


# Hotspots and Trends in Research on Treating Pain with Electroacupuncture: A Bibliometric and Visualization Analysis from 1994 to 2022

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**Purpose:** Electroacupuncture is widely used to pain management. A bibliometric analysis was conducted to identify the hotspots and trends in research on electroacupuncture for pain.

**Methods:** We retrieved studies published from 1994–2022 on the topic of pain relief by electroacupuncture from the Web of Science Core Collection database. We comprehensively analysed the data with VOSviewer, CiteSpace, and bibliometrix. Seven aspects of the data were analysed separately: annual publication outputs, countries, institutions, authors, journals, keywords and references.

**Results:** A total of 2030 papers were analysed, and the number of worldwide publications continuously increased over the period of interest. The most productive country and institution in this field were China and KyungHee University. Evidence-Based Complementary and Alternative Medicine was the most productive journal, and Pain was the most co-cited journal. Han Jisheng, Fang Jianqiao, and Lao Lixing were the most representative authors. Based on keywords and references, three active areas of research on EA for pain were mechanisms, randomized controlled trials, and perioperative applications. Three emerging trends were functional magnetic resonance imaging (fMRI), systematic reviews, and knee osteoarthritis.

**Conclusion:** This study comprehensively analysed the research published over the past 28 years on electroacupuncture for pain treatment, using bibliometrics and science mapping analysis. This work presents the current status and landscape of the field and may serve as a valuable resource for researchers. Chronic pain, fMRI-based mechanistic research, and the perioperative application of electroacupuncture are among the likely foci of future research in this area.

**Keywords:** bibliometrics, electroacupuncture, pain, VOSviewer, CiteSpace, bibliometrix

## Introduction

Pain is an unpleasant sensory and emotional experience that may or may not be linked to tissue damage.<sup>1</sup> Various methodologies are employed to categorize pain, including physiological and pathological classifications.<sup>2</sup> Physiological pain serves a protective role, while pathological pain, such as postherpetic neuralgia and trigeminal neuralgia, predominates in medical consultations. Pain can also be anatomically classified into somatic pain, visceral pain, and referred pain. Somatic pain encompasses discomfort on the body's surface and within joints and muscles. Treatment strategies depend on the underlying cause. Neuropathic pain often involves non-opioid analgesics, tricyclic antidepressants, and antiepileptic drugs. Nonneuropathic pain, such as osteoarthritis, is managed with nonsteroidal anti-inflammatory drugs. Acute pain management often entails opioid analgesics.<sup>3</sup> With pain affecting more than 30% of the global population, and resulting in substantial economic burdens, it is imperative to establish a treatment modality that is not only highly effective but also safe for prolonged implementation.<sup>4,5</sup>

Electroacupuncture (EA) is an approach that combines traditional acupuncture with electrical stimulation. EA presents favorable outcomes in pain management and quality-of-life enhancement, surpassing manual acupuncture due to its added electrical stimulation at specific frequencies.<sup>6–9</sup> The effectiveness of EA correlates with current intensity

and frequency.<sup>10</sup> Higher frequencies swiftly induce serotonin and endorphin release for short-term pain relief, while lower frequencies trigger enkephalin and dynorphin secretion, leading to prolonged analgesic effects.<sup>11</sup> Consequently, EA has emerged as a promising adjunctive therapy for both acute and chronic pain conditions.<sup>6,12</sup> Notably, EA also provides a more readily standardized and suitable treatment paradigm than manual acupuncture for future clinical studies.<sup>13</sup> Despite an increasing body of mechanistic and clinical research on EA analgesia, the status, potential clinical applications and future directions of this research remain unclear. Prior research has focused on specific pain disorders such as low back pain, migraine and chronic pain.<sup>14–16</sup> However, several systematic evaluations have suggested that current clinical studies are of poor quality. Hence, a knowledge map of the status of research is required to identify the strengths and challenges that must be addressed to facilitate the development of in-depth investigations.

The study of bibliometrics presents a valuable quantitative basis for comprehending fundamental themes and research patterns within a given discipline on a global scale. It has the advantage of identifying emerging areas of research.<sup>17</sup> A bibliometric analysis of the global use of EA for pain has not been undertaken. Therefore, The aim of this study is to comprehensively examine the research foundation of EA in pain management by reviewing the global scientific discoveries from 1994 to 2022. Additionally, a crucial objective is to investigate the most promising research teams and potential research trends to offer guidance for future research and clinical application.

## Materials and Methods

### Data Collection

We conducted a literature search on the Web of Science Core Collection Database from inception to Dec. 31, 2022. We retrieved 2057 publications in January 2023, including articles, reviews, proceeding papers, early access, book chapters, and retracted publications. The search strategy included the terms “electroacupuncture” and “pain”. The search formula is shown in detail in Table 1. We included only articles or reviews published in English. For bibliometric analysis, we extracted information such as title, author, abstract, keywords, and references. After a detailed filtering process, we ultimately analysed 2030 studies.

### Analysis Tools

Several tools were utilized in this study for data analysis and visualization. Microsoft Office Excel 2019 was used to analyze annual publications and fit a growth function to determine the current phase of the field. VOSviewer and CiteSpace were used to explore bibliometrics, including analyses of institutions, authors, journals, keywords, and references.<sup>18–20</sup> Citation bursts and relationships between citing and cited journals were also examined using CiteSpace.<sup>21</sup> Bibliometrix, an R tool, was used to generate national output, collaboration networks, and strategic diagrams.<sup>22</sup> Additionally, the H-index was utilized to evaluate academic work quality and quantity and identify important researchers and teams.<sup>23</sup>

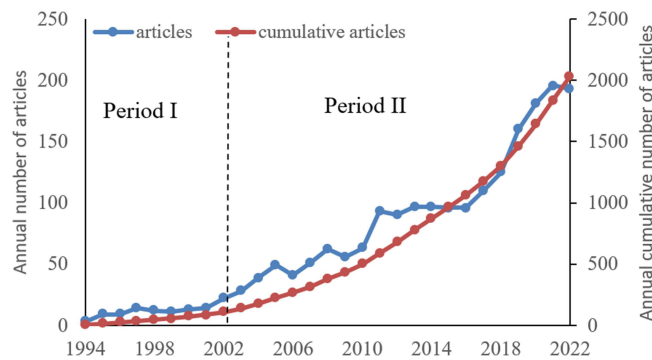
## Results

### Annual Publication Outputs and Temporal Trends

A total of 2030 publications were included in our study, including 1643 (81%) articles and 387 (19%) reviews. Along with minor fluctuations, the frequency of publications demonstrates a general upward trend (Figure 1). The initial stage, spanning from 1994 to 2002, is characterized by a gradual increase in the number of publications and represents a nascent phase. Conversely, the subsequent phase, encompassing the years 2002 to 2022, can be described as a period of flourishing, evinced by exponential growth in the proliferation of publications.

