Bibliometric Analysis

Bibliometric Analysis of Global Research on Radiofrequency in Chronic Pain Treatment

Fan Feng, MD[1], Yongzhi Fan, MD[1], Qianqian Xu, MD[2], Xianbao Yao, MD[1], and Yi Cai, MD[1]

From: [1]Department of Pain Management, The Central Hospital of Wuhan, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China; [2]Maternal and Child Health Hospital of Hubei Province, Wuhan, China

Address Correspondence:
Fan Feng, MD
Department of Pain Management,
The Central Hospital of Wuhan,
Tongji Medical College,
Huazhong University of Science and Technology,
Wuhan 430014, China
E-mail: fengfan0215@163.com

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Background: Chronic pain is a significant global health challenge, often resistant to conventional treatments, which has led to increased interest in minimally invasive interventions such as radiofrequency (RF) techniques. Over the past 2 decades, clinicians and researchers have extensively studied and utilized RF for chronic pain management. Despite its growing clinical use, the evidence supporting the efficacy of RF remains inconsistent, with outcomes varying due to differences in study design, patient selection, and procedural techniques. To improve the understanding of the current research landscape, this study conducts a bibliometric analysis with the aim of summarizing and visualizing the evolution of, research hot spots within, and future trends in the use of RF for chronic pain treatment. The findings aim to inform directions for future research and optimize the application of RF techniques in clinical practice.

Objective: This research endeavors to perform a comprehensive bibliometric analysis of global research on the use of RF in chronic pain treatment, focusing on identifying major contributing countries, institutions, journals, and authors, assessing the knowledge base, tracking trends in research hot spots, and exploring emerging topics within the field.

Study Design: A bibliometric analysis.

Methods: We searched the Web of Science (WoS) database for articles published between January 1, 2004, and December 31, 2024. CiteSpace and VOSviewer were utilized to perform bibliometric analysis and visualization.

Results: After all the data were gathered, 719 documents in total were classified and subjected to a detailed analysis that employed the aforementioned tools. The annual number of publications about the use of RF in chronic pain treatment showed a continuous growth trend that reached its peak in 2020. The United States, China, and South Korea were recognized as the most productive countries. Key institutions driving advancements included Yeungnam University, the University of Wisconsin, and Harvard Medical School. Among the authors, Min Cheol Chang and Alaa Abd-Elsayed led in productivity, while Steven P. Cohen stood as the most influential co-cited author, reflecting his foundational contributions to RF clinical applications and guidelines. Among all the journals, Pain Physician and Pain Medicine published the greatest number of relevant papers. Keyword bursts included "radiofrequency ablation," "pain management," and "postherpetic neuralgia," which were hot topics and frontiers in the research field.

Limitations: We analyzed only publications indexed in the WoS because most indicators required for bibliometric analysis could be extracted efficiently from its Web site.

Conclusion: This bibliometric analysis synthesizes 2 decades of global research on the use of RF for chronic pain, highlighting contributions from leading nations, institutions, journals, and authors. Keyword trends reflect a shift from foundational studies on thermal mechanisms to clinical validation and innovation in precision targeting and refractory pain subtypes. Further randomized controlled trials, interdisciplinary collaboration, and long-term outcome assessments are warranted to boost the therapeutic potential of RF for diverse chronic pain populations.

Key words: Bibliometric analysis, radiofrequency, chronic pain, visualization, VOSviewer, CiteSpace

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Radiofrequency (RF) techniques have emerged as a significant modality in the management of chronic pain, offering a minimally invasive approach to modulate sensory nerve transmission through thermal lesioning (1). Since its inception for cervical cordotomy in the 1960s and subsequent application to treating trigeminal neuralgia in the 1970s, RF has become a versatile tool for addressing various chronic pain conditions, particularly those of spinal origin (2). The principle behind RF denervation involves the targeted application of RF energy to create thermal lesions in nerves responsible for pain transmission, thereby interrupting or modulating pain signals (3).

The use of RF in pain management is typically considered after conservative treatments have failed, aligning with the broader principles of good medical practice (4). Over the years, RF techniques have diversified, with continuous RF, pulsed RF (PRF), and cooled RF being the most commonly used variants. Each technique has its unique mechanisms and applications, with continuous RF being the most established for creating thermal lesions, while PRF offers a nondestructive alternative by applying short bursts of RF energy (5,6). Cooled RF, meanwhile, allows for larger and more uniform lesions, making it suitable for deeper or anatomically challenging targets (7).

Based on the 2020 guidelines from the American Society of Interventional Pain Physicians (ASIPP), chronic axial spinal pain, with or without extremity pain, chest wall pain, or headaches, is a leading cause of disability and health care costs (8). Morbidity and chronic disability now account for almost half of the health burden in the United States. Dieleman et al (9,10) showed that an estimated $87.6 billion was spent in managing low back and neck pain in 2013 and that this figure increased to $134.5 billion in 2016, accounting for the highest number of the various disease categories. Manchikanti et al (11) evaluated in a recent article that RF neurotomy of the cervical and lumbar vertebrae increased by 185% and 169% respectively from 2009 to 2018.

Despite the growing adoption of RF techniques, the evidence supporting their efficacy remains mixed. While some studies have demonstrated significant pain relief and improved quality of life in patients with chronic pain conditions such as facet joint lower back pain, others have reported conflicting results, particularly in the intermediate-to-long-term follow-up periods (12,13). The variability in outcomes can be attributed to differences in study design, patient selection, and technical aspects of the RF procedures.

