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ORIGINAL RESEARCH

A bibliometric analysis of clinical research trends in temporomandibular disorders and associated pain: from pain management to AI-assisted diagnosis and treatment

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Abstract

Background: This study aimed to provide an analysis of the global research status, collaboration networks, core hotspots, and emerging trends in temporomandibular disorders (TMD) and associated pain using bibliometric methods, to identify research gaps and provide references for future basic and translational research. **Methods**: Publications on temporomandibular disorders and associated pain published between 01 January 2016 and 01 April 2026 were retrieved from the Web of Science Core Collection (WOSCC). CiteSpace and VOSviewer were used to analyse countries/regions, authors, journals, institutions, funding agencies, and keywords. **Results**: A total of 4917 publications were identified. The annual number of publications showed a steady increasing trend. The United States was the leading country in global research in this field, with 904 publications, followed by Brazil (697) and China (650). The Universidade de São Paulo was the most productive institution (233). The Journal of Oral Rehabilitation ranked first among journals with 519 publications. Keyword analysis revealed that keywords with the highest burst strength in recent years included "artificial intelligence" (7.75), "pain management" (7.23), "etiology" (5.97), and "oral behaviours" (5.05), indicating potential future research directions. **Conclusions**: Research in this field has shown a steady upward trend. Current hotspots focus on four major themes: (1) organic pathological changes and diagnosis of the temporomandibular joint; (2) pain assessment and comorbidity research; (3) epidemiological characteristics, risk factors, and psychological comorbidities; and (4) clinical management, rehabilitation strategies, and evidence-based interventions. This study also suggests that standardised pain management and Artificial Intelligence (AI)-assisted diagnosis and treatment are emerging and promising directions.

Keywords

Temporomandibular disorders; Pain; Research trends; Bibliometric analysis; Artificial intelligence

1. Introduction

The temporomandibular joint (TMJ) is the main joint responsible for mandibular movement and plays a critical role in physiological functions such as mastication, swallowing, and speech [1]. Among the disorders affecting the TMJ and related masticatory structures, temporomandibular disorders (TMD) are the most common [2, 3]. As a significant public health concern, TMD affects approximately 5%–12% of the global population [4] and is more prevalent among females [2]. In 2006, the National Institutes of Health (NIH) funded the landmark Orofacial Pain: Prospective Evaluation and Risk Assessment (OPPERA) prospective cohort study, which systematically investigated the risk factors for TMD within the framework of the biopsychosocial model. The findings demonstrated that genetic susceptibility [5], phenotypic characteristics such as heightened experimental pain sensitivity [6], psychosocial stress-related factors, including anxiety and somatisation tendencies [7], and a history of maxillofacial trauma [8] collectively contribute to the risk of developing TMD [9].

TMD is a subtype of craniofacial pain disorders and is highly prevalent in the fields of oral and maxillofacial surgery and pain medicine. It has also been referred to as TMJ pain-dysfunction syndrome [2]. Its main clinical manifestations include pain [10], restricted or asymmetric mandibular movement, and joint sounds [2]. Pain and discomfort primarily involve the TMJ, masticatory muscles, and mandibular region, and are often accompanied by otological and cervical

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symptoms such as aural fullness, tinnitus, dizziness, neck pain, and headache [2, 11]. Clinically, some patients present with acute, mild, and self-limiting symptoms, while others may develop chronic TMD characterised by persistent pain together with somatic, behavioural, and psychological manifestations similar to those seen in other chronic pain conditions. These persistent symptoms not only significantly impair patients' daily physiological functions, but also impose a substantial socioeconomic and healthcare burden [2].

Treatment for TMDs follows a reversible, stepped-care principle, with conservative therapies recommended as the first-line treatment. Four types of therapeutic exercises, including jaw excursion, stretching, resistance, and coordination training, can alleviate masticatory muscle pain and improve maximal mouth opening, among which coordination exercises appear to provide the optimal efficacy [12]. Manual therapies (MT), such as massage and joint mobilization, are superior to occlusal splints in mitigating functional impairment [13]. Occlusal splints, behavioral interventions, low-level laser therapy, transcutaneous electrical nerve stimulation, and dry needling can also serve as non-invasive adjunctive treatment approaches [14]. Pharmacotherapy is primarily used for symptomatic relief during the acute phase, and different medication regimens are required for myogenic and arthrogenic TMDs [15]. Advanced interventions, including botulinum toxin type A injections, platelet-rich plasma therapy, and 3D-printed implants, may be considered for patients with refractory symptoms who fail conservative management. Given the multifactorial pathogenesis of TMDs and the distinct pathological features between myogenic and arthrogenic lesions, individualized assessment and combined multimodal interventions are clinically essential [14].

Over the years, extensive research has been conducted worldwide on TMDs and associated pain. Early studies in this field mainly focused on structural abnormalities of the TMJ, myofascial pain involving the masticatory muscles, and the clinical manifestations of chronic orofacial pain [16], with particular emphasis on understanding the fundamental mechanisms of the disease and on conventional diagnostic and therapeutic approaches [17].

In 2014, the Journal of Oral & Facial Pain and Headache published the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), which have since become a standardized, evidence-based diagnostic system widely applied in both clinical practice and research [4]. Intra-articular injections and biological agents have also been widely used in the management of TMD and have continued to evolve over time. In recent years, regenerative biomaterials, such as chitosan-composite modified hyaluronic acid [18] and polydeoxyribonucleotide (PDRN) [19], have attracted increasing attention. Additionally, engineered M2 macrophage-derived exosomes [20], owing to their strong regenerative capacity, have prompted a shift in the treatment paradigm for TMD from symptom control alone towards regulation of the joint microenvironment and tissue regeneration. Meanwhile, TMJ surgery has progressively advanced towards minimally invasive approaches, with sophisticated arthroscopic disc repositioning techniques becoming a major research focus [21–23]. At the basic research level, studies on molecular regulatory mechanisms and signalling pathways have mainly investigated key pathological processes in TMJ osteoarthritis, including cartilage degeneration, abnormal synovial responses, dysregulation of the local inflammatory microenvironment, and cellular senescence [24–27].