**Table 1** Search Queries

#1	((TS=(electroacupuncture)) OR TS=(electro-acupuncture)) OR ALL=(electroacupuncture)) OR ALL=(electro-acupuncture)
#2	((ALL=(pain)) OR ALL=(pains)) OR TS=(pain)) OR TS=(pains)
#3	#1 AND #2



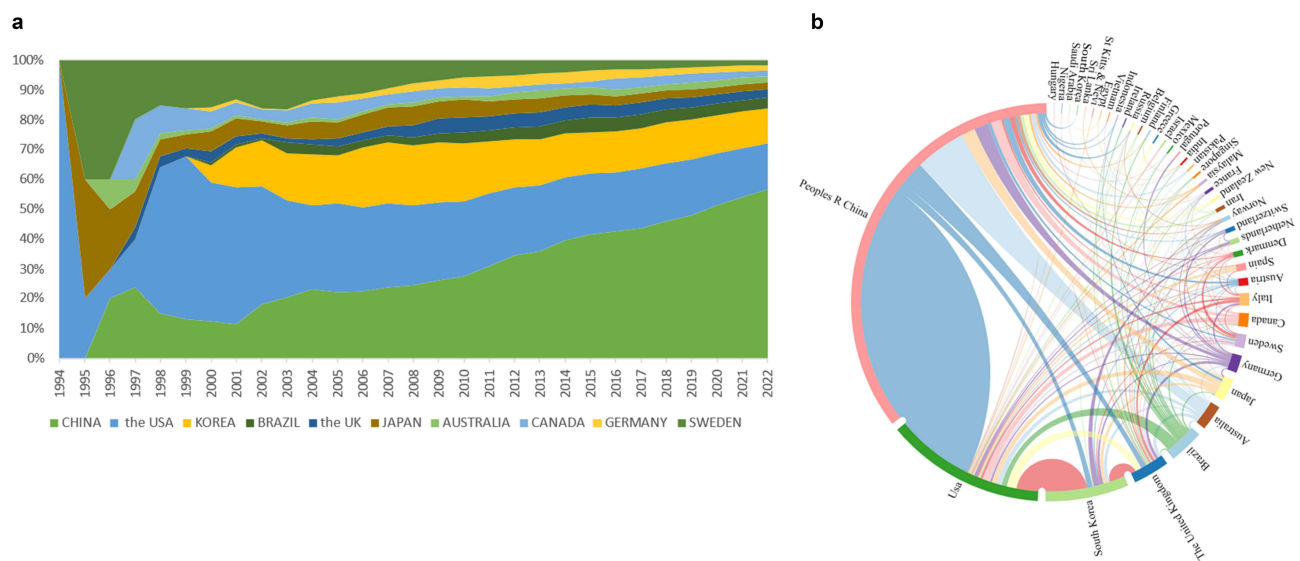
**Figure 1** Annual publications from 1994 to 2022 and logical curve of scientific literature.

### Analysis of Countries/Regions

Fifty-two countries worldwide contributed to a total of 2030 publications on EA for pain. Figure 2a shows the annual contributions of these countries in the period from 1994 to 2022. China, the United States, Japan, and Sweden were the first to begin EA-related research, but only China and the United States have continued to explore the field. Therefore, China produced the most publications (52.71%, 1070), followed by the United States (13.69%, 278) and Korea (9.95%, 202; Table 2). The dominant countries in terms of influence appear to be the United States (H=94), China (H=82), Korea (H=53), the United Kingdom (H=47), and Australia (H=35). China, the United States, Korea, the United Kingdom and Brazil were the countries that cooperated most with other countries (Figure 2b).

### Analysis of Institutions

The 2030 studies related to EA for pain originated from a total of 1830 institutions. Kyung Hee University (129), Chinese Academy of Medical Sciences (101), China Medical University (91), Beijing University of Chinese Medicine (85), and Zhejiang Chinese Medical University (78) ranked the top five institutions in terms of the number of publications (Table 3). A shift in highly productive institutions from Korea to China was observed (Figure 3a). A node with high betweenness centrality (BC) in CiteSpace has a strong influence on the relationship in the whole network (Figure 3b). The institutions with the top 3 BC values were Capital Medical University (0.19), Peking University (0.16) and Kyung Hee University (0.09), indicating that inter-institutional cooperation affects international cooperation and that only by



**Figure 2** (a) Countries' annual cumulative publication counts. (b) Collaboration network of countries/regions.

**Table 2** The Top Five Most Productive Countries

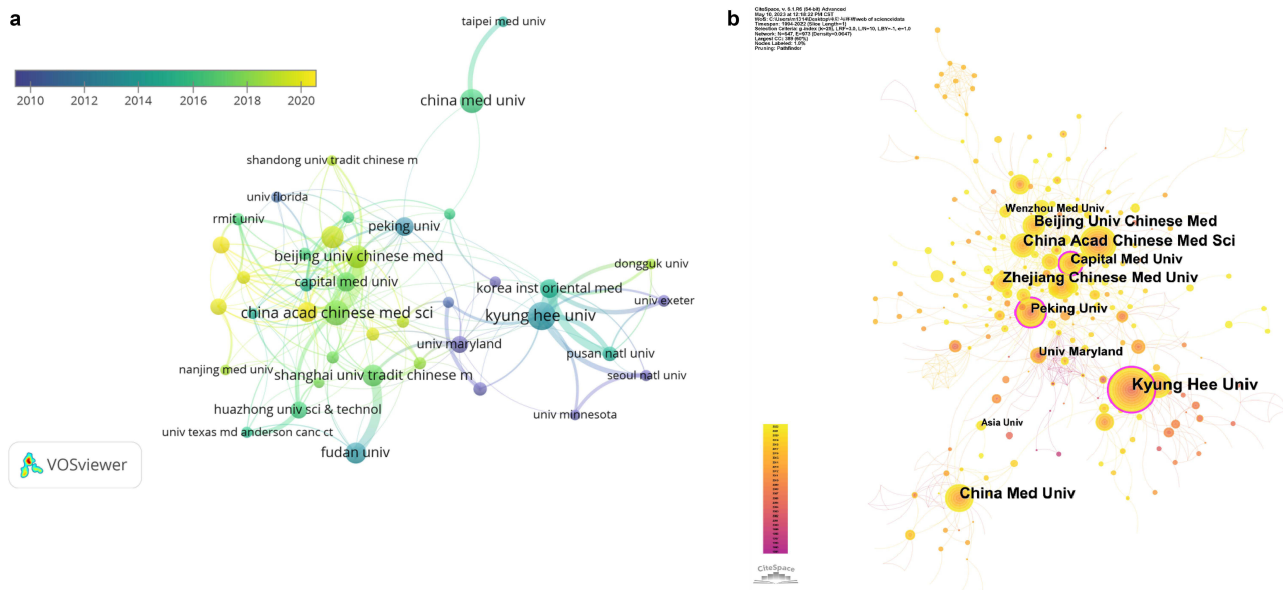
Rank	Country	Publications (%)	H-Index	SCP	MCP
1	China	1070(52.71)	82	931	139
2	USA	278(13.69)	94	199	79
3	Korea	202(9.95)	53	157	45
4	Brazil	89(4.38)	29	76	13
5	UK	48(2.36)	47	36	12

**Abbreviations:** MCP, multiple-country publications; SCP, single-country publications.

**Table 3** The Top Five Most Productive Institutions

Rank	Institutions	Publications	Rank	Institutions	BC
1	Kyung Hee Univ	129	1	Capital Med Univ	0.19
2	China Acad Chinese Med Sci	101	2	Peking Univ	0.16
3	China Med Univ	93	3	Kyung Hee Univ	0.09
4	Beijing Univ Chinese Med	85	4	China Med Univ	0.08
5	Zhejiang Chinese Med Univ	78	5	China Acad Chinese Med Sci	0.07

breaking down academic barriers and enhancing inter-institutional cooperation can we promote the development of the discipline and improve our academic influence. Especially in China, where there are numerous institutions, it is essential to enhance the collaboration among them.