In-depth exploration of historical contexts and current research trends not only provides invaluable insights into scientific advancements but also facilitates evidence-based clinical decision-making. Bibliometric analysis has emerged as a robust tool, employing diverse methodologies to conduct quantitative assessments of scholarly literature within specific domains (14,15).Given the increasing interest in RF techniques and their potential to address chronic pain, a comprehensive understanding of the global research landscape is essential. This bibliometric analysis aims to map the trends, major contributors, and emerging themes in RF research for pain treatment. By identifying the most influential studies, authors, and institutions, this analysis will provide valuable insights into the current state of research and highlight areas for future investigation. Furthermore, this study will shed light on the geographical distribution of research efforts and the collaboration patterns among researchers, offering a holistic view of the field's development over time. As RF techniques continue to evolve and gain traction in pain management, a systematic review of the existing literature through bibliometric analysis is crucial. This study will not only summarize the current knowledge but also guide future research directions, ultimately contributing to the optimization of RF techniques for chronic pain treatment.

Methods

Data Sources

The bibliometric analysis is based on the Web of Science Core Collection (WOSCC), which is widely recognized as the most appropriate database for conducting such analyses (11). Data collection was conducted throughout January 2025, with a focus on retrieving all literature published between 2004 and 2024 in the WOSCC. We used the following search algorithm: (radiofrequency OR "RF" OR "radiofrequency ablation" OR "radiofrequency therapy" OR "radiofrequency treatment") AND (pain OR "pain relief" OR analgesia OR "pain management" OR nociception OR "chronic pain" OR "neuropathic pain" OR "radiofrequency neurotomy"). Only original research and review studies were selected for inclusion. All articles with titles that fulfilled the search criteria were screened for eligibility.

Inclusion and Exclusion Criteria

We included only original articles and reviews writ-

ten in English. Documents were excluded if they met any of the following criteria:

1. They were letters, meeting abstracts, editorial materials, proceeding papers, corrections, early access, or news Items.
2. They had no abstract or digital object identifier (DOI) number.
3. Their full texts were unavailable.
4. They were translations of articles or reviews from other languages.
5. Their publication had been retracted.
6. They were duplicates of other documents.

Data Retrieval and Classification

All data (author, year, title, journal, volume, issue, page, article type, abstract, key words, references, and citations) were exported from the WoS database. The first and second authors independently examined the retrieved information to assess the eligibility of the articles for further analysis. Disagreements between reviewers were resolved by the third author or through consensus-based discussion. The EndNote 20 reference management software program was used to identify duplicate publications.

Data Analysis and Visualization

Linear regression analysis was performed, using the Microsoft Excel 2019 software program (Microsoft Corporation), to analyze trends in annual publications and citations over time. VOSviewer (version 1.6.2) was used to build and view bibliometric maps. By employing the clustering algorithm embedded in the software, we constructed and visualized the co-occurrence network of key words in scientific literature (16). Furthermore, this study focused on the analysis of co-authorship and key word co-occurrence, utilizing the tool to explore collaboration patterns among countries, institutions, and authors.

The CiteSpace 6.4 R1 package (a widely used scientometric analysis tool) was used to generate a co-citation network map, which demonstrated emerging trends, benchmark publications, and clusters of citation bursts (17,18). The program was also used for the timeline viewer and detection of key word bursts.

Results

Publication Trend

The overall flow of the study is summarized in Fig. 1A. In total, 719 articles were acquired from WOSCC and downloaded for subsequent analysis. The annual publication counts were subsequently tabulated in Excel 2019 (Microsoft Corporation) to facilitate further examination. Based on these results, a line graph and trend line were generated, as depicted in Fig. 1B. The number of annual publications about the use of RF in chronic pain treatment generally shows an increasing trend from 2004 to 2019. The publication output reached its peak around 2020 and has since maintained a consistently high level, with growth trends showing a plateau in subsequent years. It can also be seen that the average number of citations for articles published each year in the field demonstrates a steady increase.

Countries

Based on statistical data, 719 papers in total were published across 47 countries and regions globally from 2004 to 2024. Table 1 presents the top 10 most prolific countries. The country with the highest number of publications is the United States (n = 197), followed by China (n = 136) and South Korea (n = 73). Fig. 1C depicts the network diagram of cooperation among countries. Fig. 1D displays the world map of collaborative relationships, which demonstrates strong cooperation among countries such as the United States, China, and South Korea. The United States was also the leading country in total link strength.

Institutions

The collaborative partnership among the institutions is depicted graphically in Fig. 2A. From this figure, it can be inferred that Yeungnam University, the University of Wisconsin, Harvard Medical School, and Capital Medical University are in larger circles, representing the higher volume of publications from these institutions. The 10 most prolific institutions are shown in Fig. 2B. Yeungnam University has the most publications (Korea, 22 publications), followed by the University of Wisconsin (USA, 19 publications), Harvard Medical School Clinic (USA, 17 publications), and Capital Medical University (China, 14 publications).

Journals and Co-Cited Journals

We performed a visual analysis of the published literature with VOSviewer. Outcomes are delineated in Table 2. The 719 papers were published across 261 journals. *Pain Physician* journal ranked first in number of publications (n = 75), followed by *Pain Medicine* (n = 53). Among the top 10 journals, the journal of *Regional*

