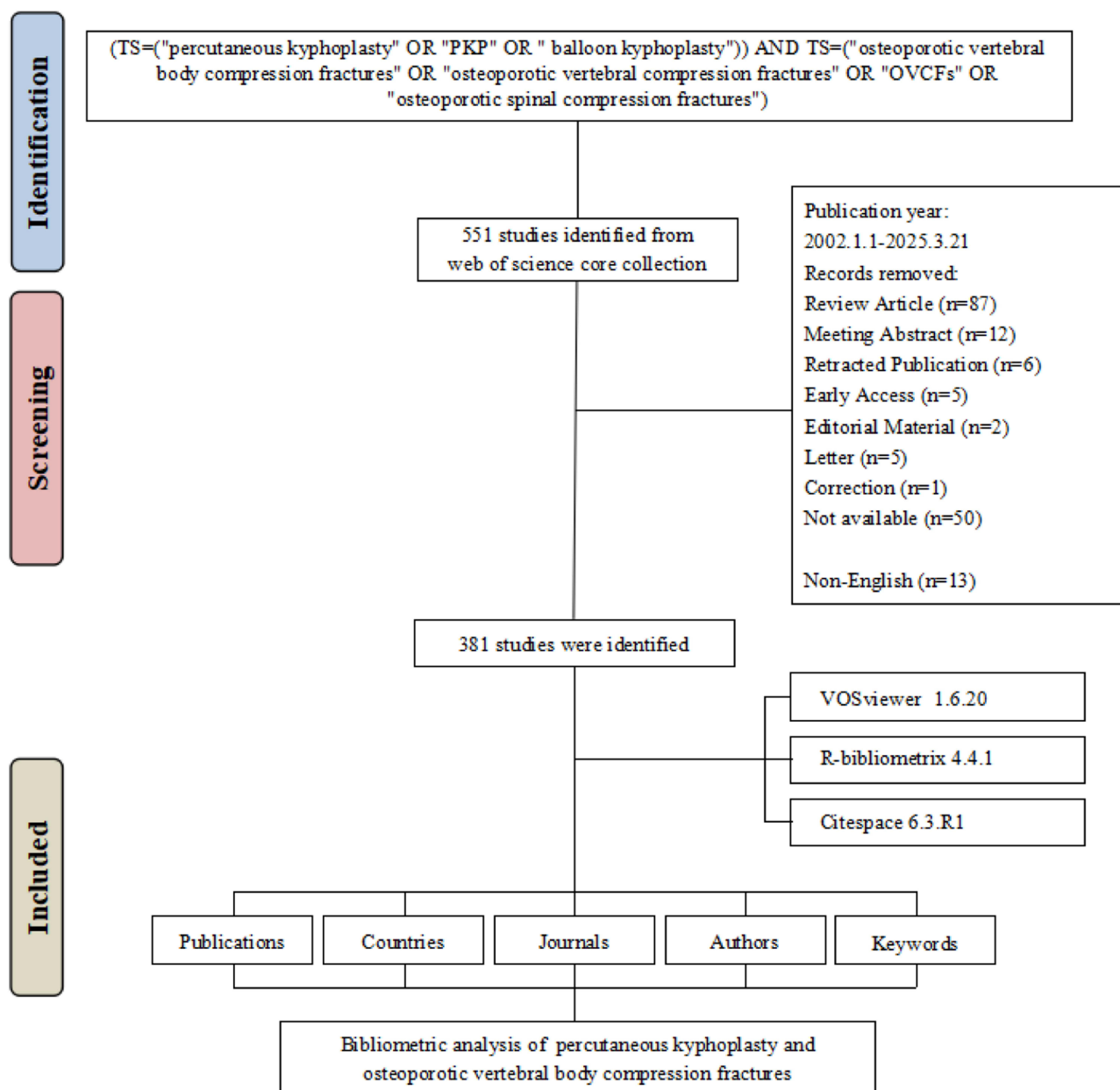
### Journal Distribution and Impact Analysis

In the field of PKP and OVCFs, top 20 high-impact journals were identified based on their h-index and citation metrics (Supplementary Table 1). *Spine* emerged as a leading journal, with an h-index of 14 and a total citation count of 1740, ranking first in terms of total citations. The *European Spine Journal* secured the second position in terms of total citations, with an h-index of 12 and 726 citations. Other notable journals included *Pain Physician*, which had an h-index of 12 and 256 citations, and *Osteoporosis International*, with an h-index of 10 and 622 citations.

The co-occurrence networks of journals in the field of PKP and OVCFs comprised 112 journals, each with at least one occurrence (Figure 3A). The three journals with the highest total link strength in these networks were *Spine* with 229, *European Spine Journal* with 183, and *International Orthopaedics* with 118. The coupling networks of journals included 120 journals, each having at least one coupling connection (Figure 3B). The *European Spine Journal* exhibited the highest total link strength at 8266, closely followed by *Spine* with 6365 and *World Neurosurgery* with 6337.