Over the past five decades, scientific understanding of TMDs, associated pain symptoms, pathological changes, and rehabilitation and treatment strategies has developed rapidly [28]. However, research in this field remains highly diverse and fragmented, while its disciplinary boundaries continue to expand. The overall trajectory of academic development in this area has not yet been systematically synthesised, making it difficult for researchers to identify emerging trends and research frontiers. This lack of systematic integration may, in turn, limit interdisciplinary collaboration and hinder the exploration of previously unrecognised pathogenic mechanisms.

To address this gap, the present study is the first to conduct a bibliometric analysis of this field and systematically map its research landscape. The findings may provide evidence to support research decision-making, selection of collaborators, journal targeting, and manuscript preparation, and may also serve as a reference for identifying key research directions and future priorities.

2. Materials and methods

2.1 Data source and literature retrieval

The Science Citation Index Expanded (SCI-EXPANDED) database within the Web of Science Core Collection (WOSCC) is one of the most commonly used and authoritative databases in biomedical research and is widely applied for citation analysis. Therefore, it was selected as the data source for this study [29, 30].

A rigorous search strategy was developed, with reference to previously published bibliometric studies [31–34], to ensure accurate retrieval of relevant literature and to improve the representativeness of the results. Two groups of search terms were used (the asterisk * represents a wildcard character used to capture all word variants derived from a root term): TS = ("temporomandibular joint" OR "temporomandibular disorder*" OR TMJ OR TMD OR TMJD OR "temporomandibular joint disease*" OR "temporomandibular joint dysfunction" OR "craniomandibular disorder*" OR "temporomandibular joint syndrome") AND TS = (pain OR painful OR myalgia OR "muscle pain" OR "masticatory muscle pain" OR "myofascial pain" OR "myofascial trigger point" OR arthralgia OR "bone pain" OR osteoarthralgia OR "joint pain" OR "orofacial pain" OR "facial pain" OR "craniofacial pain" OR tenderness OR hyperalgesia OR allodynia OR dysaesthesia).

The detailed search strategy and study selection process are shown in Fig. 1. The search period was limited to publications from 01 January 2016 to 01 April 2026. This study focuses on emerging hotspots and recent research trends in the field rather than providing a comprehensive historical review of its 50-year development. Although the DC/TMD guidelines were published in 2014, a time lag is expected between guideline publication and subsequent research implementation, study

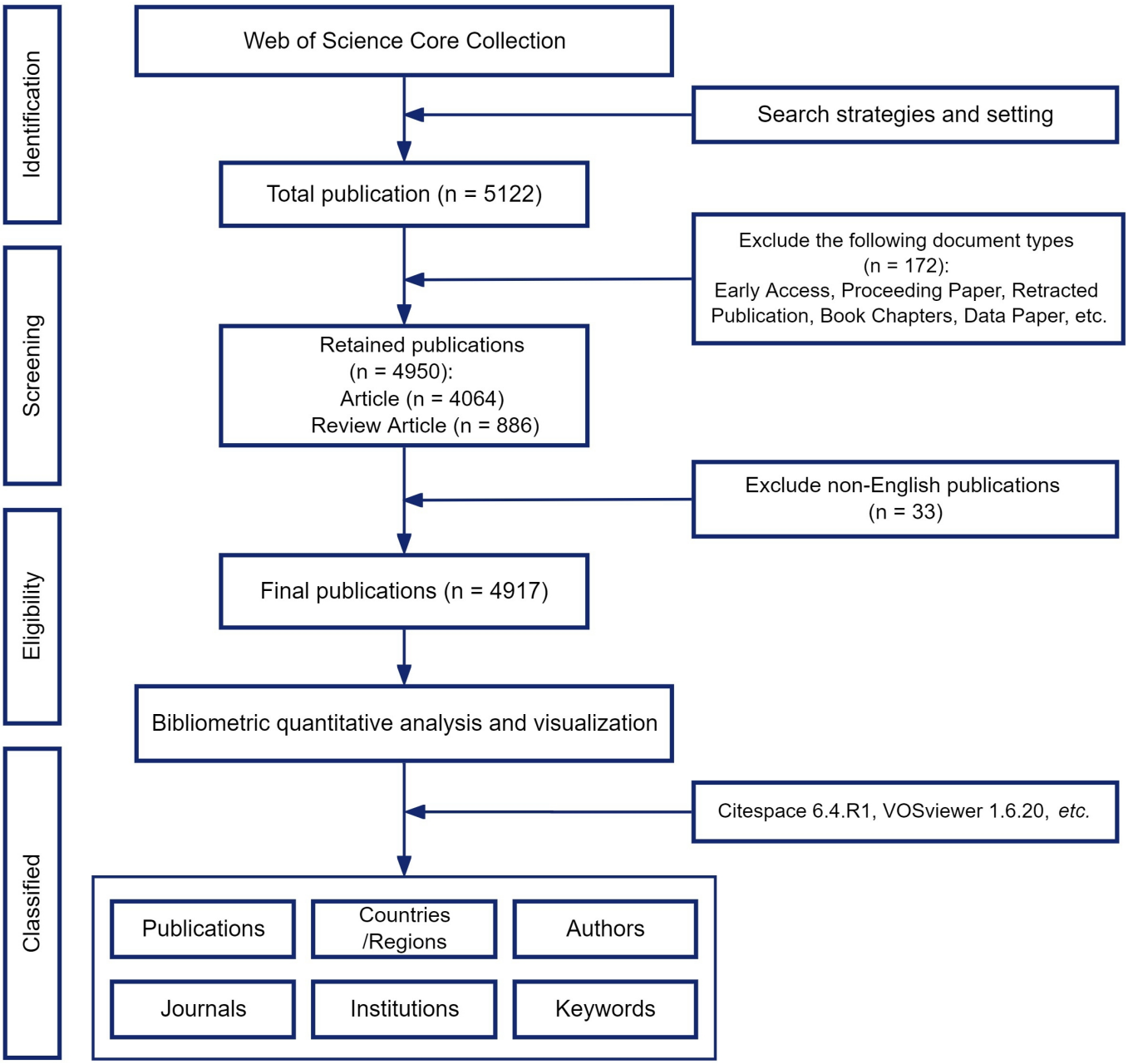


FIGURE 1. Flowchart of literature retrieval, filtering, inclusion, and bibliometric analysis. Publications were retrieved from the Web of Science Core Collection (total: 5122). After excluding non-relevant document types (n = 172) and non-English publications (n = 33), 4917 publications were included for bibliometric analysis using CiteSpace and VOSviewer, covering publication output; countries/regions; authors; journals; institutions; and keywords.

completion, peer review, and publication. Therefore, 2016 was selected as the starting year to better capture the current research landscape and more accurately reflect recent trends in this field.