**Figure 3** (a) Institutional collaboration network visualization map generated by VOS viewer. (b) Institutional collaboration network visualization map generated by CiteSpace.

## Analysis of Authors and Co-Cited Authors

The survey includes 8703 authors and 33941 co-cited authors. Table 4 and Table 5 present the ten most productive and co-cited authors among all authors. Figure 4 shows a visualization of the co-author network.

### Analysis of Authors

Highly productive and influential authors and their teams drive the development of related disciplines. The top five most productive authors are Fang Jianqiao (54), Han Jisheng (41), Lao Lixing (40), Lin Yinwen (33), and Shao Xiaomei (30; Table 4). A high H-index means that an author is an influential person who has a high number of publications and citations. The top 5 authors with the highest H-index values were Han Jisheng (H=22), Lao Lixing (H=21), Berman, Brian m (H=20), Wu Gencheng (H=18), and Fang Jianqiao (H=17; Table 4). Interestingly, most of these researchers were the same as the high-yield authors. The analysis of research teams reveals core teams (Figure 4). One team, led by Lao Lixing, Berman, Brian M, and Ren Ke, collaborates closely with Liang Fanrong and Bai Lijun's teams. The purple and yellow clusters represent teams anchored by Han Ji Sheng and by Fang Jianqiao, Liang Yi, Shao Xiaomei, and Du Junying respectively. Comparatively, Hsieh Ching-Liang, Lin Yiwen, and Lin Jaunggeng's teams tend to operate independently, engaging in little collaboration with others. Additionally, Wu Gencheng and Wang Yanqing lead independent teams.

### Analysis of Co-Cited Authors

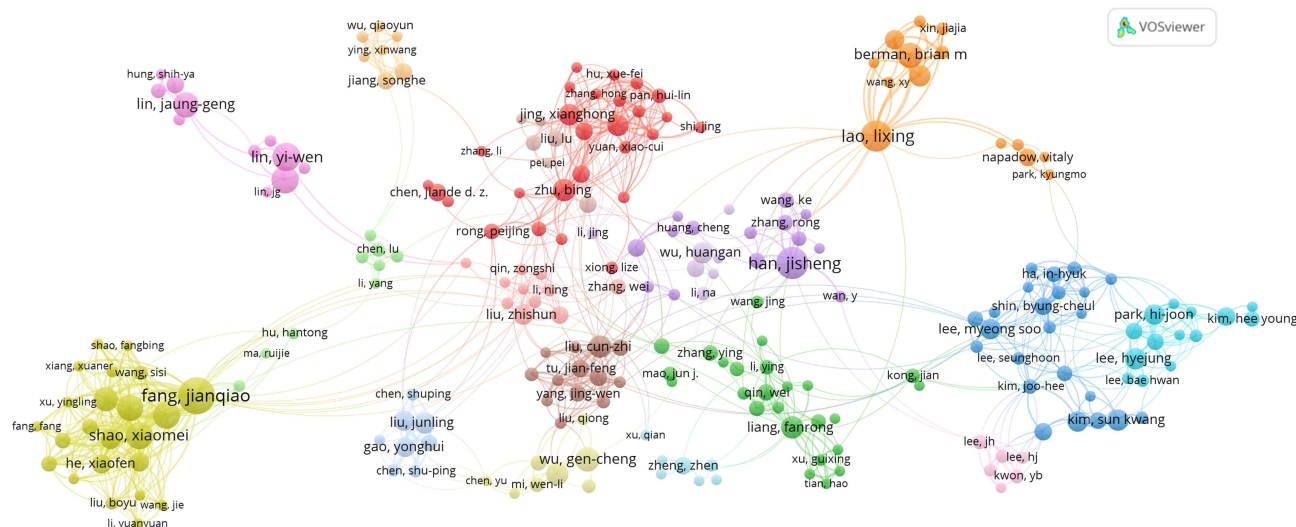
The most cited author was Han Jisheng (638), followed by Zhang Ruixin (336) and Zhao Zhiqi (234). Vickers Andrew J (208), Lin Jaung-Geng (207; Table 4). The top 5 authors in terms of BC were Pomeranz Bruce (0.09), Birch Stephen

**Table 4** Top Five Active and Influential Authors on the Topic of EA for Pain

Rank	Author	Publications	Institution	Rank	Author	H-Index
1	Fang Jianqiao	54	Zhejiang Chinese Medical University	1	Han Jisheng	22
2	Han Jisheng	41	Peking University	2	Lao Lixing	21
3	Lao Lixing	40	University of Maryland	3	Berman, Brian m	20
4	Lin Yinwen	33	China Medical University	4	Wu Gencheng	18
5	Shao Xiaomei	30	Zhejiang Chinese Medical University	5	Fang Jianqiao	17

**Table 5** Top Ten Authors on EA and Pain, Ranked by Citation Count and Co-Citation BC

Rank	Author	Citations	Rank	Author	BC
1	Han Jisheng	638	1	Pomeranz Bruce	0.09
2	Zhang Ruixin	336	2	Birch Stephen	0.09
3	Zhao Zhiqi	234	3	Melzack Ronald	0.08
4	Vickers Andrew J	208	4	Lao Lixing	0.08
5	Lin Jaung-Geng	207	5	Lee Jun-Hyuk	0.08
6	MacPherson Hugh	198	6	Takehige C	0.08
7	Ulett George A	196	7	Berman, Brian m	0.07
8	Melzack Ronald	167	8	Deluze C	0.07
9	Huang Cheng	152	9	Manfred Zimmermann	0.06
10	Lao Lixing	147	10	Chen Xiaohong	0.06



**Figure 4** Co-authorship analyses of authors carried out with VOSviewer.

(0.09), Melzack Ronald (0.08), Lao Lixing (0.08), and Lee Jun-Hyuk (0.08; Table 5). Based on analysis of these results, it can be seen that Lao Lixing’s team is a very influential team, devoting themselves to mechanistic research from a neuro-immuno-endocrine perspective and improving the quality of randomized controlled trials in acupuncture.<sup>24-26</sup>

### Analysis of Journals

Evidence-Based Complementary and Alternative Medicine (n =194), Acupuncture in Medicine (n =110), and Medicine (n =56) are the top 3 academic publications out of 493 journals (Table 6). These three journals’ publications made up 28.54% of all publications. Half of the ten journals in the quartile category fell into Q4, (the last 25% of the impact factor (IF) distribution). More than half of the journals’ IFs were below 3 and the average IF of these 10 journals was 2.9835. Table 7 demonstrates that Pain was the most influential journal in EA for pain. In terms of JCR, ten journals belonged almost evenly to all quartiles. More than half of the journals’ IFs were higher than 3 and the average IF of these 10 journals was 5.2955.