### International Research Landscape: Country Analysis

As shown in the Figure 4A and Supplementary Table 2, China dominated research on PKP and OVCFs, contributing the highest number of articles (265), which accounted for 69.6% of the articles. China also ranked first in total publications (565) and citations (3599). The USA followed with 26 articles, ranking second in both total publications (82) and



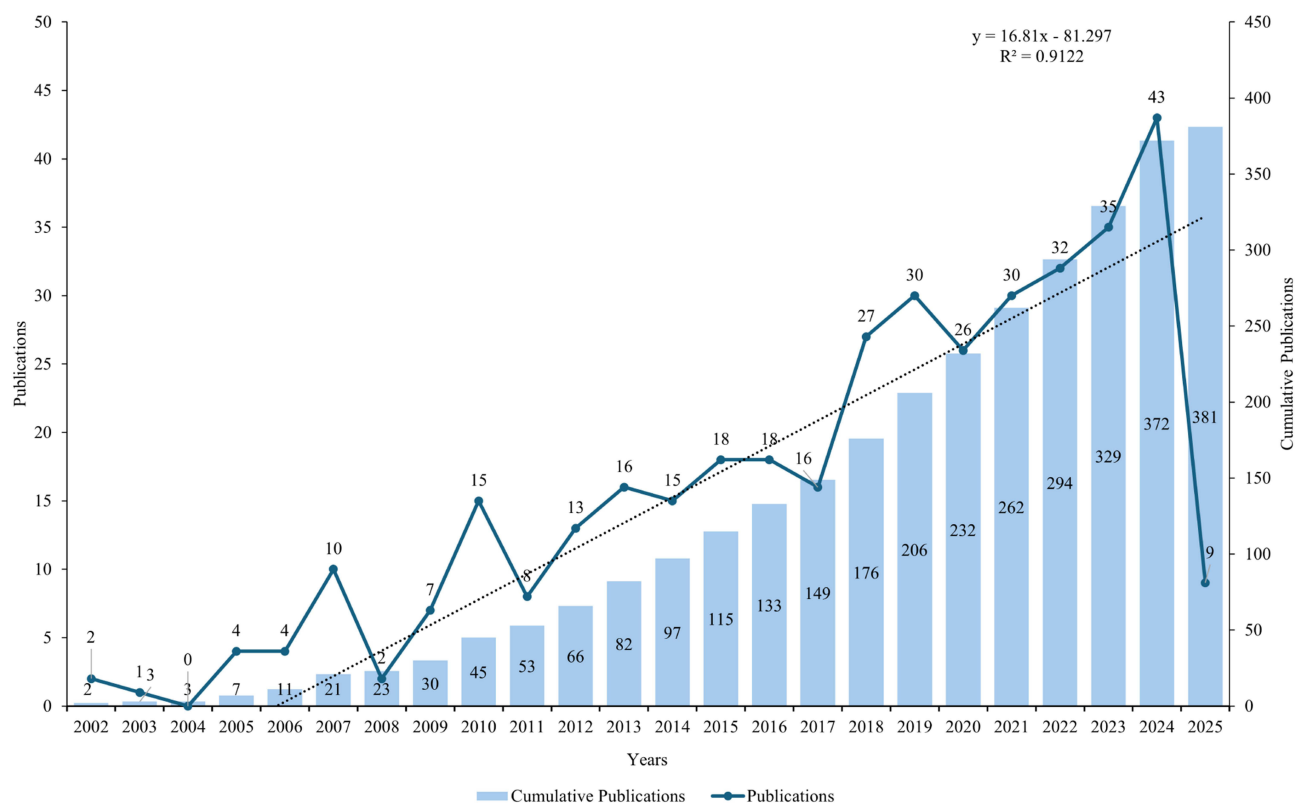
**Figure 1** Flowchart of the literature screening process.

citations (1366). It demonstrated the highest average citations per article (52.5). Korea and Germany ranked third and fourth in citations, with 662 and 600 total citations, respectively.

The visualization map highlighted international collaborations among countries in research on PKP and OVCFs (Figure 4B and Supplementary Table 3). Among the 18 countries engaged in international collaborations, each contributing at least one article, Germany demonstrated the strongest collaboration network with a total link strength of 25. This was followed by Switzerland with a total link strength of 19, and the USA with 18. Italy and the UK both exhibited a total link strength of 17.

### Institutional Productivity and Research Collaboration

The top ten institutions by article count in research on PKP and OVCFs are displayed in Figure 5A. Soochow University ranked first, contributing the highest number of articles, totaling 42. Capital Medical University and Xi’an Jiaotong



**Figure 2** Annual number of publications on percutaneous kyphoplasty and osteoporotic vertebral body compression fractures.

University shared the second position, each publishing 24 articles. Wenzhou Medical University followed closely in fourth place with 22 articles. Other notable institutions included Nanjing Medical University (16 articles), Zhejiang University (14 articles), and both Guangzhou University of Chinese Medicine and Xuzhou Medical University, each with 13 articles. Among the 43 institutions involved in international collaborations with at least two articles, the collaborative networks in research on PKP and OVCFs were highlighted in [Figure 5B](#) and [Supplementary Table 4](#). ISMAR Healthcare and Klinikum Bayreuth demonstrated the strongest international collaboration networks, each with a total link strength of 14. Aintree University Hospital NHS Foundation Trust followed closely, exhibiting a total link strength of 13.