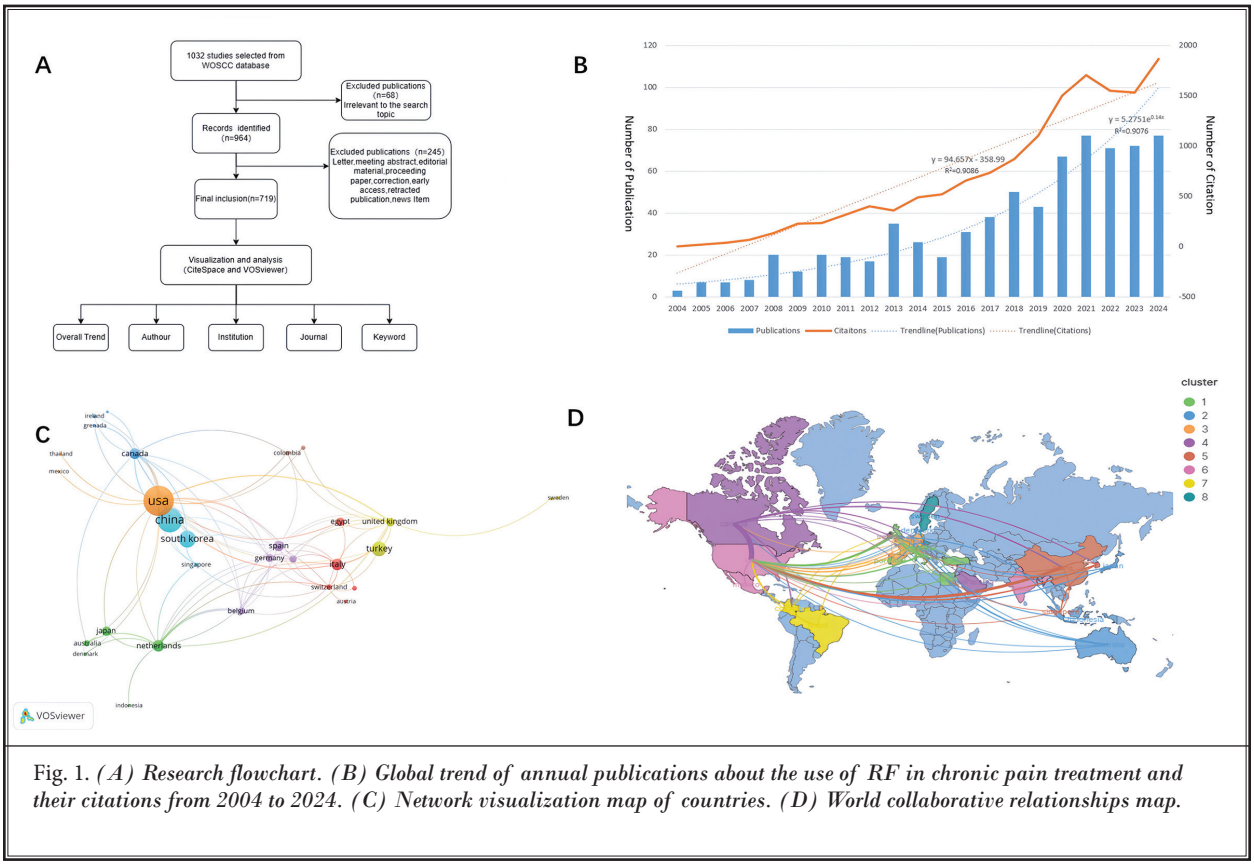


Fig. 1. *(A) Research flowchart. (B) Global trend of annual publications about the use of RF in chronic pain treatment and their citations from 2004 to 2024. (C) Network visualization map of countries. (D) World collaborative relationships map.*

Table 1. *Top 10 countries based on the total number of publications for the period of 2004-2024.*

Rank	Country	Publications	Citations	Average Citation/ Publicaiton
1	USA	197	4052	20.6
2	China	136	1316	9.7
3	South Korea	73	1427	19.5
4	Turkey	56	881	15.7
5	Italy	38	311	8.2
6	Netherlands	37	1460	39.5
7	Spain	34	417	12.3
8	Canada	33	709	21.5
9	Japan	27	458	17.0
10	UK	25	383	15.3

Anesthesia and *Pain Medicine* holds the highest impact factor (IF = 5.4). The 10 journals with the most co-citations are compiled in Table 2. *Pain Physician* (n = 1552), *Pain Medicine* (n = 1324) and *Spine* (n = 1027) were the 3 most frequently co-cited journals. *Pain Physician* and *Pain Medicine* have the highest number of research outputs and co-citations, reflecting their prominence in the field of RF use for chronic pain treatment.

The double map of journals shows the citing journals on the left and the cited journals on the right, with the colored paths between them indicating the citation relationship (19). The green path in Fig. 3 indicates that the citing journals were mainly from the medicine/medical/clinical and neurology/sports domains while the cited journals were primarily from health/nursing/medicine and psychology/education/social domains.

Authors and Co-Cited Authors

During the study period, 3,190 authors in total were included in this research domain. Fig. 4A shows the network map of authors whose names were signed to more than 4 publications. Fig. 4B depicts 10 clusters that were formed, indicating specialized research subgroups within the field. Table 4 presents the 10 authors who had contributed to the greatest number of publications in the study. Min Cheol Chang emerged as the most prolific author with 26 publications, followed by Alaa Abd-Elsayed (n = 21) and Zachary L. McCormick (n = 15). Authors from the same nation demonstrate high