**Table 6** Distribution of the Top Ten Journals on EA for Pain

Rank	Journals	Documents (%)	IF (2021)	JCR (2022)
1	Evidence-Based Complementary and Alternative Medicine	194(9.56)	2.650	Q4
2	Acupuncture in Medicine	110(5.42)	1.976	Q3
3	Medicine	56(2.76)	1.817	Q4
4	American Journal of Chinese Medicine	54(2.66)	6.005	Q2
5	Journal of Pain Research	50(2.46)	2.832	Q3
6	Trials	49(2.41)	2.728	Q4
7	Acupuncture & Electrotherapeutics Research	38(1.87)	0.684	Q4
8	Frontiers in Neuroscience	38(1.87)	5.152	Q2
9	Journal of Alternative and Complementary Medicine	37(1.82)	2.381	Q4
10	Brain Research	35(1.72)	3.610	Q3



**Table 7** Top Ten Co-Cited Journals on EA for Pain

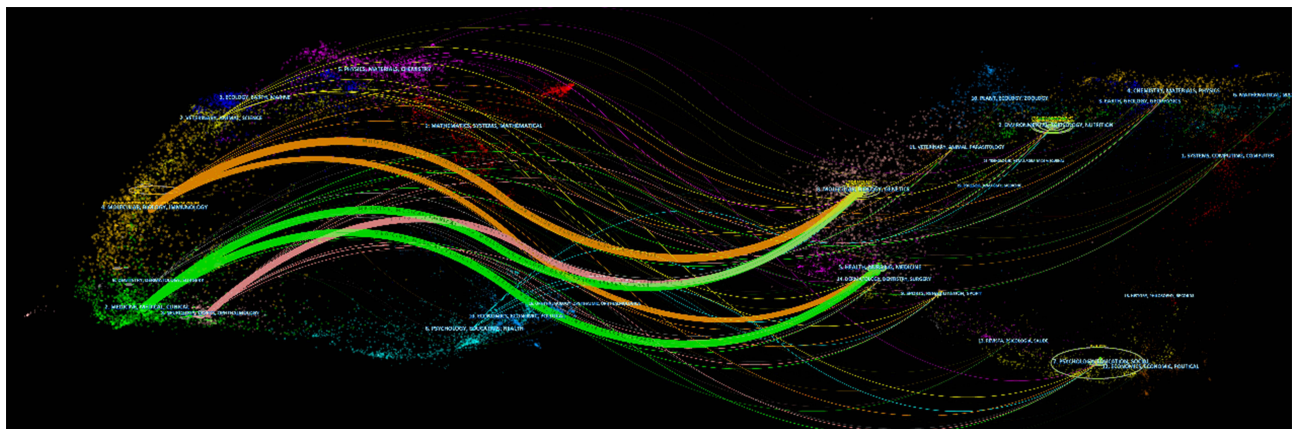
Rank	Journals	Citations	IF (2021)	JCR (2022)	Countries
1	Pain	4475	7.926	Q1	USA
2	Evidence-Based Complementary and Alternative Medicine	2005	2.650	Q4	UK
3	Brain Research	1972	3.610	Q3	Netherlands
4	Acupuncture in Medicine	1804	1.976	Q3	UK
5	Neuroscience Letters	1427	3.197	Q4	Netherlands
6	American Journal of Chinese Medicine	1227	6.005	Q2	USA
7	Journal of Alternative and Complementary Medicine	1208	2.381	Q4	USA
8	Journal of Neuroscience	1004	6.709	Q1	USA
9	Anesthesia and Analgesia	930	6.627	Q2	USA
10	Cochrane Database of Systematic Reviews	886	11.874	Q2	UK

A Dual map of journals can facilitate analysis in terms of patterns emerging from the distributions of citation threads and the dynamics of trajectories as a function of space and time.<sup>27</sup> The left side of the map refers to citing journals, and the right side of the map denotes the corresponding cited journals (Figure 5). As shown in Figure 5, the cited journals are mainly from disciplines “Molecular/Biology/Immunology”, “Medicine/Medical/Clinical” and “Neurology/Sports/Ophthalmology”. The citing journals are from multiple fields, such as “Health/Nursing/Medicine” and “Molecular/Biology/Genetics”.