## Author Impact and Scholarly Contributions

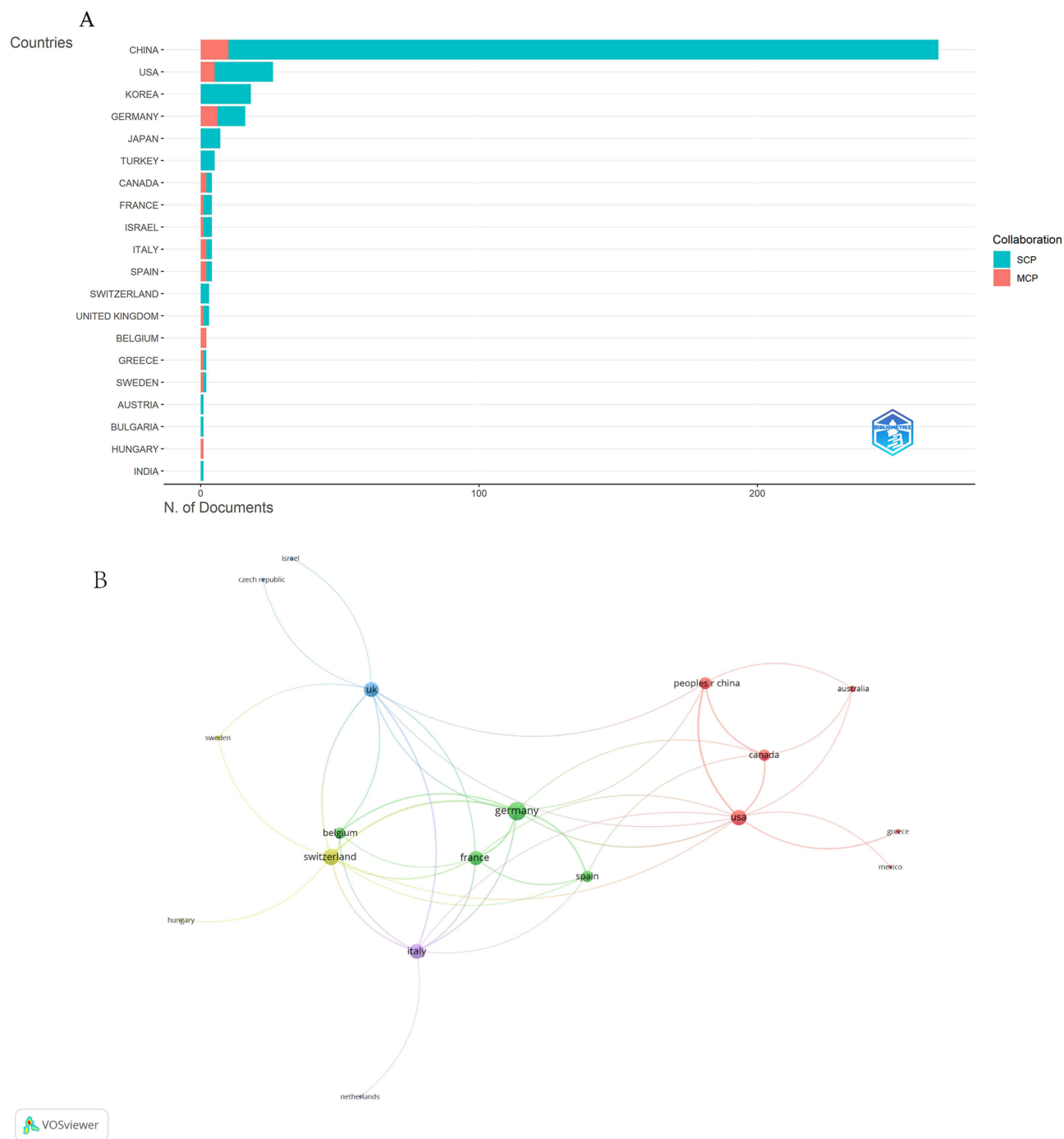
The publication and citation profiles of influential authors ranked by their h-index were summarized in the [Supplementary Table 5](#). Yang HL stood out as the leading author, with an h-index of 12 and a g-index of 21, contributing 22 publications and accumulating the highest total citation count of 483. Hao DJ and Wang Y followed, both with an h-index of 6 and a g-index of 7, each producing 7 publications. Wang Y achieved a higher total citation count of 205, ranking third overall in citations, while Hao DJ ranked fifth with 159 citations. Other notable contributors included Tang TS, with an h-index of 5 and a total citation count of 254, ranking second in citations, and Liu T, who had an h-index of 5 and accumulated 149 citations.

Among the 68 authors involved in international collaborations with at least two articles, the collaboration network was visualized in [Figure 6](#) and [Supplementary Table 6](#). Yang Huilin demonstrated the strongest collaborative connections, achieving the highest total link strength of 66. Zou Jun followed with a total link strength of 26, while both Chen Liang and Hanakita Junya exhibited a total link strength of 24.

## Keyword Analysis: Trends and Hotspots

In total, 55 keywords with a minimum of 7 occurrences were identified in keyword co-occurrence analysis. This study categorized keywords into five distinct clusters based on the analysis of 55 items ([Figure 7A](#) and [Supplementary Table 7](#)).