2.2 Literature filtering and eligibility criteria

A total of 5122 records were initially retrieved in this study, followed by manual screening via Excel to eliminate publications that failed to meet the eligibility criteria. Inclusion criteria: (1) studies focusing on temporomandibular disorders and associated pain; (2) document types including original articles and review articles. Exclusion criteria: (1) irrelevant studies with mismatched research themes; (2) early access articles; (3) proceeding papers; (4) retracted publications; (5) book chapters; (6) data papers.

Only English-language publications were included in this study to maintain consistency in the bibliometric analysis. However, this criterion may have introduced potential language bias by excluding relevant non-English publications and should be considered a limitation of the present study. After screening, 4917 publications were retained for the final analysis.

To minimise potential bias in data quality control, two researchers independently conducted the literature retrieval, and the results were cross-checked. In case of disagreement, dis-

crepancies were resolved through consultation with a third senior expert in the field. All searches were completed within one day to avoid bias caused by database updates.

2.3 Bibliometric and visualisation analysis

Bibliometric analysis and visualisation were conducted using VOSviewer (version 1.6.20, Centre for Science and Technology Studies (CWTS), Leiden University, Leiden, The Netherlands), CiteSpace (version 6.4.R1, Drexel University, Philadelphia, PA, USA), and Microsoft Excel 2021 (Microsoft Corporations, Redmond, WA, USA). Data cleaning, statistical analysis, and visualisation were further supported by online bibliometric platforms, including Bioinformatics (http://www.bioinformatics.com.cn), Bibliometric (https://bibliometric.com/app), and BiblioVista (https://smuonco.shinyapps.io/BiblioVista/).

CiteSpace is a Java-based bibliometric and knowledge mapping visualisation software developed by Professor Chaomei Chen. It uses modules such as time slicing, co-citation analysis, and burst detection to provide intuitive visualisation of research hotspots, evolutionary trajectories, and key turning points within a scientific field [35]. Burst detection, in particular, indicates a rapid increase in attention to specific research topics and is used to identify emerging research directions. Compared with other bibliometric tools, CiteSpace emphasises dynamic temporal evolution and can systematically reveal the developmental trajectory and research frontiers of a discipline. In this study, the final program parameters for bibliometric analysis were as follows: "Time period = January 2016–April 2026," "Year Slice = 1," "g-index = 25," and "Top N% = 10." All the other parameters were selected to default. It was mainly used to generate collaboration network maps, burst analysis maps, and timeline visualisations.

VOSviewer focuses on static network visualisation and clearly displays keyword co-occurrence, co-authorship networks, and thematic clustering. It is particularly suitable for identifying research hotspots and the overall knowledge structure of a field [36]. In this study, the minimum occurrence threshold for nodes was manually adjusted according to visualisation requirements, while all other parameters remained at their default settings. The minimum number of documents by an author was 8 and the minimum number of occurrences of a keyword was 73. VOSviewer was mainly used to construct clustering maps.

In the network and clustering maps of countries/regions, authors, institutions, and keywords, nodes represent research items or topics, while links indicate co-occurrence or co-citation relationships. The size of a node reflects its frequency of occurrence, and the thickness of the connecting lines represents the strength of co-occurrence relationships. Betweenness centrality is shown by a purple ring surrounding the node, with a thicker ring indicating higher centrality. Nodes with a centrality value $\geq$0.1 are considered key hubs in the field and play important bridging roles in knowledge dissemination and interdisciplinary collaboration. Nodes within the same cluster are assigned the same colour, providing an intuitive visualisation of thematic distribution patterns.

In burst analysis maps of authors and keywords, burst strength indicates the intensity of a sudden increase in citations or occurrences. Blue segments show periods of stable citation activity, while red segments represent the duration of burst periods. Online bibliometric platforms were used to visualise the global distribution of publication output by countries and regions, international collaboration chord diagrams, and keyword evolution and prediction maps. In international collaboration chord diagrams, the sector area represents the total number of publications from each country, and interconnecting lines indicate the intensity of bilateral collaboration between countries. Different colours correspond to distinct thematic clusters within the field. Microsoft Excel was used to visualise annual publication trends and generate statistical charts of funding support.

3. Results

3.1 Overview of publications

According to the search strategy, a total of 4917 publications related to temporomandibular disorders and associated pain published over the past decade were retrieved, including 4064 original articles and 886 reviews. Fig. 2 presents the overall characteristics of the field. From 2016 to 2025, the annual number of publications showed a continuous upward trend, increasing from 293 in 2016 to a peak of 722 in 2025. During this period, only minor high-level fluctuations were observed in 2021 and 2022 (495 and 464 publications, respectively), with no substantial decline, indicating that this topic has remained a long-term and stable research hotspot in oral and maxillofacial medicine.

The compound annual growth rate (CAGR) was used to quantify the long-term growth trend of publication output. The calculation formula is as follows (Eqn. 1):

$$CAGR = \left(\frac{N_{end}}{N_{start}}\right)^{\frac{1}{Y_{end} - Y_{start}}} - 1 \qquad (1)$$

N_{start} denotes the number of publications in the starting year (2016, N_{start} = 293) and N_{end} denotes the number of publications in the ending year (2025, N_{end} = 722), while Y_{start} and Y_{end} refer to the corresponding years. The resulting CAGR for the period 2016–2025 was 10.54%, which far exceeds the long-term global average CAGR of 4.10% for all scientific research [37], indicating a steady annual growth in research activity within the field. The total annual citation frequency also increased rapidly, peaking in 2025 alongside publication output. Both metrics declined sharply in 2026; however, this is attributed to incomplete coverage of the full year at the time of data retrieval, resulting in incomplete dataset capture.