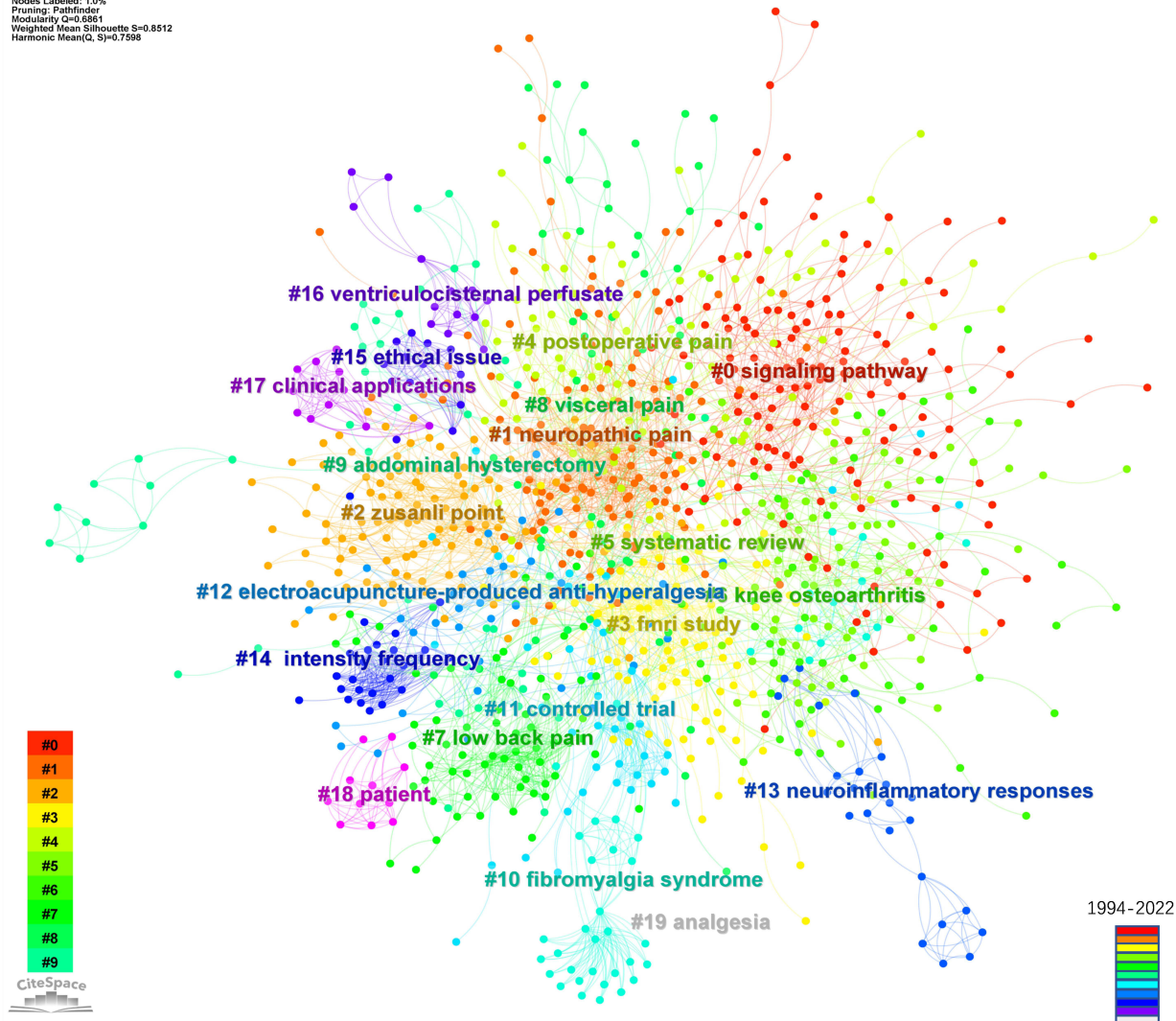
## Analysis of Co-Cited References

### Co-Cited Reference Networks and Co-Cited Papers

Co-citation analysis was performed to assess the correlation between articles.<sup>28</sup> The cross-reference of publications shows the structure and trend of the corresponding scientific field.<sup>29</sup> In our study, 52,074 cited publications were our knowledge base. By the logarithmic likelihood ratio (LLR) algorithm, we found the largest 20 clusters and clusters labelled by the titles of the citing publications (Figure 6). The total Q-value was 0.6861, and each cluster had a weighted mean silhouette of 0.8512, suggesting that the clusters had high quality. Based on the association between clusters, four major research trends were uncovered. We present clusters ranked from the largest (#0) to the smallest (#19).

**Figure 5** Dual-map of the overlay of journals.

CiteSpace, v. 6.1.R6 (64-bit) Advanced  
 April 5, 2023 at 11:22:57 AM CST  
 WOS: C:\User\1314\Desktop\电针与疼痛\web of science\data  
 Timespan: 1994-2022 (Slice Length=1)  
 Selection Criteria: g-index (k=25), LRF=3.0, U/N=10, LBY=-1, e=1.0  
 Network: N=1210, E=4141 (Density=0.0057)  
 Largest CC: 1123 (92%)  
 Nodes Labeled: 1.0%  
 Pruning: Pathfinder  
 Modularity Q=0.6981  
 Weighted Mean Silhouette S=0.8512  
 Harmonic Mean(Q, S)=0.7598



**Figure 6** Network map of co-citation of references.

The first and largest trend started in 1994 with 8 research clusters. These clusters, with specific information such as the label, size, silhouette score, and the average year of publication of the articles included in the cluster were as follows: cluster #10 (“fibromyalgia syndrome”; 42;  $S=0.972$ ; 1996), which shared hot topics with cluster #7 (“low back pain”; 64;  $S=0.898$ ; 1995), and cluster #17 (“clinical applications”; 12;  $S=0.998$ ; 1987). These clusters further evolved into cluster #11 (“controlled trial”; 41;  $S=0.933$ ; 1997) and cluster #8 (“visceral pain”; 59;  $S=0.826$ ; 2005). The findings of the above clusters promote the research in cluster #5 (“systematic review”; 81;  $S=0.799$ ; 2010), which further branches into #6 (“knee osteoarthritis”; 69;  $S=0.847$ ; 2010).

The second major trend of research concerns the mechanisms of acupuncture. It starts with research on EA frequency with cluster #14 (“intensity frequency”; 25;  $S=0.966$ ; 1985), which develops research on the rat model with cluster #16 (“ventriculocisternal perfusate”; 13;  $S=0.994$ ; 1988), #12 (“electroacupuncture-produced anti-hyperalgesia”; 35;  $S=0.881$ ; 1997) and #2 (“zusanli point”; 111;  $S=0.774$ ; 1989). More recently, these clusters became cluster #1 (“neuropathic pain”; 134;  $S=0.793$ ; 2004) and cluster #3 (“fMRI study”; 106;  $S=0.835$ ; 2004), with strong links to #0 (“signaling pathway”; 139;  $S=0.869$ ; 2004), which is mainly dedicated to exploring the mechanisms of acupuncture analgesia, not only central mechanisms but also peripheral mechanisms such as local changes at acupoints.



The third major research trend concerns perioperative acupuncture. These trends began in 1995, with the first cluster on EA anesthesia for hysterectomy, cluster #9 (“abdominal hysterectomy”; 44;  $S=0.924$ ; 1998) and cluster #19 (“analgesia”; 5;  $S=1$ ; 1997), which evolved into cluster #4 (“postoperative pain”; 93;  $S=0.782$ ; 2005) and has currently evolved into cluster #8 with EA in pain after abdominal surgery (“visceral pain”; 59;  $S=0.826$ ; 2005). In addition, there are some clinical studies of EA for dysmenorrhea and perimenopausal syndrome in cluster #9.

The fourth trend concerns ethical issues, and starts with a cluster on “ethical issue”, #15 ( $S=0.998$ ; 13; 1988). This topic was picked up again approximately 2000 on neuroinflammatory responses, #13 ( $S=0.928$ ; 25; 2000). This cluster is proximal to “postoperative pain”, cluster #4, into which it merges.

The top five studies that received the most attention from researchers are included in Table 8. All publications were reviews. Examining this table, it becomes evident that the majority of scholars devoted considerable attention to investigating the mechanism underlying EA for pain.

### Turning-Point Papers

Furthermore, we conducted a structural variation analysis, and identified the top 10 intellectual “turning-point” papers (Table 9).  $\Delta BC$  measures the structural variation caused by an article in terms of BC in the baseline network.<sup>30</sup> The BC is potentially valuable for detecting interdisciplinary activities. These 10 articles are not the most cited, even with fewer than 20 citations, but they are playing a key role in setting new research trends. They all influenced the structure of at least two clusters. The top 5 studies mainly focused on the verified effectiveness and safety of EA for menopausal symptoms, postoperative analgesia and low back pain.<sup>11,31,32</sup> One of the papers calls for urgent improvement in the quality of acupuncture clinical trial design and notes that sham acupuncture has a greater effect than drugs and other placebos.<sup>33</sup> Additionally, a new animal model of external ankle joint pain was established.<sup>34</sup>

## Analysis of Keywords

### Theme Evolution Analysis

Theme evolution analysis can be used to detect, quantify and visualize areas of hotspots of research interest.<sup>35</sup> Based on the previous description, we used 2002 as a cut-off point in the strategy map, and the horizontal axis and vertical axis