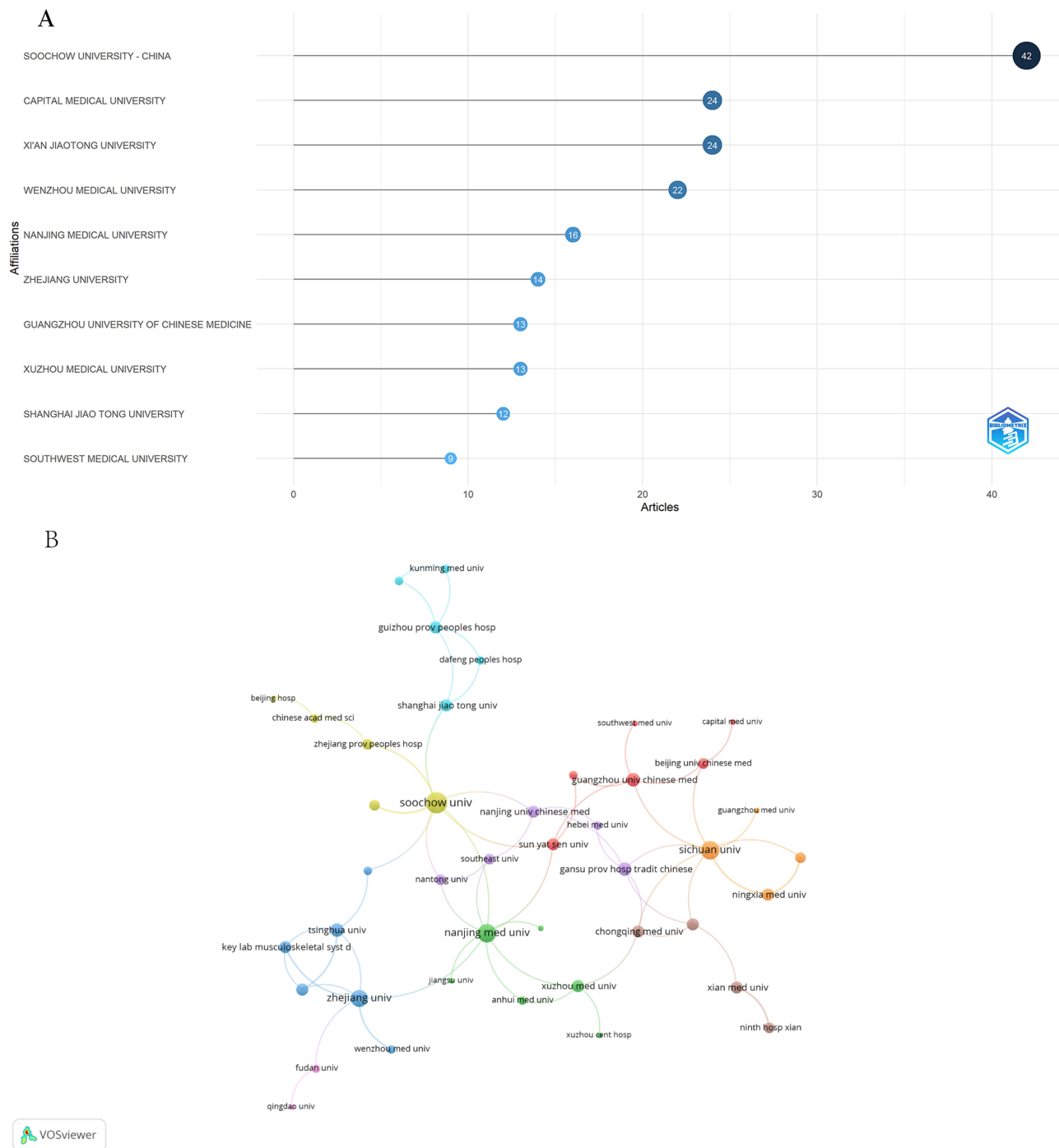




**Figure 4** Analysis of countries contributing to research on percutaneous kyphoplasty and osteoporotic vertebral compression fractures. **(A)** Distribution of corresponding author's publications by country. **(B)** Visualization map depicting the collaboration among different countries.