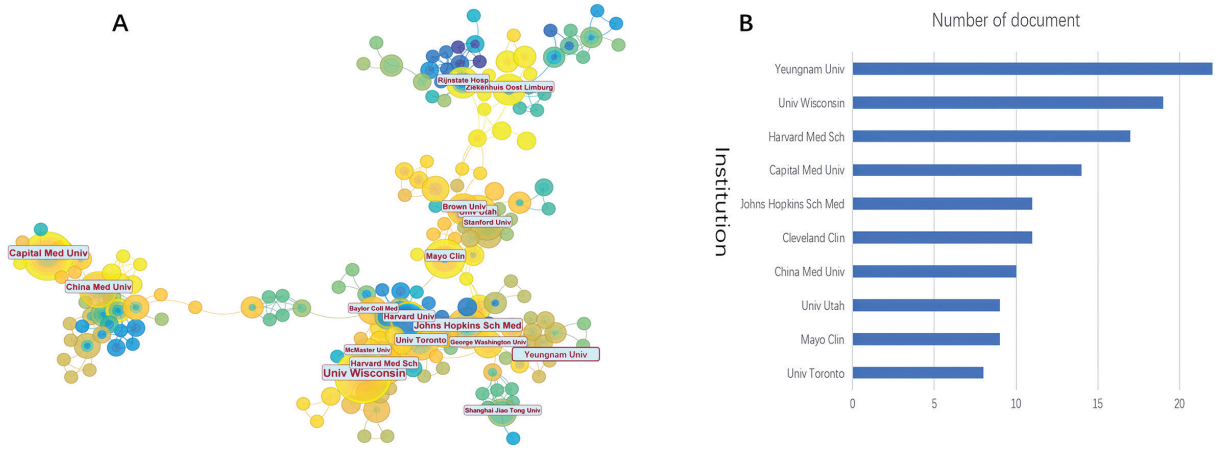


Fig. 2. *(A) The co-authorship network visualization map of institutions that use RF in chronic pain treatment research. (B) The 10 most productive institutions between 2004 and 2024.*

Table 2. *Top 10 journals and co-cited journals by number of articles related to the use of RF in chronic pain treatment.*

Rank	Journal	Publications	Quartile	IF	Co-Cited Journals	Citations	Quartile	IF
1	*Pain Physician*	75	Q2; Q2	3.1	*Pain Physician*	1552	Q2;Q2	3.1
2	*Pain Medicine*	53	Q1; Q1	3.2	*Pain Medicine*	1324	Q1;Q1	3.2
3	*Pain Practice*	36	Q2; Q2	2.8	*Spine*	1027	Q1;Q2	3.3
4	*Journal of Pain Research*	29	Q2	2.8	*Pain*	910	Q1;Q1	7.1
5	*Regional Anesthesia and Pain Medicine*	26	Q1	5.4	*Pain Practice*	894	Q2;Q2	2.8
6	*Medicine*	25	Q2	1.6	*Regional Anesthesia and Pain Medicine*	790	Q1	5.4
7	*Cureus Journal of Medical Science*	15	Q3	1.1	*Clinical Journal of Pain*	412	Q2;Q2	3.5
8	*Pain and Therapy*	10	Q1	4.2	*Anesthesiology*	339	Q1	8.6
9	*World Neurosurgery*	10	Q3; Q2	2	*European Journal of Pain*	275	Q1;Q1	3.8
10	*Clinical Journal of Pain*	9	Q2; Q2	3.5	*Journal of Pain Research*	271	Q2	2.8

levels of connectivity and collaboration. The co-cited authors are authors who are cited simultaneously in multiple studies, and this association constitutes a co-citation relationship (20). The top 10 co-cited authors are shown in Table 3. Steven P. Cohen was the most frequently cited author, with 572 citations.

References and Co-Cited References

Table 4 lists the top 10 co-cited references (9 articles, one review) (3,21-29). Three articles address RF mechanisms, structural changes, and thermal effects through basic research; 3 employ animal models to investigate neurophysiological, cellular, and neurochemical mechanisms; and 3 validate RF efficacy in humans via randomized controlled trials (RCTs). The review integrates mechanisms and clinical applications, connecting research to therapy. was The most frequently cited publication, written by ER Cosman Sr and Jr, can be seen in the first row of Table 4 (n = 86). Figure 5A depicts the co-citation network, in which this study serves as the most influential node, showing dense connections to other works, which indicates its central role in the knowledge domain. Figure 5B highlights the top 20 references that exhibit the strongest citation bursts. As we can see, RF therapy research has evolved through 3 phases: foundation (2005-2010), validation (2011-2016), and innovation (2017-2024). Early studies established RF's thermal and neuronal activation mechanisms, with later work linking pulsed RF to nonthermal neuromodulation. High-impact RCTs expanded clinical applications,

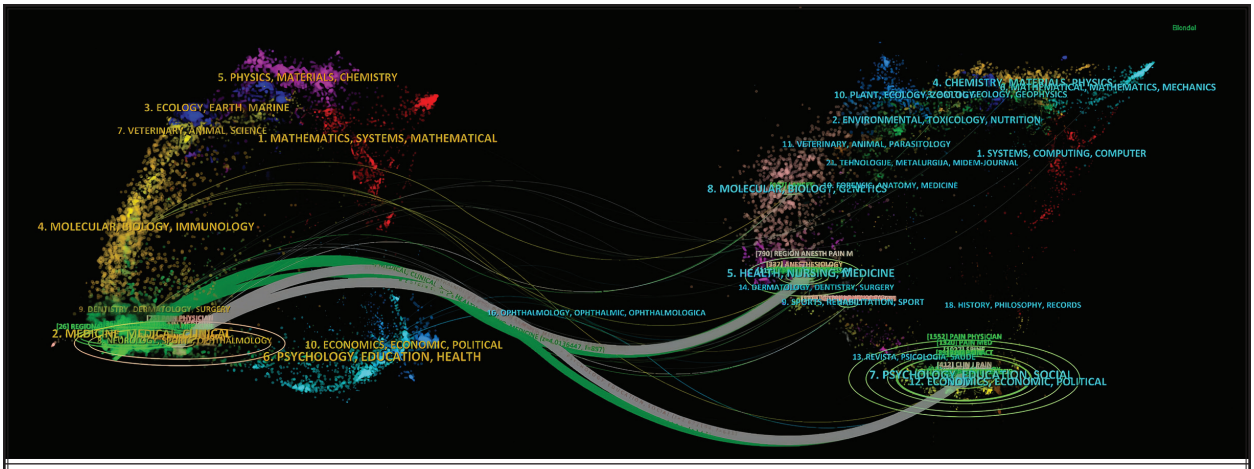


Fig. 3. *The dural map overlay of journals on the use of RF in chronic pain treatment.*