3.2 Analysis of countries/regions

In terms of global publication output (Table 1), the United States ranked first worldwide with 904 publications, making it the most productive country in this field. Brazil (697 publications) and China (650 publications) ranked second and third, respectively, placing them among the top three contributing

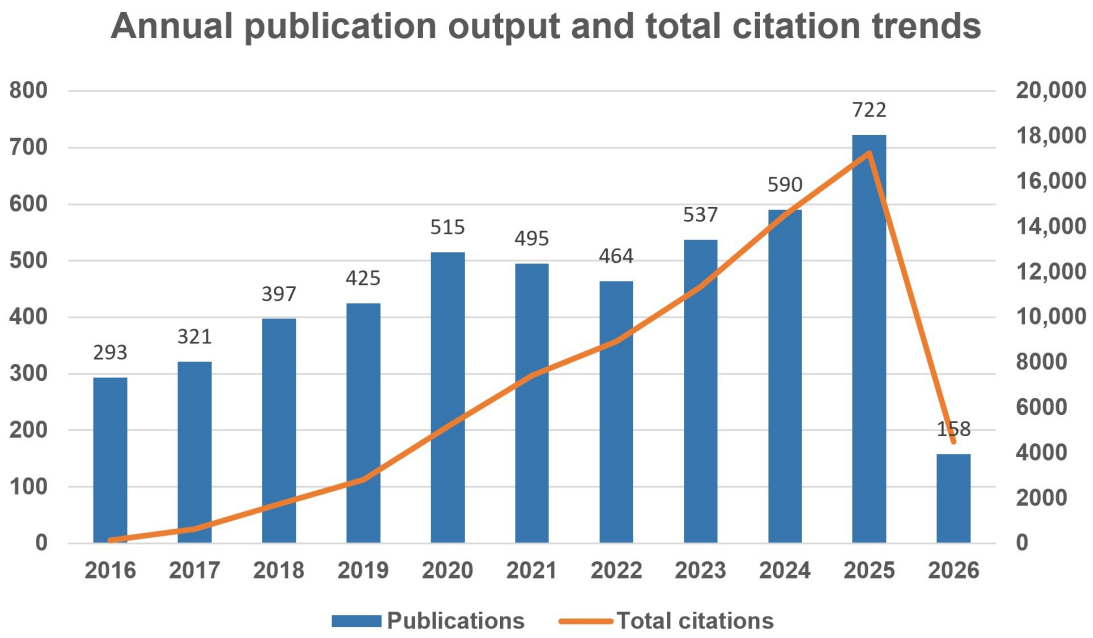


FIGURE 2. Annual publication output and total citation trends. Blue bars represent the annual number of publications, and the orange line indicates the corresponding total annual citations. Note that data for 2026 are incomplete because it is early in the year, reflecting only partial publication and citation counts.

TABLE 1. Top 10 countries/regions in global publication output.

Rank	Countries/Regions	Articles Numbers	Total Citations	Average Citation	H-index
1	USA	904	19,482	21.55	57
2	BRAZIL	697	10,902	15.64	45
3	PEOPLES R CHINA	650	7550	11.62	37
4	ITALY	442	10,310	23.33	53
5	SWEDEN	311	6944	22.33	40
6	GERMANY	211	4226	19.12	31
7	CANADA	220	7355	33.43	38
8	SPAIN	216	3421	15.84	32
9	POLAND	210	3348	15.94	28
10	NETHERLANDS	206	5666	27.5	38

countries. This ranking aligns with the sector size distribution shown in the international collaboration chord diagram (Fig. 3).

Significant differences in research quality and academic impact were observed among leading countries. Canada had the highest average citations per article (33.43) among all surveyed countries. At the national level, aggregated citation indicators can serve as proxy measures of research impact and scientific performance, as indicated in previous studies [38]. In contrast, the United States ranked first in terms of national aggregated H-index (57). The national aggregated H-index enables cross-country comparison of highly cited publications and provides an indication of overall research influence and scientific performance. Its robustness across different databases further supports its suitability for comparative assessment at the country level [39], suggesting relatively strong and balanced scientific research capabilities in the United States. China demonstrated rapid growth in publication output; however, its relatively lower average citations per article (11.62) and national aggregated H-index (37) among high-output countries may reflect differences in citation impact and research visibility rather than intrinsic research quality. Future research may further focus on enhancing international visibility and scientific impact [38, 39]. Notably, highly cited publications do not necessarily reflect higher research quality, as citation counts may be influenced by methodological limitations or topic popularity. Empirical evidence shows that citations are only weakly associated with independent indicators of research quality, including reproducibility and statistical rigor [40]. Therefore, citation-based metrics should be interpreted with caution.

The countries/regions collaboration network (Fig. 4) shows that the United States had the highest centrality (0.29) and has established extensive international collaborations with most