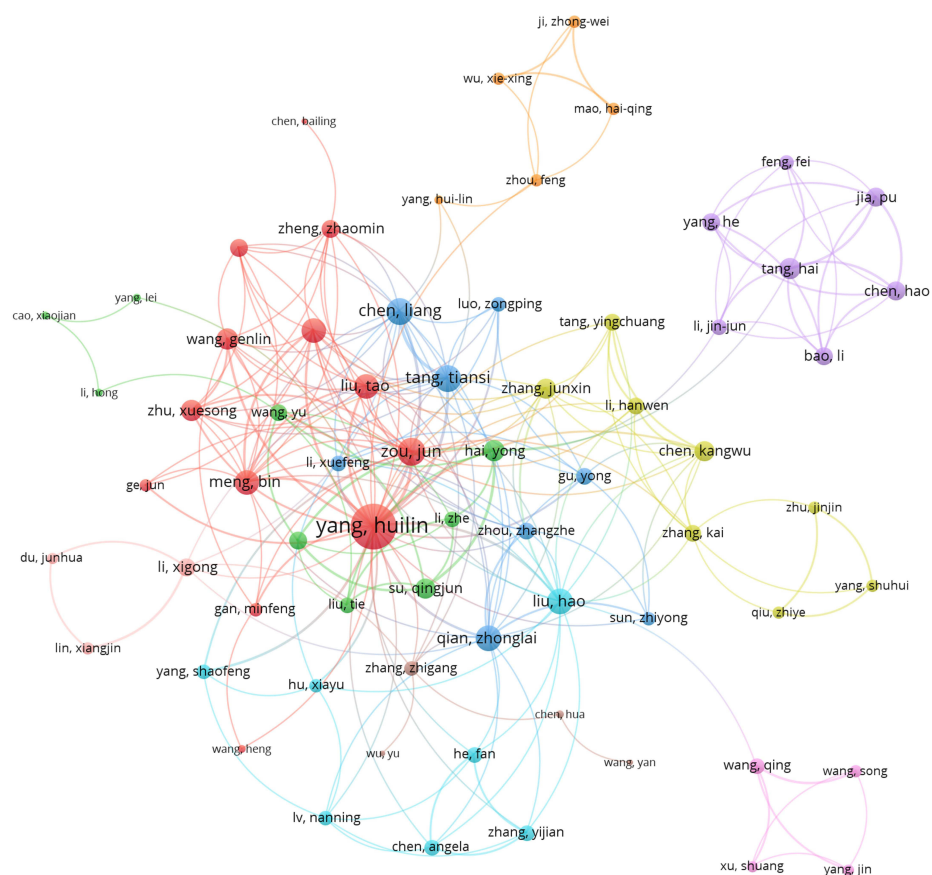
**Abbreviations:** SCP, Single Country Publications; MCP, Multiple Country Publications.

Red cluster, comprising 17 items, emphasized clinical outcomes and patient-centered themes, with keywords such as “back pain”, “balloon kyphoplasty”, and “quality of life”. Green cluster, containing 13 items, focused on procedural complications and technical factors, including terms like “cement leakage”, “recompression”, and “risk factors”. Blue cluster, consisting of 12 items, highlighted material properties and procedural efficacy, featuring keywords such as “bone cement”, “calcium-phosphate cement”, and “cement volume”. Yellow cluster, composed of 9 items, concentrated on biomechanical aspects and fracture management, with terms like “augmentation”, and “bone mineral density”. Finally,



**Figure 5** Analysis of institutions involved in research on percutaneous kyphoplasty and osteoporotic vertebral compression fractures. **(A)** Top ten institutions by article count and rank. Circle size shows article count. Darker shades indicate higher ranks. **(B)** Visualization map depicting the collaboration among different institutions.

purple cluster, the smallest cluster with 4 items, addressed management strategies and spinal restoration, including keywords such as “management”, “restoration”, and “sign”. The network visualization of keyword co-occurrence was presented in Figure 7B. In the early stage (2014–2016), research primarily focused on “cement”, “pain relief”, and “clinical outcomes”. Keywords with higher co-occurrence intensity were observed during the mid-stage (2016–2018), highlighting themes such as “cement leakage”, “mortality”, and “calcium-phosphate cement”. In the recent period (2018–2020), emerging trends included “risk factors”, “stiffness”, and “intravertebral cleft”.



**Figure 6** Visualization map depicting the collaboration among different authors publishing on percutaneous kyphoplasty and osteoporotic vertebral compression fractures.

## Burst Keyword Detection and Evolution of Research Topics

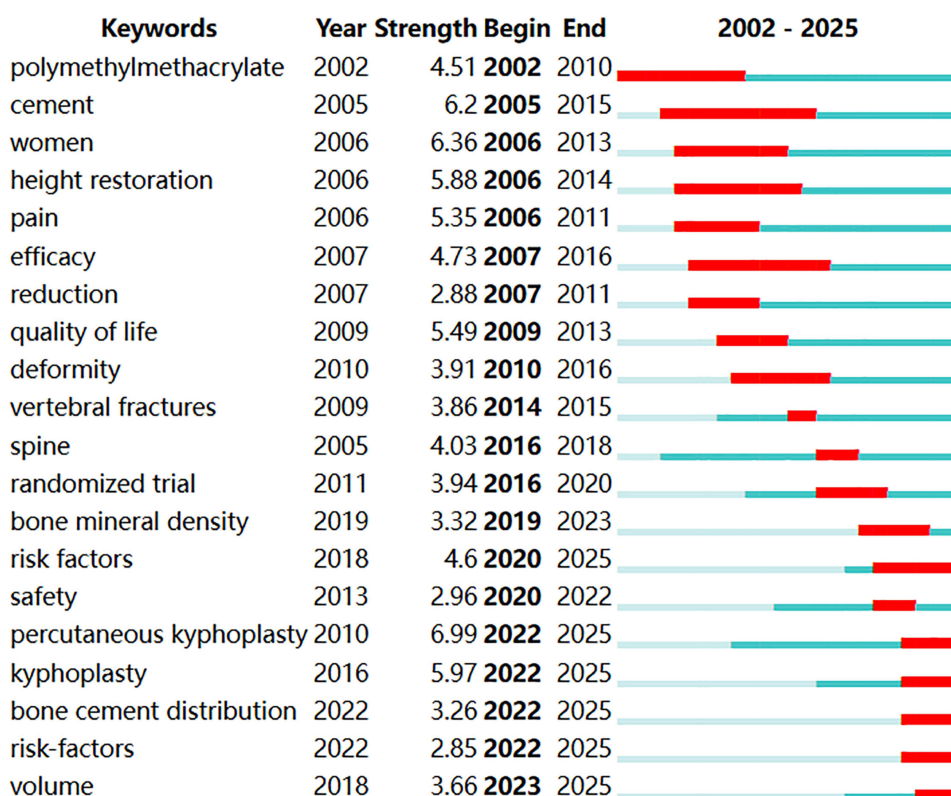
The evolution of research trends in PKP and OVCFs was highlighted through the emergence of burst keywords (Figure 8). The keyword with the strongest burst strength was “women” (strength = 6.36), which dominated research discussions from 2006 to 2013. Breaking down the timeline, earlier bursts included “polymethylmethacrylate” (strength = 4.51) from 2002 to 2010, reflecting early interest in material properties. From 2018 to 2020, keywords such as “risk factors” (strength = 4.6) and “bone mineral density” (strength = 3.32) gained attention, emphasizing risk assessment and bone health. From 2022 to 2025, “bone cement distribution” (strength = 3.26) remained significant focuses. Between 2023 and 2025, terms like “volume” (strength = 3.66) and “risk-factors” (strength = 2.85) gained prominence, indicating a shift toward procedural optimization and safety considerations in kyphoplasty research.