**Table 8** Top Five Co-Cited Publications on EA for Pain

Author	Year	Title	Journal	Frequency
Han JS	2003	Acupuncture and endorphins	Trends in Neuroscience	273
Zhao ZQ	2008	Neural mechanism underlying acupuncture analgesia	Progress in Neurobiology	233
Zhang RX	2014	Mechanisms of Acupuncture–Electroacupuncture on Persistent Pain	Anesthesiology	206
Ulett GA	1998	Electroacupuncture: mechanisms and clinical application	Biological Psychiatry	180
Han JS	2004	Acupuncture: neuropeptide release produced by electrical stimulation of different frequencies	Neuroscience Letters	166

**Table 9** Top Five Publications with the Strongest BC Divergency in the Co-Citation Network

Frequency	$\Delta$ Modularity	$\Delta BC$	Authors, Year	DOI
13	100	0.30	Alfhaily F, 2007	10.1080/13697130701612315
161	100	0.29	Lin JG, 2002	10.1016/S0304-3959(02)00261-0
87	100	0.28	Linde K, 2010	10.1159/000320374
68	100	0.24	Koo ST, 2002	10.1016/S0304-3959(02)00164-1
15	100	0.23	Lewis K, 2010	10.1097/AJP0b013e3181bad71e

represent the centrality and density of the keywords respectively. The strategy map can be divided into four quadrants based on centrality and density. Quadrant one comprises clusters that possess strong centrality and high density and are crucial to the knowledge base structure. Quadrant two includes well-developed clusters that are not currently significant to the research field. Quadrant three features themes that are not yet fully developed but may be new and emerging. Quadrant four hosts basic, important themes to the research field.

“Acupuncture/pain/nociception”, “electroacupuncture/analgesia/spinal cord/chronic pain”, “physical therapy/tennis elbow”, and “met-enkephalin/immunocytochemistry” were motor themes from 1994 to 2002. Mechanisms of “orphan fibropeptide” are also well explored. “Chronic pain” and “central nervous system” were emerging. (Figure 7a).

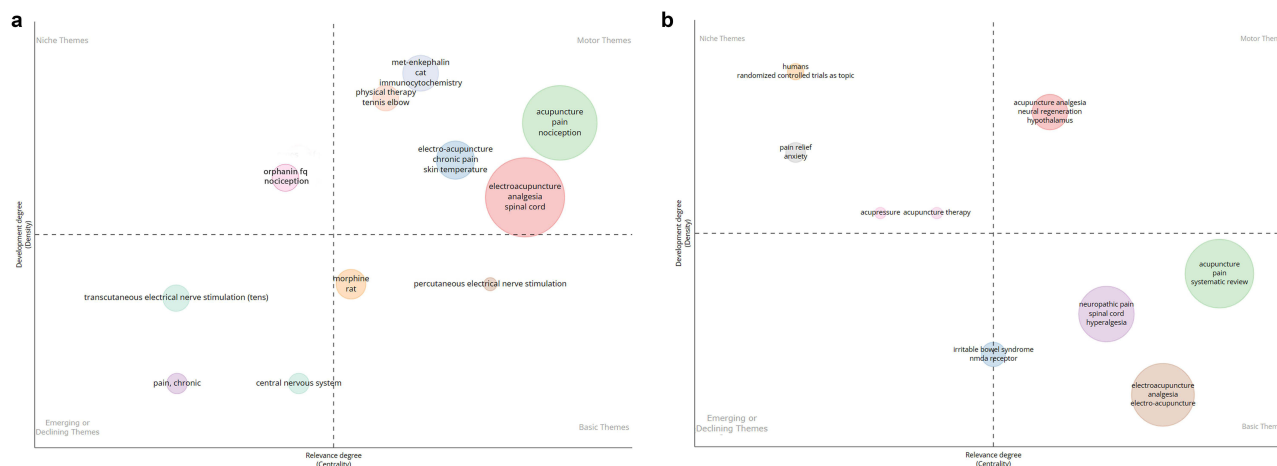
From 2002 to 2022, motor themes in the previous stage were developed into basic themes. Notably, “randomized controlled trials”, “pain relief”, and “anxiety” have been niche themes. “Acupuncture analgesia” remained a motor theme. Additionally, “neural generation” and “hypothalamus” could be related to “central nervous system” (Figure 7b).

## Co-Occurrence Analysis

Co-occurrence network analysis of keywords was conducted by VOSviewer.<sup>36</sup> Keywords were divided into 5 clusters (Figure 8) and the largest red cluster included 82 keywords, among which the keywords “analgesia” and “neuropathic pain” received the most attention (Table 10). The second is the green cluster, which consists of EA clinical applications, such as “electroacupuncture”, “pain”, “management”, and “randomized controlled trial”. The blue cluster focused on the use of perioperative acupuncture named acupuncture anesthesia, and the yellow cluster focused on human brain fMRI studies of acupuncture analgesia.

## Keywords Burst Detection Analysis

A total of 74 keywords were detected in the keyword co-occurrence network for EA and pain, and the top 25 keywords are shown in Table 11. Based on the chronological order, the earliest keyword cited in the outbreak was “acupuncture analgesia” (15.66), and this keyword was focused on for 20 years (1994–2014). It was followed by “electroacupuncture analgesia” (1995–2003) and “analgesia”, but there are differences in their scope. With the deepening of research, the keywords “knee osteoarthritis”, “systematic review”, “depression”, “guideline”, “surgery”, and “validation” have received attention in recent years. It is clear that recent studies have focused more on clinical efficacy. Besides, we performed keyword bursting for each cluster individually, and the results are consistent with the trend of the results above, as detailed in the Supplementary File. The top 5 keywords are drawn from distinct clusters, with some being unique to a single cluster. For instance, the first two keywords originated from Cluster 1 (Supplementary Figure 1) and the third keyword from Cluster 3 (Supplementary Figure 2). While the fourth keyword recurs in Cluster 0 (Supplementary Figure 3), Cluster 1, and Cluster 4 (Supplementary Figure 4), and the fifth keyword is repeatedly found in Cluster 3, Cluster 2 (Supplementary Figure 5), and Cluster 0.



**Figure 7** (a) Strategic diagrams of EA for pain research (1994–2002). (b) Strategic diagrams of EA for pain research (2002–2022).



**Table 11** Top 25 Keywords with the Beginning Year of Burst

Keywords	Strength	Begin	End	1994–2022
Acupuncture analgesia	15.66	1994	2014	
Electroacupuncture analgesia	7.81	1995	2003	
Analgesia	8.42	1996	2011	
Electrical stimulation	12.44	1997	2011	
Naloxone	9.85	1997	2008	
Brain stem	6.03	1997	2004	
Morphine	5.64	1998	2008	
Periaqueductal grey	7.07	2000	2010	
Beta endorphin	9.82	2001	2007	
Brain	5.83	2001	2007	
Fos expression	5.86	2004	2012	
Opioid receptor	7.91	2005	2012	
Auricular acupuncture	6.11	2005	2015	
Fos protein expression	5.79	2005	2011	
Functional MRI	5.61	2005	2012	
Point	10.41	2006	2011	
Human brain	8.88	2007	2014	
Response	5.65	2008	2013	
Neural regeneration	5.56	2012	2014	
Knee osteoarthritis	8.95	2018	2022	
Systematic review	7.21	2018	2022	
Depression	7.06	2019	2022	
Guideline	6.61	2020	2022	
Surgery	6.31	2020	2022	
Validation	5.91	2020	2022	

has enacted legislation to determine the status of traditional Chinese medicine and provided strong support for its development, inspiring numerous scholars. This may also be the reason for the increase in the number of publications in China. The top 10 output institutions originated from South Korea and China. Kyung Hee University is the most prolific institution, followed by several Chinese medicine schools in China. The top three high-yield authors are Fang Jianqiao, Han Jisheng, and Lao Lixing. Correspondingly, they come from China and the United States.