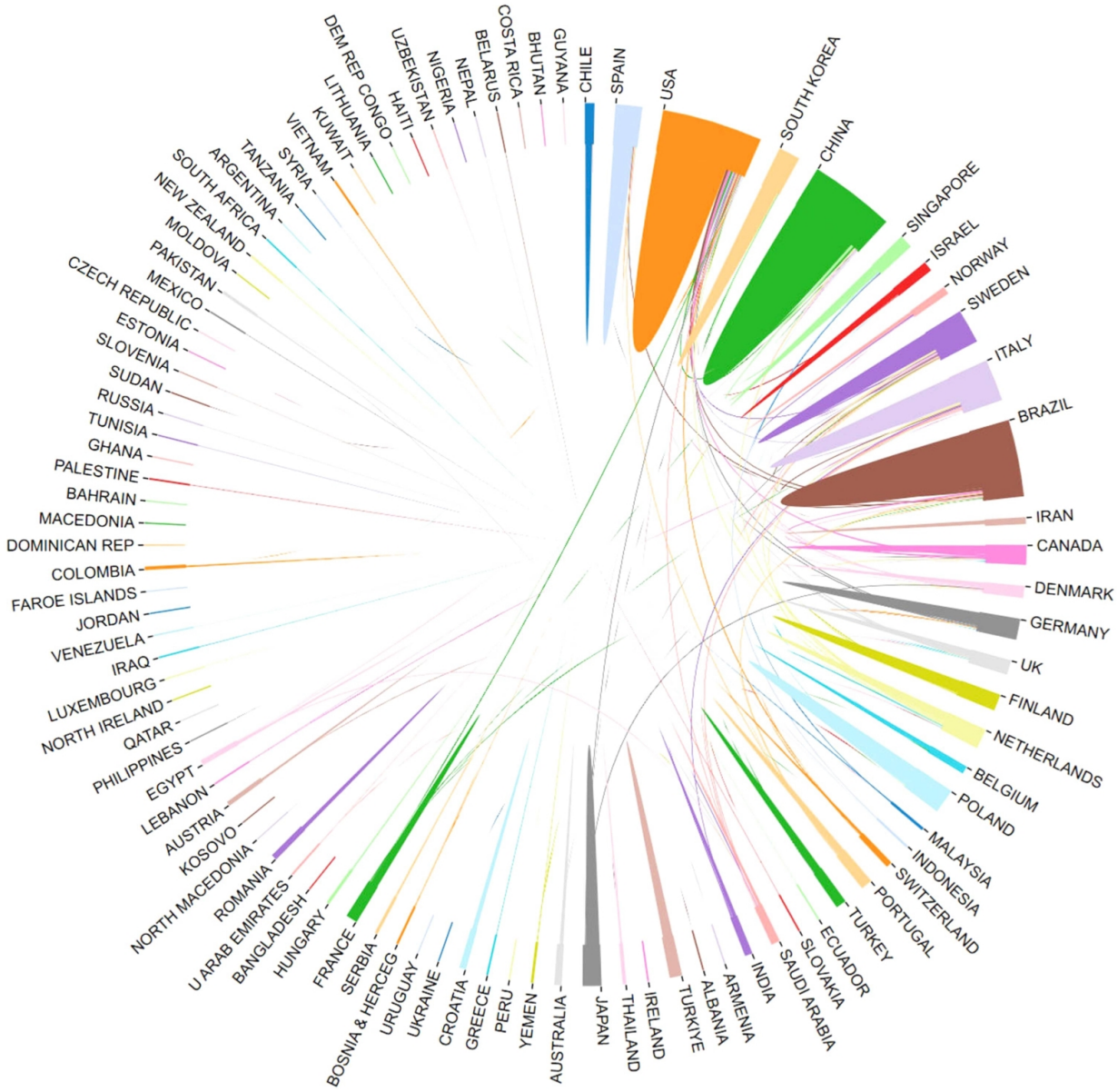


FIGURE 3. Chord diagram of international collaboration. This chord diagram illustrates the distribution of publications across countries/regions. The arc length (or sector size) of each country represents its total publication output, and the connecting lines illustrate the collaborative relationships between countries.

countries worldwide. The global publication distribution map (Fig. 5) further indicates an uneven geographical distribution of research activity, with outputs highly concentrated in North America, East Asia, Europe, and Brazil in South America, while research activity remains very limited or absent in Africa, Central Asia, and Russia.

3.3 Author analysis

In terms of core author rankings (Table 2), Lobbezoo F ranked first globally with 120 publications. Although Ohrbach R ranked fourth in publication output, he had the highest average citations per article (49) and the highest H-index (33), indicating consistently high-quality research outputs and strong long-term academic influence.

The author collaboration network (Fig. 6) shows that Lobbezoo F (yellow cluster), Svensson P (dark blue cluster), Manfredini D (orange cluster), and Ohrbach R (light blue cluster) serve as central nodes in the network. These authors represent the largest nodes within their respective clusters and exhibit the highest total link strength, acting as key hubs in the global academic collaboration system. Collaboration within each cluster is dense and strongly interconnected.

The author's burst analysis map (Fig. 7) identifies key influential researchers and emerging hotspots within specific time periods. Minervini Giuseppe ranked first globally with a burst strength of 12.38, with a citation burst period from 2023 to 2024. Xiong Xin ranked third with a burst strength of 7.48 and has shown the most significant recent increase in attention among researchers in this field. His burst period extends to 2026, suggesting that his research direction may remain influential in the future.