## Discussion

This bibliometric analysis of PKP and OVCFs revealed a consistent and growing global interest in this field. A notable increase in publications occurred between 2017 and 2024, peaking at 43 publications in 2024, demonstrating an intensified focus on this critical area. This study included 381 articles authored by 1739 researchers from 486 institutions across 28 countries, reflecting a broad and collaborative research landscape in PKP and OVCFs. The journals *Spine* was key outlets with high citation impact. China was the leading contributor, with 265 publications and the highest citation count of 3599, highlighting its dominant role in this field. Soochow University emerged as the most productive institution, while Yang HL was the most influential author, with 22 publications and 483 citations.

The three most cited articles in the field of PKP and osteoporotic vertebral compression fractures were all published in *Spine* between 2002 and 2005. The most cited article’s focus on extravertebral cement leakage not only highlighted





**Figure 8** Top 20 keywords with the strongest citation bursts in research on percutaneous kyphoplasty and osteoporotic vertebral compression fractures.

kyphoplasty, provided robust evidence supporting rapid pain relief and vertebral height restoration, thereby validating kyphoplasty as a superior alternative to conservative management and vertebroplasty in select patients. This work underscored the importance of restoring vertebral body height to improve spinal biomechanics and patient quality of life.<sup>20</sup> The third highly cited publication, focusing on correction of spinal deformities, advanced the understanding of kyphoplasty's role in improving sagittal balance and vertebral alignment, which has been linked with better functional outcomes and reduced risk of adjacent vertebral fractures. This insight has encouraged more detailed investigations into spino-pelvic parameters and the long-term impact of kyphoplasty on global spinal alignment.<sup>21</sup>

The journal *Spine* has consistently served as a key publication outlet in the field of PKP and OVCFs, demonstrating a high citation impact.<sup>19</sup> Established in 1976, *Spine* was the first journal dedicated exclusively to spinal research and has since maintained a strong reputation for publishing high-quality clinical and basic science studies related to musculoskeletal and neurological aspects of the spine. Its editorial scope encompasses a broad range of topics including spinal surgery techniques, biomechanics, clinical outcomes, and innovations in minimally invasive procedures, making it a central platform for disseminating influential findings that shape clinical practice and research priorities.<sup>22</sup>

China's leading role in kyphoplasty research, demonstrated by its high number of publications and citations, stemmed from a strong foundation in both clinical practice and substantial research investments. The prominence of Soochow University and other Chinese institutions underscored the strategic prioritization of kyphoplasty research within China. This dominance was likely influenced by China's large population, which increases the prevalence of OVCFs, and its significant investments in healthcare research.<sup>23</sup> Soochow University's dominance in this area may also be attributed to its location in China, where there is a high prevalence of OVCFs due to the large and aging population.<sup>24</sup> This demographic context creates a pressing need for effective treatments like PKP, driving research efforts and innovation.

Regarding authorship, Yang Huilin emerged as a leading contributor in PKP and OVCFs research, evidenced by his substantial contributions. Yang's work encompassed key themes such as the clinical efficacy and safety of kyphoplasty, particularly in the context of severe osteoporotic fractures. One of his studies investigated the influence

of different surgical timing on outcomes after PKP for OVCFs. The research found that emergency kyphoplasty resulted in better clinical and radiological outcomes compared to delayed surgeries, with significant improvements in pain relief and functional recovery, highlighting the importance of timely surgical intervention in improving patient outcomes.<sup>25</sup>

The co-occurrence analysis of keywords in PKP and OVCFs research revealed five distinct clusters, each highlighting different aspects of the field.