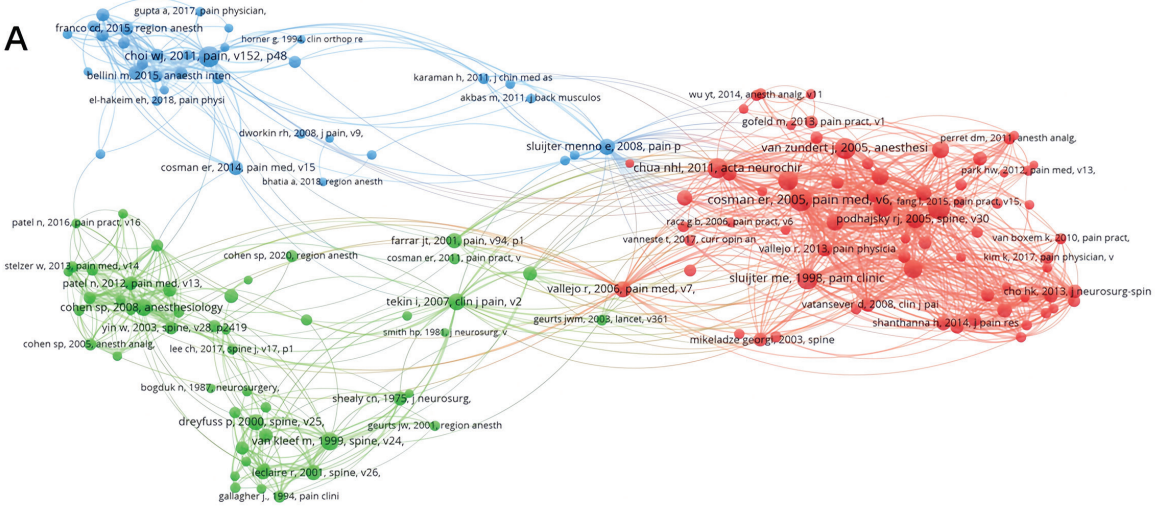


Fig. 4. *(A) A VOSviewer visualization map of co-cited authors. (B) A CiteSpace visualization map of authors.*

Table 4. *Top 10 most cited references.*

Rank	Cited Reference	Citation	Year	Journal	First author
1	Electric and thermal field effects in tissue around radiofrequency electrodes	86	2005	*Pain Medicine*	Eric R. Cosman
2	Exposure of the dorsal root ganglion in rats to pulsed radiofrequency currents activates dorsal horn lamina I and II neurons	78	2002	*Neurosurgery*	Yoshinori Higuchi
3	Radiofrequency treatment relieves chronic knee osteoarthritis pain: A double-blind randomized controlled trial	75	2011	*Pain*	Woo-Jong Choi
4	Pulsed and continuous radiofrequency current adjacent to the cervical dorsal root ganglion of the rat induces late cellular activity in the dorsal horn	74	2005	*Anesthesiology*	Jan Van Zundert
5	Pulsed radiofrequency treatment in interventional pain management: mechanisms and potential indications—A review	70	2011	*Acta Neurochirurgica*	Nicholas H. L. Chua
6	Ultrastructural changes in axons following exposure to pulsed radiofrequency fields	66	2009	*Pain Practice*	Serdar Erdine
7	Mechanisms of analgesic action of pulsed radiofrequency on adjuvant-induced pain in the rat: Roles of descending adrenergic and serotonergic system	62	2009	*European Journal of Pain*	Satoshi Hagiwara
8	Pulsed radiofrequency adjacent to the cervical dorsal root ganglion in chronic cervical radicular pain: A double-blind sham controlled randomized clinical trial	58	2007	*Pain*	Jan Van Zundert
9	The histologic effects of pulsed and continuous radiofrequency lesions at 42°C to rat dorsal root ganglion and sciatic nerve	53	2005	*Spine*	Podhajsky, Ronald
10	Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain	53	1999	*Spine*	Van Kleef, Maarten

Table 3. *The 10 most prolific authors and co-cited authors on the use of RF in chronic pain treatment research from 2004-2024.*

Rank	Author			Co-Cited Author		
	Name	Publications	Country	Name	Co-Citations	Country
1	Chang, Min Cheol	26	Korea	Cohen, Steven P	572	USA
2	Abd-Elsayed, Alaa	21	USA	Manchikanti, L	460	USA
3	McCormick, Zachary L	15	USA	Van Zundert, Jan	441	Netherlands
4	Van Zundert, Jan	14	Netherlands	Sluijter, Menno E	385	Switzerland
5	Cohen, Steven P	12	USA	Chang, Min Cheol	374	Korea
6	Manchikanti, L	9	USA	Van Kleef, Maarten	343	Netherlands
7	Conger, Aaron	8	USA	Kapural, Leonardo	337	USA
8	Kapural, Leonardo	8	USA	McCormick, Zachary L	311	USA
9	Cho, Yun Woo	7	Korea	Shin, Jin-Woo	291	Korea
10	Van Boxem, Koen	7	Netherlands	Hurley, Robert W	285	USA

though debates remain over sham-controlled outcomes and mechanisms. This progression reflects a shift from empirical exploration to precision strategies, calling for standardized protocols and multimodal integration to address therapeutic variability.

Key words and Hot Spots

The focus issue and summary content of a document are reflected by its key words, while the frequency of these key words indicates the research hot spots in the field. (30). VOSviewer is particularly adept at creating, visualizing, and exploring key word co-occurrence maps (31).