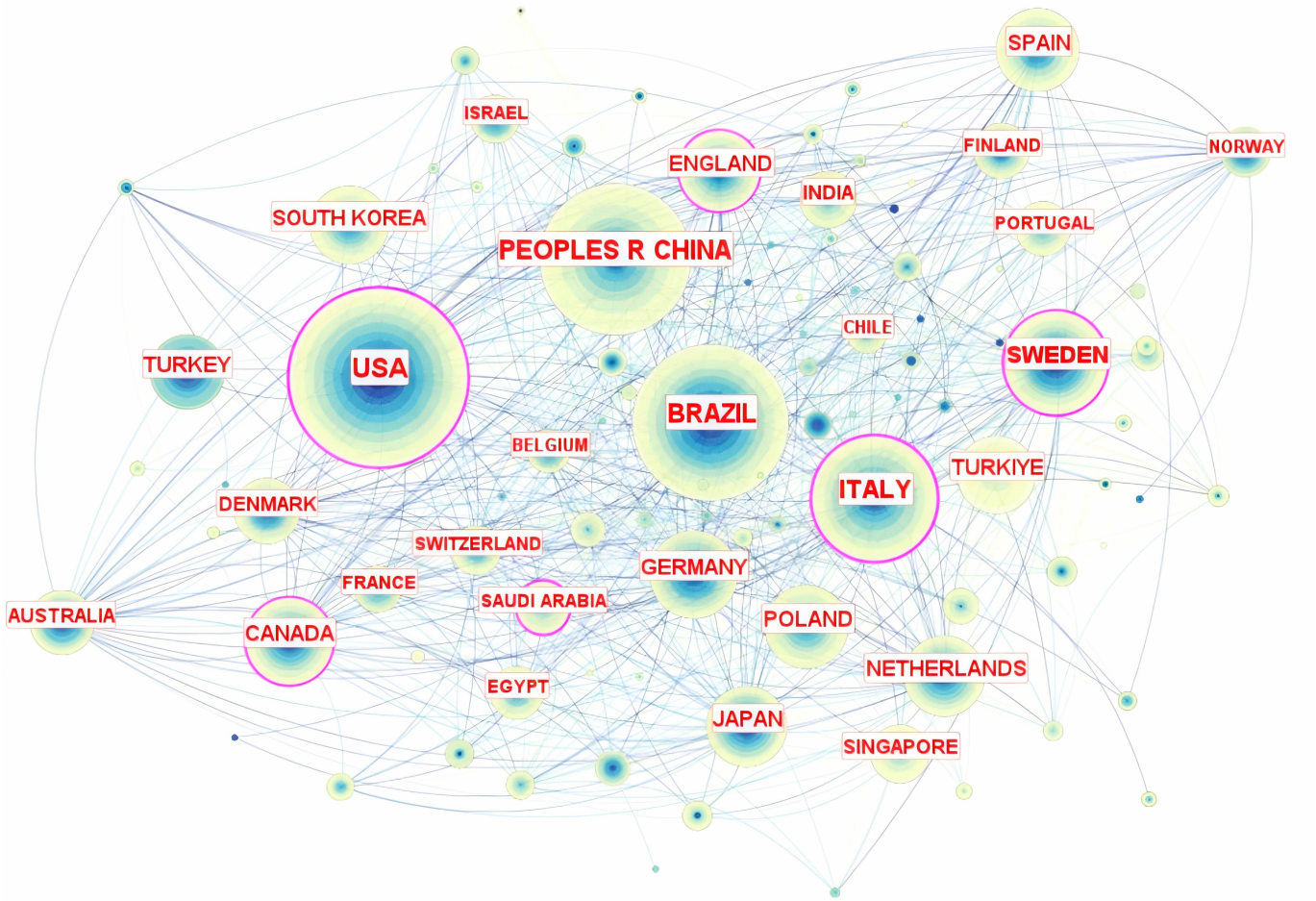


FIGURE 4. Countries/regions collaboration network map. This network visualisation depicts the research collaboration relationships among contributing countries/regions. Nodes represent individual countries/regions, with node size corresponding to the total number of publications. Links between nodes indicate collaborative relationships, where line thickness reflects the strength of cooperation. The purple rings around some nodes represent betweenness centrality; thicker rings indicate higher centrality, identifying these countries as key hubs in the international collaboration network.

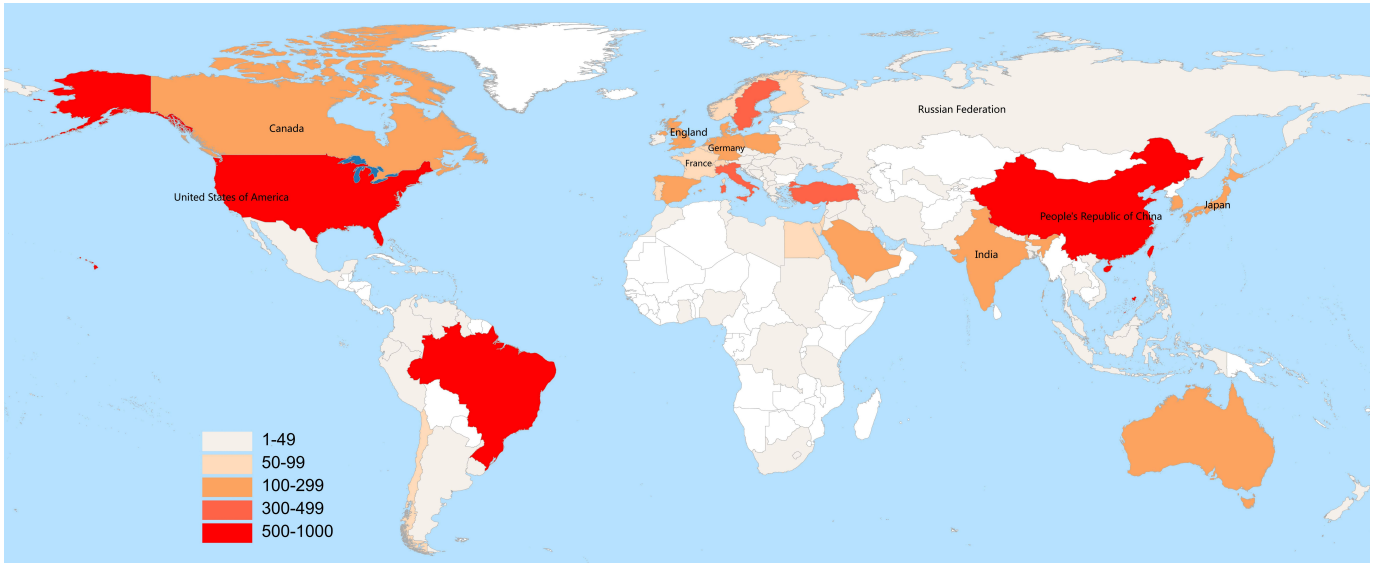


FIGURE 5. Global distribution of publications by countries/regions. This world map visualises the distribution of included publications across countries/regions. Colour intensity corresponds to publication volume: light beige (1–49 publications), light orange (50–99), orange (100–299), red-orange (300–499), and deep red (500–1000).

TABLE 2. Top 10 influential authors by publication output.

Rank	Authors	Articles Number	Total Citations	Average Number of Citation	H-index
1	Lobbezoo F	120	4632	38.6	31
2	Svensson P	81	3184	39.31	24
3	Manfredini D	79	3521	44.57	29
4	Ohrbach R	76	3724	49	33
5	Yap AU	72	878	12.19	19
6	Xiong X	65	417	6.42	12
7	Conti PCR	62	1541	24.85	23
8	Visscher CM	62	1608	25.94	22
9	Michelotti A	50	2250	45	24
10	Durham J	46	1629	35.41	20