### Red Cluster: Clinical Outcomes and Patient-Centered Themes

The red cluster, comprising 17 items, focused on clinical outcomes and patient-centered themes, including terms like “back pain”, “balloon kyphoplasty”, and “quality of life”. This cluster emphasized the importance of understanding patient experiences and improving treatment outcomes. Yang et al developed a novel scoring system to predict residual back pain after PKP for single-vertebral osteoporotic compression fractures. The scoring system identified age  $\geq 60$  years, thoracic or lumbar fracture location, OF4 fracture type, segmental kyphosis  $\geq 20^\circ$ , and bone cement volume  $< 5$  mL as predictors of residual back pain.<sup>26</sup> A meta-analysis comparing balloon kyphoplasty and percutaneous vertebroplasty found that kyphoplasty reduced the kyphotic wedge angle and risk of cement leakage while increasing vertebral body height. However, there was no significant difference in clinical outcomes such as pain relief and disability scores between the two procedures.<sup>27</sup> Zhai et al evaluated the clinical effect of PKP in treating multiple OVCFs, assessing outcomes via visual analogue scale (VAS) and Oswestry Disability Index (ODI). The results showed significant improvements in both VAS and ODI scores postoperatively, indicating enhanced quality of life and reduced disability.<sup>28</sup> Collectively, future research should prioritize the analysis of postoperative complication risks, identify high-risk populations, and develop personalized PKP approaches to improve patients’ outcomes.

### Green Cluster: Procedural Complications and Technical Factors

The green cluster, containing 13 items, centered on procedural complications and technical factors, featuring terms like “cement leakage”, “recompression”, and “risk factors”. This cluster reflected research aimed at identifying and mitigating risks associated with kyphoplasty, such as cement-related complications. Chen et al identified risk factors for cement leakage and adjacent vertebral fractures after vertebral augmentation. It found that compromised cortical integrity and the volume of injected cement significantly increased the risk of cement leakage, while factors like diabetic status and changes in the Cobb angle correlated with new adjacent fractures.<sup>29</sup> A prospective clinical study investigated the incidence and risk factors of new symptomatic OVCFs after percutaneous vertebroplasty (PVP) and kyphoplasty (PKP) compared to conservative treatment. The study found no significant difference in the incidence of new OVCFs between operative and conservative groups but noted a higher rate of adjacent fractures in the operative group.<sup>30</sup> Yu et al aimed to identify risk factors for postoperative residual low back pain in patients with osteoporotic vertebral fractures treated with PKP. It developed a nomogram to predict the occurrence of residual low back pain, highlighting the importance of identifying predictors to improve treatment outcomes.<sup>31</sup>

### Blue Cluster: Material Properties and Procedural Efficacy

The blue cluster, consisting of 12 items, highlighted material properties and procedural efficacy, with keywords such as “bone cement”, “calcium-phosphate cement”, and “cement volume”. This cluster underscored ongoing efforts to improve the materials used in kyphoplasty, enhancing both safety and effectiveness. Pan et al investigated the impact of bilateral bone cement distribution on the clinical efficacy of PKP for OVCFs. The results showed that different types of cement distribution (diffuse, dense, mixed) affected postoperative pain relief and vertebral height restoration, with diffuse distribution often leading to better clinical outcomes.<sup>32</sup> A prospective study evaluated balloon kyphoplasty using resorbable calcium phosphate cement (CPC) for acute osteoporotic fractures, demonstrating significant pain relief and vertebral height restoration.<sup>33</sup> In thoracic PKP, cement volumes  $> 6$  mL were linked to greater kyphotic angle correction but higher adjacent fracture rates, whereas lumbar PKP showed no volume-dependent complications. The study emphasized cautious volume use in thoracic procedures to mitigate fracture risks.<sup>34</sup>

## Yellow Cluster: Biomechanical Aspects and Fracture Management

The yellow cluster, composed of 9 items, concentrated on biomechanical aspects and fracture management, including terms like “augmentation” and “bone mineral density”. Hinde et al compared vertebroplasty, kyphoplasty, and implant-assisted methods, finding that kyphoplasty’s modest kyphosis reduction in OVCFs did not justify its higher cost compared to vertebroplasty. However, kyphoplasty remained preferred for traumatic fractures due to better deformity correction.<sup>35</sup> A retrospective study of 232 OVCF patients found that PKP provided greater wedge angle correction and pain relief (VAS scores) in osteoporosis patients compared to osteopenia and normal BMD groups. Despite lower baseline BMD, the osteoporosis group showed no significant difference in cement leakage rates, supporting PKP’s safety across BMD levels.<sup>36</sup>

## Purple Cluster: Management Strategies and Spinal Restoration

The purple cluster, the smallest with 4 items, addressed management strategies and spinal restoration, featuring keywords such as “management”, and “restoration”. Kyphoplasty demonstrated superior restoration of anterior vertebral height (3.48 mm, 19.14%) and kyphotic angle correction (2.85°) compared to vertebroplasty, though unilateral VP showed higher central vertebral height restoration (4.38 mm) at the cost of increased cement leakage. Both procedures effectively restored vertebral height in osteoporotic fractures, but standardized reporting and patient-specific cement volume optimization are critical for balancing efficacy and safety.<sup>37</sup>

A burst analysis of keywords revealed the evolving landscape of PKP and OVCFs research. In the early 2000s, terms like “polymethylmethacrylate”, “cement”, and “pain” dominated, driven by the need to establish the safety and biocompatibility of bone cement materials during PKP’s initial adoption phase. Concerns about cement leakage and acute symptom management prioritized biomaterial optimization and procedural standardization. This focus on foundational technical aspects was critical, as early studies highlighted leakage risks and the mechanical properties of polymethylmethacrylate, which influenced surgical protocols and device design.<sup>38</sup>