From countries to institutions and authors, the findings of this survey indicate that China, the United States, and South Korea are leading the trend in EA for pain.

### Status of Journals

Evidence-Based Complementary and Alternative Medicine, Acupuncture in Medicine, and Medicine were the top three journals. Their IF are all below 3 for two reasons in particular. First, research quality may need improvement. Second, the

effects of acupuncture are quite complex and the mechanisms underlying its efficacy are difficult to elucidate. The aforementioned issues constitute the challenges that we must confront in future research endeavors. Evidence-Based Complementary and Alternative Medicine, Cochrane Database Systematic Reviews, and Pain were the most influential journals, which may be related to the type and scope of literature in the journals. The high self-citation rate in the field may be attributed to the fact that Evidence-Based Complementary and Alternative Medicine boasts the highest number of publications and H-index in the field.

We can see that the journal sources of the citing papers are more abundant, and the cited journals are relatively concentrated (Figure 5). EA and pain research presents a trend of interdisciplinary research, and EA is increasingly widely used clinically.

In future research, it is imperative that we enhance interdisciplinary collaboration to modernize acupuncture. We must place equal emphasis on both the quantity and quality of research results while striving for publication in high-level journals.

### Status of Cooperation

China, the United States, and South Korea are recognized as highly influential and possess extensive collaborative relationships with other nations. Capital Medical University, Peking University, and Kyung Hee University are the most influential institutions. Kyung Hee University also has the largest amount of literature, while Capital Medical University and Peking University have temporarily fallen behind in this regard. However, through their collaborative efforts with other academic institutions, it is anticipated that both the quantity and quality of their literature will improve in the future.

As the discipline has evolved, several core author teams have gradually formed. From diverse perspectives, the mechanisms of EA analgesia were investigated by various research teams. The investigation was conducted by Lao Lixing's team and emphasized neuro-immuno-endocrine interactions, whereas Liang FanRong's team used fMRI to observe how EA modulates brain networks.<sup>24,37–40</sup> Han Jisheng's team focused on frequency-dependent mechanisms, and Wu Gencheng delved into orphan fibropeptides.<sup>41,42</sup> Furthermore, researchers have probed various chronic pain types; for example, Liang focused on osteoarthritis in the knee, neck pain, primary dysmenorrhea, and migraine. Fang Jianqiao's team examined complex regional pain syndrome, diabetic neuropathic pain and trigeminal neuralgia, whereas Hsieh Ching-Liang's team concentrated on fibromyalgia. The function of EA within the emotional dimension of pain and its utility for mitigating lower abdominal pain and chronic pain induced anxiety and depression were also scrutinized.<sup>9</sup> Additionally, studies were conducted on chemotherapy-induced side effects in cancer patients and irritable bowel syndrome. The research conducted in this domain has substantially augmented our comprehension of EA and its prospective benefits for pain management.

The meso-institutional cooperation network and micro-author cooperation network indicate insufficient cooperation due to low density. Moreover, domestic cooperation frequently occurred, while international cooperation was lacking and needed to be strengthened. In particular, collaboration should be strengthened between China, the United States, and South Korea.

### Research Hotspots of EA for Pain

We investigated hotspots of EA for pain from three perspectives, namely, co-cited authors, keywords, and cited references.<sup>43</sup>

In terms of co-cited authors, Han Jisheng and Zhang Ruixing belonged to the core author teams mentioned above. Zhao Zhiqi mainly focused on the cellular and molecular mechanisms of nociception modulation by EA.<sup>44</sup> Vickers Andrew J focused on clinical decision models and chronic pain.<sup>45–47</sup> Similarly, Lin JaungGeng focused on the clinical application and mechanism of EA in patients with perioperative pain and cancer pain.<sup>48,49</sup> From this, it can be seen that mechanisms and clinical application are the focus of research.

Keyword co-occurrence analysis showed that the top ten recurring keywords (Table 8) were related to the mechanisms of acupuncture analgesia. Depending on the underlying cause, pain is classified into two types: inflammation due to tissue damage and neuropathy due to nerve damage. The mechanisms of pain can be further divided into three levels: peripheral, spinal and supraspinal. In terms of inflammatory pain, in the periphery, EA promotes the release of opioids



from peripheral inflammatory cells and reduces the expression of proinflammatory factors in local areas of inflammation.<sup>50–52</sup> At the spinal level, EA inhibits the transmission of noxious stimuli through the involvement of spinal opioids, 5-HT, norepinephrine, glutamate, spinal glial cells, cytokines and signalling molecules.<sup>53–55</sup> However, it should be emphasized that these pathways do not act individually and their combined efficacy in pain management is not fully understood. In neuropathic pain, the mechanisms have been studied more intensively in the spine, and opioids, serotonin, norepinephrine, excitatory amino acids, inhibitory amino acids, and glial cell/cytokines all play key roles.<sup>56</sup>

Our clustering analysis of keywords revealed four focus areas of EA for pain. In addition to the molecular biological mechanisms mentioned earlier, clinical randomized controlled trials are also hot topics in EA for pain. Furthermore, The multimodal analgesia approach has propelled EA's role as a perioperative adjunct. Preoperative EA at Zusanli (ST36) prior to anesthesia has reduced morphine use by 61%, delaying postoperative pain onset by 18 minutes.<sup>11</sup> Post anesthesia EA has significantly lowered analgesic doses and postoperative pain in knee joint replacement and radical prostatectomy.<sup>57,58</sup> The application of EA in post cardiac surgery pain management is also effective.<sup>59</sup> Owing to its proven efficacy with minimal side effects, the integration of EA has been proposed by researchers as an adjunct modality for analgesia in obstetric and pediatric populations, with the aim of minimizing analgesic drug administration.<sup>60,61</sup> A meta-analysis has shown a role for EA in postoperative pain management and better results with bilateral EA.<sup>48,62</sup> However, some are hesitant to endorse EA as an adjunct for analgesia due to concerns about its efficacy being contingent on surgical type and the perceived lower quality of evidence.<sup>63,64</sup> As far as disease types are concerned, the most studied are mainly chronic pain, including low back pain, knee osteoarthritis, migraine, shoulder pain, fibromyalgia, and dysmenorrhea. EA is endorsed as an adjuvant therapy for chronic pain and nonspecific low back pain in the United Kingdom and the United States, respectively.<sup>65–67</sup> It is noted that EA offers significant benefits in pain reduction and improvement in quality of life without any associated harm. It is important to highlight that acupuncture is currently not recommended in NICE's 2022 guidelines for the management of osteoarthritis, low back pain, and migraine. However, this recommendation is not due to its lack of effectiveness, but primarily because of the limited availability of high-quality literature. The guidelines explicitly state that experts consider the use of EA and recommend further research to identify the characteristics of patients with osteoarthritis who would benefit from EA. At the same time, EA has shown marked effectiveness in managing acute pain. Meta-analyses suggest that EA yields more pronounced alleviation of acute lumbar pain when contrasted with medication and basic manual acupuncture.<sup>12</sup> Furthermore, EA therapy for acute herpes zoster-associated pain also surpasses conventional approaches such as oral antiviral medications.<sup>68</sup>