The co-occurrence map of key words constructed with VOSviewer is depicted in Fig. 6A. The most frequently occurring key words include "pulsed radiofre-

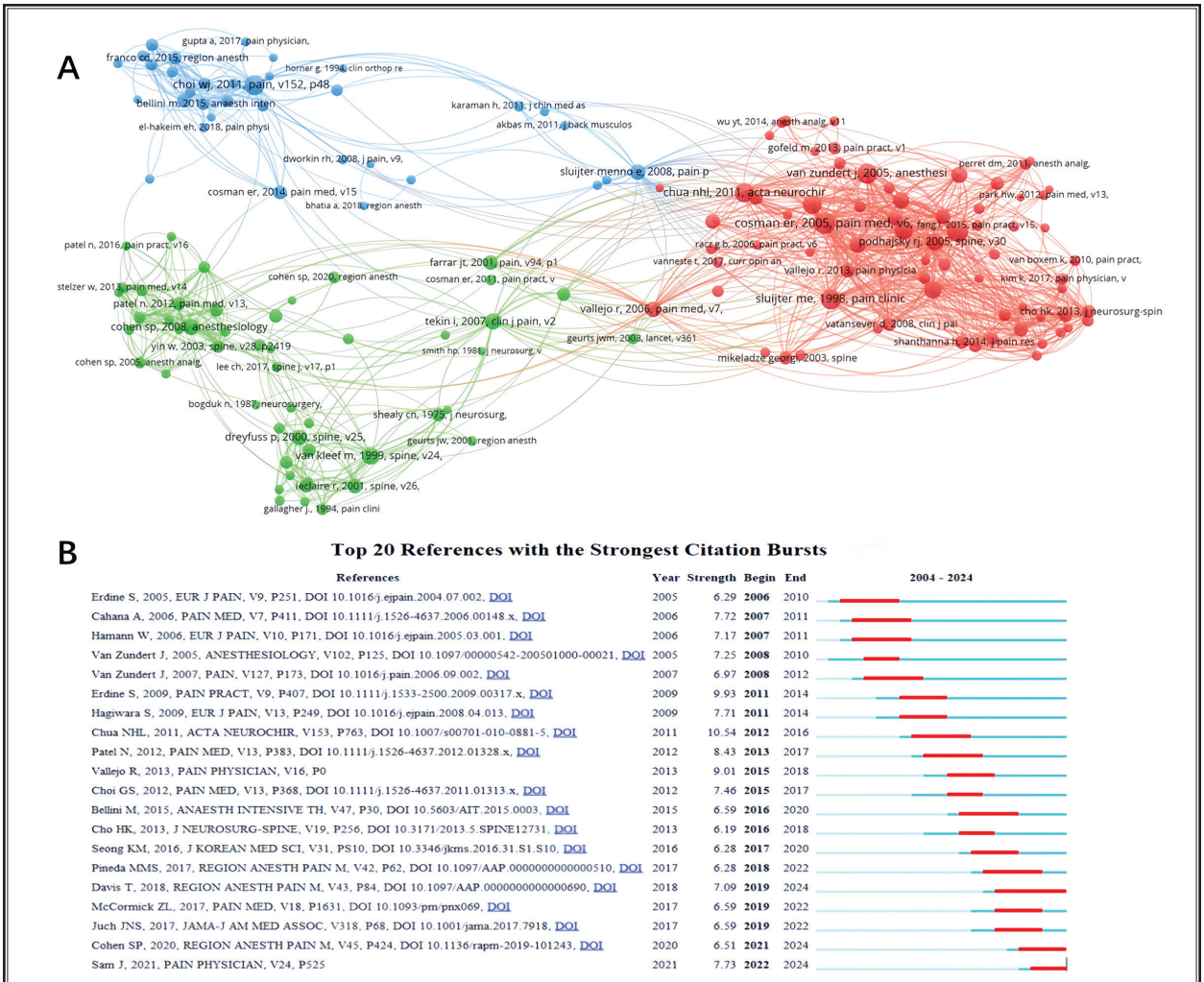


Fig. 5. *(A) The co-citation network visualization map of references. (B) The top 20 references with the strongest citation bursts. (The red segment of the blue line denotes the burst duration of a keyword).*

quency" (n = 207), "efficacy" (n = 114), "radiofrequency ablation" (n = 114), "dorsal root ganglion" (n = 113), "denervation" (n = 107), "management" (n = 106), "double-blind" (n = 104), "low-back-pain" (n = 89), "neuropathic pain" (n = 78), "osteoarthritis" (n = 75), etc. These terms, which emerged as the focal points of our research, had captivated the attention of scholars over the past 2 decades.

Key word bursts are utilized to reflect hot spots, frontiers, and trends in the research field (32). As illustrated in Fig. 6B, the following inferences can be made:

1. The surge in research on "radiofrequency ablation" (2021–2024) is likely driven by its proven clinical efficacy or advancements in procedural techniques, positioning it as a cornerstone of modern pain interventions.
2. The high-strength key word "pain management" (2022–2024) signifies a paradigm shift from isolated therapies to systemic strategies, integrating pharmacological interventions, interventional technologies, and personalized protocols.
3. The burst of "postherpetic neuralgia" (2022–2024) underscores growing clinical demand or therapeutic innovations targeting this debilitating condition, reflecting heightened attention to neuropathic pain subtypes.