By the late 2000s and early 2010s, keywords shifted to “efficacy”, “reduction”, “quality of life”, and “deformity”, signaling a transition toward evaluating PKP’s long-term functional benefits. This shift coincided with accumulating clinical evidence demonstrating PKP’s superiority over conservative management in restoring vertebral height and correcting kyphotic deformities. Research began emphasizing patient-centered outcomes, such as mobility improvement and spinal alignment, rather than purely technical metrics.<sup>39</sup> The maturation of PKP as a mainstream intervention necessitated comparative studies to validate its role in fracture management and rehabilitation. Post-2014, the emergence of keywords like “vertebral fractures”, “spine”, and “randomized trial” marked a paradigm shift toward evidence-based practice. This period also saw heightened scrutiny of complications such as adjacent vertebral fractures, driving research into risk stratification and preventive strategies. Network meta-analysis further demonstrated that adjacent fracture risks following PKP or vertebroplasty were comparable to the natural history of osteoporotic progression, challenging earlier assumptions about procedural causation.<sup>40</sup> The burst of “bone cement distribution” (2022–2025) indicated a move towards improving cement delivery techniques to reduce complications. Greater bone cement distribution correlates with improved vertebral height restoration (AVHRR) and Cobb angle correction but increases the risk of cement extravasation (BE), highlighting its dual role as a predictor of efficacy and complication risks. Despite uniform pain relief (VAS/ODI) across distribution patterns, optimal cement spread balances structural restoration with procedural safety.<sup>41</sup> The presence of “volume” (2023–2025) alongside suggested an ongoing effort to refine procedural parameters and enhance safety in kyphoplasty. A bone cement filling ratio of 0.4–0.6 optimizes clinical outcomes, with lower leakage rates (25% vs 52.46% in >0.6 groups) and superior 3-month pain relief (VAS) and functional recovery (ODI) compared to higher volumes. While higher cement volumes (>0.6) achieve better vertebral height restoration, they introduce greater variability and complication risks, underscoring the need for balanced volume selection to maximize safety and efficacy.<sup>42</sup> Higher bone cement volumes (>4 mL) significantly improved anterior vertebral height restoration compared to lower volumes (≤4 mL), demonstrating enhanced structural recovery after unilateral kyphoplasty. However, increased cement volume was associated with a higher rate of cement leakage and adjacent vertebral fractures, indicating an elevated risk of complications. Both groups experienced comparable pain relief and functional improvement (VAS and

ODI), highlighting a volume-dependent trade-off between maximizing vertebral restoration and minimizing procedural risks.<sup>43</sup> This shift towards procedural optimization and safety considerations highlighted the evolving focus on improving patient outcomes and reducing complications in kyphoplasty research.

Based on the most recent data up to 2025, the emergence and persistence of keywords related to cement distribution and volume suggest that future research will likely prioritize procedural refinement, patient-specific risk stratification, and long-term safety monitoring. Market analyses and recent literature predict continued growth in kyphoplasty-related procedures, driven by innovations in biomaterials, imaging guidance, and minimally invasive techniques.<sup>3</sup> These projections are supported by recent high-quality studies emphasizing the importance of individualized cement application and complication prevention.<sup>44</sup> As such, the field is expected to move toward precision medicine approaches, leveraging technological advances and robust clinical evidence to further improve outcomes for patients with OVCFs.

## Strengths and Limitations

This study had several strengths. First, it identified key contributors such as leading countries, institutions, and influential authors, offering valuable insights into research leadership. Second, the study examined publication trends over two decades, revealing the field's growth and development. Third, keyword and burst keyword analyses uncovered emerging research hotspots and evolving themes. This study had several limitations. First, the bibliometric analysis was conducted using the WoSCC database, which, while comprehensive, may have excluded relevant studies indexed in other databases such as PubMed or Scopus. This could introduce a selection bias and limit the generalizability of the findings. Second, the analysis was limited to English-language articles, which might have excluded relevant studies published in other languages, potentially leading to a biased representation of global research trends. Future studies incorporate multi-database search strategies to further enhance coverage and reduce potential bias. Third, the analysis focused primarily on quantitative metrics like publication counts and citations, which might not fully capture the impact or influence of individual studies on clinical practice or policy, especially for recently published studies.

## Conclusion

This bibliometric analysis delineates the evolving landscape of PKP research for OVCFs, identifying five thematic clusters: clinical outcomes, procedural complications, material properties, biomechanics, and management strategies. Keyword co-occurrence revealed a shift from early focus on cement materials to emerging emphasis on risk factors, bone cement distribution, and volume optimization. These insights highlight the critical need for developing standardized surgical protocols that balance effective vertebral stabilization with minimizing adverse events. In the future, the field is expected to move toward precision medicine approaches, leveraging technological advances and robust clinical evidence to further improve outcomes for patients with OVCFs.

## Data Sharing Statement

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

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

The study was supported by The Scientific Research Project of Heilongjiang Provincial Health Commission.

## Disclosure

Haibo Wang and Xuejiao Cao are co-first authors for this study. The authors declare that they have no competing interests in this work.

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