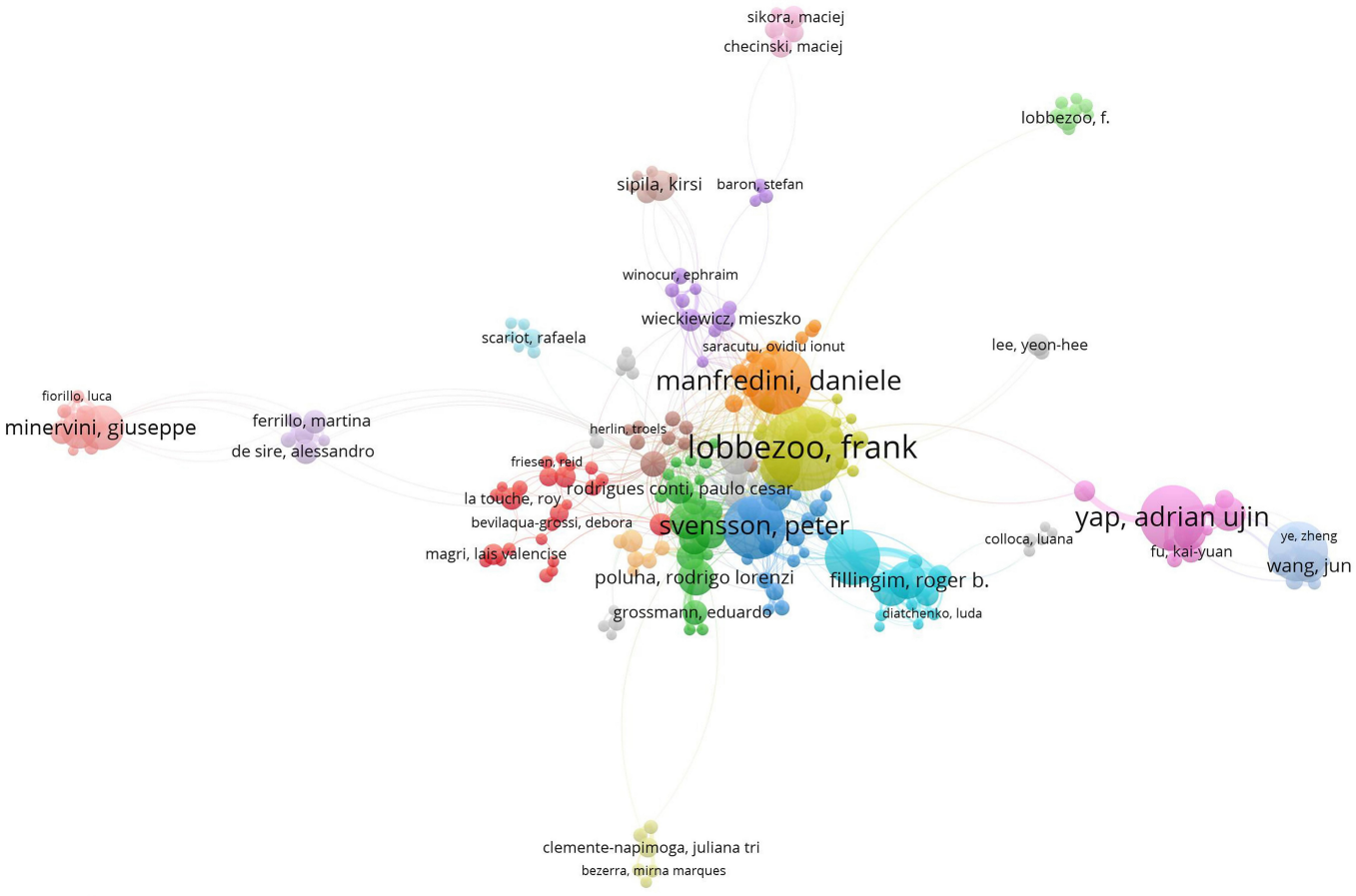


FIGURE 6. Authors collaboration clustering map. This network visualisation depicts the co-authorship relationships among contributing authors. Nodes represent individual authors, with node size corresponding to the total number of publications by each author. Links between nodes indicate collaborative relationships, where line thickness reflects the strength of co-authorship. Authors are grouped into thematic clusters, with each cluster assigned a distinct colour.