These hot spots are likely to repeat in the near future. From a total of 719 documents, 2291 key words

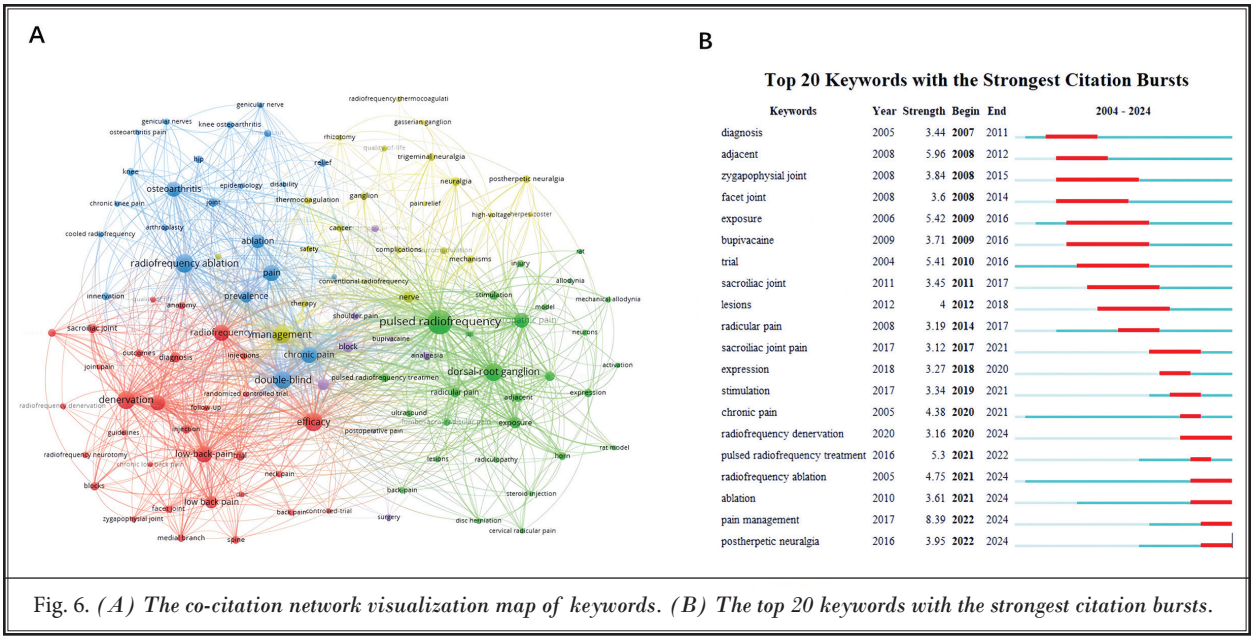


Fig. 6. *(A) The co-citation network visualization map of keywords. (B) The top 20 keywords with the strongest citation bursts.*

were extracted. When the number of occurrences was limited to 10 or more, 112 key words were identified and distributed into 8 clusters based on their research directions. In Fig. 7, larger node sizes indicate higher key word frequencies, while nodes positioned farther to the left correspond to earlier time of joint occurrence. Notably, nodes with purple outer circles exhibit the highest centrality and typically represent core research focuses. Nodes appearing on the right side signify emerging research directions in recent years. As can be seen in the figure, key words such as "denervation," "efficacy," "dorsal root ganglion," "diagnosis," and "radiofrequency ablation" were more prominent in the early period (2004-2009), indicating that the focus of early research in this field was biased toward mechanisms and anatomical foundations. As time progressed to the middle period (2010-2015), key words such as "management," "low back pain," "neuralgia," and "sacroiliac joint pain" gradually became research hot spots, indicating that the focus of research eventually shifted to some chronic pains commonly observed in clinical practice and that the treatment methods became systematic. After 2015, key words such as "herpes zoster" and "palliative care" have become more prominent. These words are often associated with refractory pains such as neuropathic pain and cancer pain. The use of RF technology to treat some relatively rare and difficult-to-manage pains has attracted the interest of researchers over time.

Discussion

This bibliometric analysis offers a comprehensive overview of the global research landscape on RF techniques in chronic pain treatment over the past 2 decades. By synthesizing publication trends, geographic and institutional contributions, influential journals, and evolving research hot spots, this study highlights both the progress and challenges within the field while identifying critical areas for future exploration.

Publication Trends and Research Maturation

The steady increase in annual publications from 2004 to 2020 reflects growing interest in RF as a minimally invasive alternative for chronic pain management. The plateau observed after 2020 suggests a phase of consolidation, in which research priorities may have shifted from validating basic efficacy to optimizing procedural protocols and addressing long-term outcomes. This phenomenon aligns with clinical observations that RF techniques, while widely adopted, still face debates over durability and patient selection criteria. The rising citation rates indicate sustained academic engagement, particularly around high-impact randomized RCTs and mechanistic studies.

Geographic and Institutional Leadership

The dominance of the United States, China, and South Korea in publication output underscores the role of economic investment and specialized pain manage-

ment programs in driving innovation. The strong collaborative network among these nations likely facilitates knowledge transfer. Institutions like Yeungnam University and Harvard Medical School have emerged as hubs for procedural refinement. The American Society of Interventional Pain Physicians (ASIPP) has conducted many in-depth and fruitful studies in this field (33). By organizing experts from all over the world, ASIPP has formulated guidelines for interventional techniques in the management of chronic spinal pain. In addition, ASIPP is committed to the innovation and development of related technologies for this application, evaluating and verifying the effectiveness of new treatment methods constantly. While having a wide influence in the academic circle, ASIPP has also provided important guidance for clinical practice.

Moreover, the contribution of the Netherlands as a European research hub in this field cannot be ignored. For example, the University Pain Centre Maastricht (Universitair Pijn Centrum Maastricht) has led several multicenter randomized controlled trials to systematically evaluate the long-term efficacy of PRF in patients with chronic low back pain (27). Maastricht University Medical Center has revealed the dynamic regulatory mechanism of RF on the spinal dorsal horn's pain-signaling pathway, providing a major theoretical basis for optimizing the clinical application of ablation. This finding makes the Netherlands an important source on the clinical conversion of RF technology (28). However, the underrepresentation of African and South American countries highlights disparities in resource allocation and access to interventional pain therapies, urging global initiatives to bridge this gap.