The top five most co-cited references indicated that EA is more effective than manual acupuncture and suggested combining EA with low-dose traditional analgesic medication to reduce drug side effects.<sup>9,56</sup> Endogenous opioid peptides play a crucial role in mediating the analgesic effects of EA in the central nervous system and have frequency-dependent properties.<sup>10,69,70</sup>

Therefore, according to the findings of this study, EA is mainly used to treat pain during the perioperative period and chronic pain, especially musculoskeletal pain.<sup>47</sup> The analgesic effect of EA is essentially a manifestation of the integration process of impulse inputs from the pain area and acupuncture points at different levels of the central nervous system.<sup>69</sup> However, this is a complex process and different signalling pathways can influence each other. Among these pathways, the role of endogenous opioids is crucial.

## Global Trends in EA and Pain Research

The global trend in EA and pain research was investigated from the burst analysis of keywords, turning point papers and clusters of references.

Burst means that certain keywords are heavily cited in a short period, indicating that these topics have received more attention. In Table 10, the top five keywords in terms of strength among the ten latest keywords are point, human brain, knee osteoarthritis, systematic review, and depression. Similarly, according to the clustering of references, the two latest clusters were #5 (“systematic review”; 81;  $S = 0.799$ ; 2010) and #6 (“knee osteoarthritis”; 69;  $S = 0.847$ ; 2010).

The top five turning point papers were all focused on the theme of clinical efficacy, with two reviews, one a meta-analysis, and two clinical trials.<sup>11,31–34</sup> Knee osteoarthritis is just one type of chronic pain, but it has received more

attention due to negative results published in JAMA.<sup>71</sup> There is increasing discussion about the efficacy of acupuncture for pain, leading to an increase in both clinical trials and systematic reviews.

With the development of neuroimaging technology, fMRI is widely used to study the mechanism of acupuncture. In the context of EA treatment for acute pain, its primary effect involves the inhibition of activity in central pain perception and processing-related regions. Optimal intensity yields superior outcomes compared to minimal intensity.<sup>72</sup> Similarly, different frequencies mediate distinct analgesic mechanisms. At 2 Hz, stimulation activates the primary motor and supplementary motor areas, along with the temporal gyrus, while inhibiting both hippocampi. At 100 Hz, stimulation activates the inferior parietal lobule, anterior cingulate cortex, hypothalamus, and pons, while inhibiting the contralateral amygdala. EA's impact on neuropathic pain has been extensively researched.<sup>73</sup> In animal experiments, models of brachial plexus and sciatic nerve injuries have consistently demonstrated definitive therapeutic effects after three months of EA treatment. fMRI findings indicate that compared to sham acupuncture, EA effects manifest as synchronized activation patterns in regions tied to somatosensory perception and pain, alongside fluctuations in the limbic/paralimbic system.<sup>74</sup> The effect of EA is linked to the reversal of maladaptive plasticity associated with neuropathic pain.<sup>75</sup> EA stimulation prompts spontaneous activity coupling in brain areas involved in pain perception modulation.<sup>76</sup> The specific activation of the medial prefrontal cortex implies that EA's analgesic action may encompass emotional regulation. Changes in the insula and thalamus may also play a pivotal role.<sup>77,78</sup> In the treatment of migraines using EA, changes in the insula and thalamus are also pivotal.<sup>79</sup> Clinical trials suggest that EA's mechanism for carpal tunnel syndrome potentially involves reshaping the white matter microstructure in the primary somatosensory cortex, concurrently enhancing functional connectivity between the primary somatosensory area and regions associated with emotional processing.<sup>80,81</sup> For chronic pain conditions such as fibromyalgia, EA can regulate primary somatosensory function linked with insular neurochemistry, thereby alleviating pain severity.<sup>82</sup> In summary, the limbic system may be the key area where acupuncture works.<sup>83</sup> fMRI is also often used for acupoint-specific studies, such as KI 3, LI 4, and KI 4.<sup>84–86</sup> Compared to sham acupuncture, genuine acupuncture can cause different responses of mu-opioid receptors and significantly reduce periaqueductal grey matter activity.<sup>76,87</sup> In addition, the mechanisms of different treatment paradigms have been explored, such as the combination of Ting Points and Gathering Points, EA versus acupressure, and contralateral and ipsilateral selection of points at the affected site.<sup>88–90</sup> Notably, it has been suggested that manual acupuncture should be studied separately from EA, which produces a more extensive increase in signal than manual acupuncture, especially in the anterior middle cingulate layer.<sup>83,91</sup>

In addition to attention to pain symptoms, negative emotions such as anxiety or depression due to pain also received attention.<sup>92,93</sup> The dopamine system, amygdala and anterior cingulate gyrus are involved in the regulation of negative emotions associated with pain.<sup>94</sup>

In summary, the trend of EA for pain focuses on the brain response to EA, especially in patients with chronic pain. When evaluating the efficacy, both pain relief and emotional improvement of the patient were considered. Meanwhile, in the clinical application and efficacy evaluation of EA, emphasis has increasingly been placed on quality, in addition to the continuously increasing quantity.

## Future Outlook

It is important to pay more attention to the design of clinical trials on EA than before, distinguishing between EA and manual acupuncture, exploring appropriate EA parameters to improve clinical efficacy, and standardizing EA patterns to reduce variability and increase reproducibility.<sup>91,95</sup> A greater proportion of patients suffering from chronic pain were female but the models were mostly male rats, which may overlook the crucial influence of gender on the therapeutic effect of pain.<sup>96–98</sup> Future researchers should improve the quality and completeness of data reporting to publish more high-quality and influential papers.

## Limitations

There are still some limitations in this study that need to be addressed. First, due to the limitations of the data format, we only analyze English articles from the Web of Science database, which might lead to language and publication bias. Second, our co-citation network is only based on first authors, which does not adequately reflect the authors' influence;

however, we also considered the impact of the author's team in our subsequent analysis. Third, because there may be a delay in new articles being cited after publication, this may lead to an underestimation of the impact of the article, but the way we assess impact is not just in the number of citations but is also reflected in the names of the clusters.

## Conclusion

The present results have provided the basis and reference for research topic selection. Chronic pain and related negative emotions, as well as perioperative pain, have become key points of clinical research. In particular, the mechanisms underlying the brain's response to EA represent a key focus for ongoing inquiry. In addition, China, the United States, and South Korea should take a leading role in enhancing international cooperation. This may involve efforts to enhance the quality and rigor of experiments, to adhere to widely accepted consensus guidelines and to publish findings in high-impact journals to foster broader dissemination of results.

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The authors declare no conflicts of interest in this study.

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