Mechanistic Insights and Clinical Translation

The co-citation analysis reveals a robust foundation of basic science exploring RF's thermal and electric field effects on neural tissues. Early animal studies laid the groundwork for understanding lesion characteristics, while later RCTs focused on validating efficacy for conditions like facet joint syndrome and postherpetic neuralgia. Notably, the key word burst of "dorsal root ganglion" (2015–2024) correlates with advancements in precision targeting, enabling RF to address complex neuropathic pain etiologies. However, the persistent debate around conflicting results emphasizes the need for standardized protocols to reduce heterogeneity in study design.

Evolving Research Hot Spots

The transition from foundational key words (e.g., "denervation," "efficacy") to clinical applications (e.g., "low back pain," "sacroiliac joint") and finally to refractory pain subtypes (e.g., "postherpetic neuralgia," "palliative care") mirrors the field's progression from empirical use to personalized strategies. The recent surge in "radiofrequency ablation" (2021-2024) likely reflects technological advancements, such as water-cooled systems that enable larger lesion areas, while "pain management" (2022-2024) signals a holistic

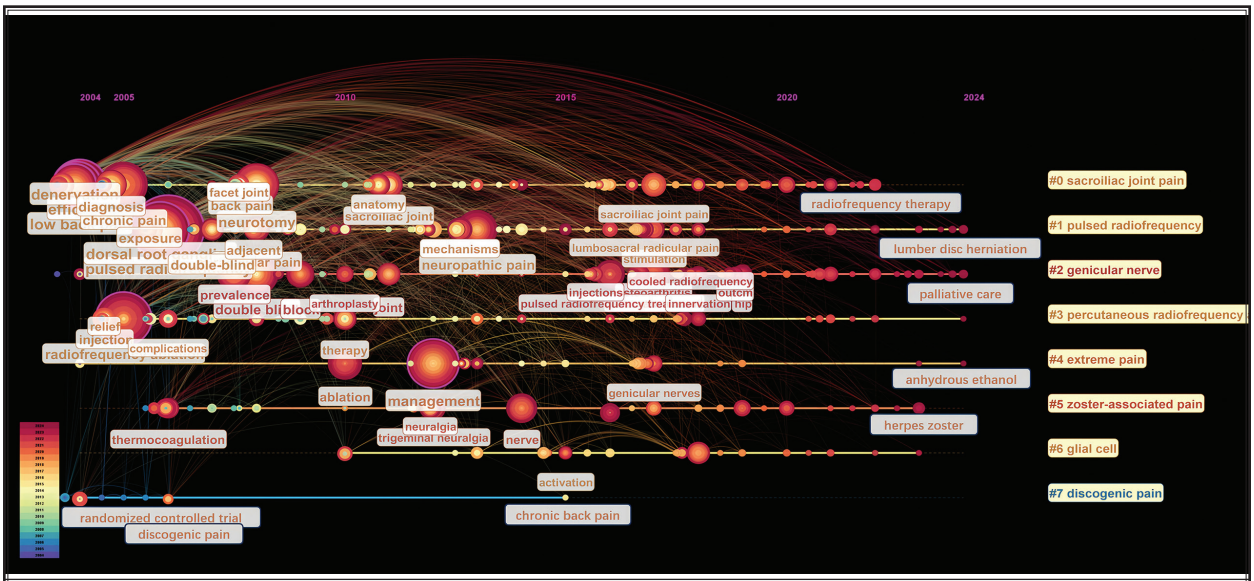


Fig. 7. *The timeline view of keywords.*

shift toward integrating RF into multimodal regimens. Emerging terms like "palliative care" suggest RF's expanding role in oncology pain, though this concept remains underexplored compared to musculoskeletal applications (34).

Future Directions

To address existing gaps, the following avenues are proposed:

1. Standardization of protocols: Develop consensus guidelines for patient selection, procedural parameters (e.g., temperature, duration), and outcome measures to enhance comparability across studies.
2. Mechanistic Exploration: Investigate the nonthermal effects of PRF, particularly its modulation of inflammatory cytokines and synaptic plasticity, to expand applications beyond nociceptive pain.
3. Combination therapies: Explore synergies between RF and adjuvant treatments (e.g., biologics, neuromodulation devices) to improve durability and broaden indications.
4. Equity in access: Promote international collaborations to disseminate RF technologies in low-resource settings, supported by cost-effectiveness analyses.
5. Long-term outcomes: Prioritize longitudinal studies to assess RF's impact on opioid dependence, functional recovery, and quality of life over decades.

Limitations and Methodological Considerations

While this study offers valuable insights, several limitations must be acknowledged. First, reliance on the WoS database may exclude regionally prominent journals or non-English publications, potentially skewing geographic representation. Second, the exclusion of conference abstracts and gray literature limits insights into preliminary findings or negative results. Third, the projected data for 2024 are extrapolated from trends and may not capture sudden shifts in research priorities. Finally, bibliometric analysis inherently emphasizes quantity over quality; thus, high citation counts may not always correlate with clinical relevance.

Conclusion

This bibliometric analysis synthesizes 2 decades of global research on the use of RF for chronic pain treatment, highlighting contributions from leading nations, institutions, journals and authors. Key word trends reflect a shift from foundational studies on thermal mechanisms to clinical validation and innovation in precision targeting and refractory pain subtypes. Further randomized controlled trials, interdisciplinary collaboration, and long-term outcome assessments are warranted to boost RF's therapeutic potential for diverse chronic pain populations.

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