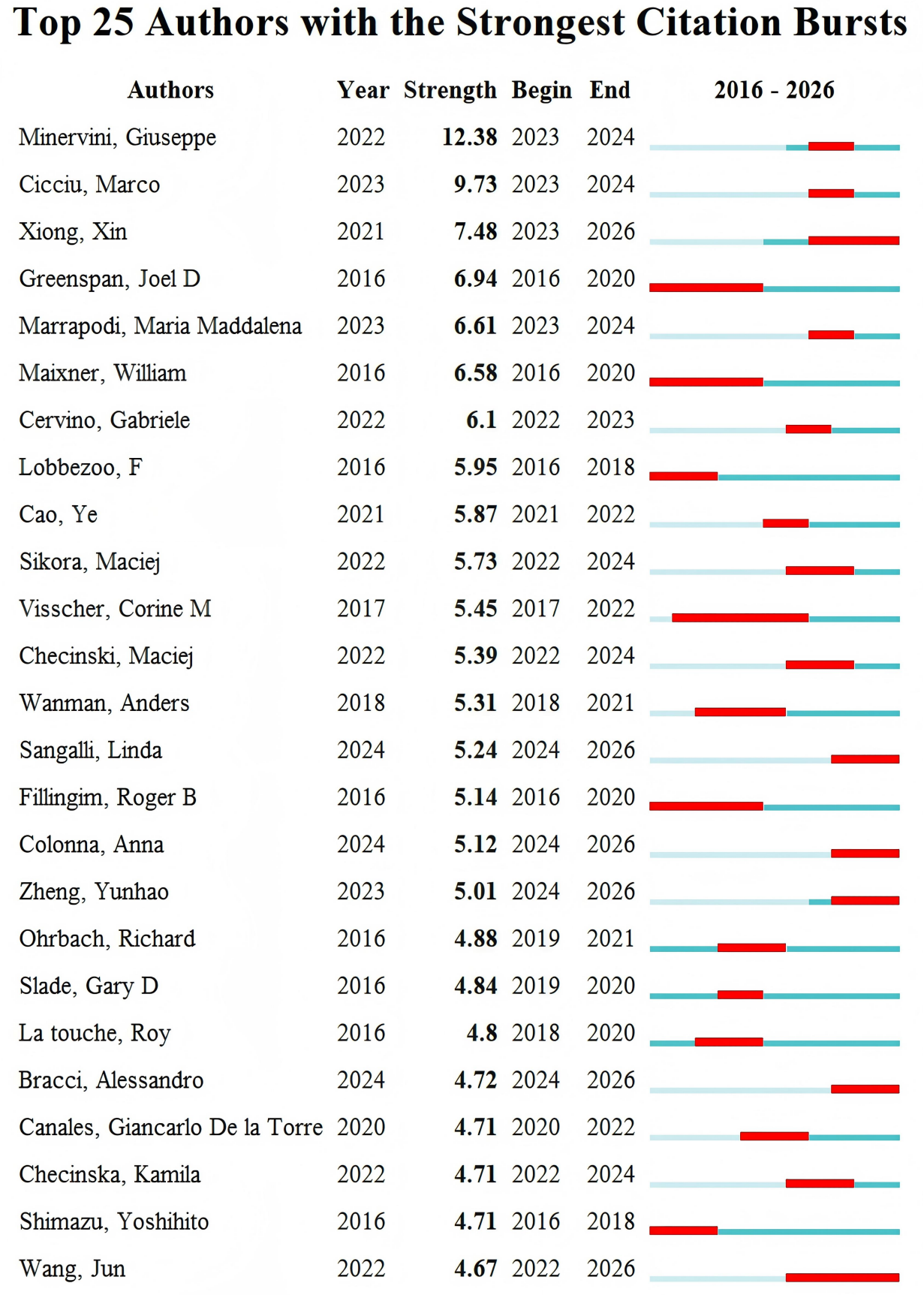


FIGURE 7. Top 25 authors with strongest citation bursts. This figure presents the top 25 authors with the highest citation burst strength between 2016 and 2026. For each author, the publication year of their burst-triggering work, burst strength value, and the start and end years of the burst period are presented. The horizontal timeline visualizes the duration of each citation burst, where blue segments indicate periods of stable citation activity and red segments represent the burst periods.

3.4 Journal analysis

In terms of journal publication output (Table 3), the Journal of Oral Rehabilitation ranked first in the field with 519 publications and an impact factor (IF: 4.0), indicating its leading position and high academic impact and recognition in this area. It was followed by CRANIO: The Journal of Craniomandibular & Sleep Practice with 323 publications, while the Journal of Oral Facial Pain and Headache ranked third with 225 publications. The remaining journals in the ranking are authoritative multidisciplinary journals, including craniomaxillofacial surgery, oral surgery, oral clinical research, and general clinical medicine.

Notably, the Journal of Oral Facial Pain and Headache ranked third in publication output, highlighting that the mechanisms and clinical management of orofacial pain represent core research hotspots in this field.

3.5 Institution analysis

In terms of global institutional publication rankings (Table 4), Universidade de São Paulo ranked first worldwide in this field with 233 publications. Sichuan University ranked sixth globally with 122 publications, serving as a leading institution in China in this research area. However, Universidade de São Paulo showed a relatively low average citations per article (15.48), indicating room for improvement in research quality. Similarly, although Sichuan University showed rapid growth in publication output, its relatively low average citations per article (11.34) and H-index (18) suggest a comparatively low academic impact among the top ten institutions worldwide. Future efforts should focus on improving research quality, strengthening international collaboration, and achieving a better balance between quantity and quality. Among the top ten institutions globally, only these two are from developing countries, while the remaining institutions are all based in developed countries. Notably, two institutions from the United States—the State University of New York (SUNY) System and the University at Buffalo SUNY—ranked at the lower end of the top ten in publication output but exhibited relatively higher average citations per article (36.39 and 38.37, respectively), suggesting higher citation impact compared with their publication volume.

The institutional collaboration network (Fig. 8) shows dense and highly interconnected collaborations among major global institutions. The University of Amsterdam, Malmö University, and Vrije Universiteit Amsterdam exhibited prominent purple rings, with centrality values of 0.22, 0.20, and 0.17, respectively. Although Universidade de São Paulo (centrality = 0.10) had the largest node size and the highest publication output, its relatively low network centrality suggests a research model characterized by high productivity but limited cross-institutional and international collaboration.

3.6 Funding analysis

This study analysed the distribution of publications supported by major global funding agencies in this field. As shown in Fig. 9, the United States occupies a dominant position in global research funding. Several funding entities within the United States Department of Health and Human Services (HHS) system ranked among the top ten worldwide, including HHS (285 publications), the National Institutes of Health (NIH; 281 publications), and the NIH National Institute of Dental and Craniofacial Research (NIDCR; 132 publications). Notably, these entities represent different administrative levels within the same funding hierarchy, with NIH operating under HHS and NIDCR being an institute within NIH. Therefore, these funding sources should be interpreted as components of the broader HHS funding system rather than completely independent funding agencies.

The National Natural Science Foundation of China (NSFC) supported 238 publications, ranking third globally and accounting for approximately 37% of China's total publications in this field. This reflects the steadily increasing funding support from China's national science foundation in this area, which is consistent with the previously observed trend that

TABLE 3. Top 10 journals by publication output.

Rank	Journals	Articles Numbers	IF as of 2024–2025
1	JOURNAL OF ORAL REHABILITATION	519	4.0
2	CRANIO THE JOURNAL OF CRANIOMANDIBULAR SLEEP PRACTICE	323	1.9
3	JOURNAL OF ORAL FACIAL PAIN AND HEADACHE	225	2.4
4	JOURNAL OF CLINICAL MEDICINE	158	2.9
5	BMC ORAL HEALTH	139	3.1
6	JOURNAL OF ORAL AND MAXILLOFACIAL SURGERY	137	2.6
7	JOURNAL OF CRANIO MAXILLOFACIAL SURGERY	105	2.1
8	INTERNATIONAL JOURNAL OF ORAL AND MAXILLOFACIAL SURGERY	103	2.7
9	CLINICAL ORAL INVESTIGATIONS	98	3.1
10	ORAL SURGERY ORAL MEDICINE ORAL PATHOLOGY ORAL RADIOLOGY	77	1.9

IF: impact factor.

TABLE 4. Top 10 influential institutions by publication output.

Rank	Institutions	Articles Numbers	National Affiliations	Total Citations	Average Citation	H-index
1	UNIVERSIDADE DE SAO PAULO	233	BRAZIL	3608	15.48	30
2	VRIJE UNIVERSITEIT AMSTERDAM	164	NETHERLANDS	4989	30.42	35
3	MALMO UNIVERSITY	161	SWEDEN	3524	21.89	31
4	UNIVERSITY OF AMSTERDAM	159	NETHERLANDS	4826	30.35	34
5	KAROLINSKA INSTITUTET	122	SWEDEN	3554	29.13	28
6	SICHUAN UNIVERSITY	122	CHINA	1384	11.34	18
7	AARHUS UNIVERSITY	117	DENMARK	3340	28.55	29
8	NATIONAL UNIVERSITY OF SINGAPORE	106	SINGAPORE	1767	16.67	22
9	STATE UNIVERSITY OF NEW YORK SUNY SYSTEM	100	UNITED STATES	3639	36.39	33
10	UNIVERSITY AT BUFFALO SUNY	94	UNITED STATES	3607	38.37	33

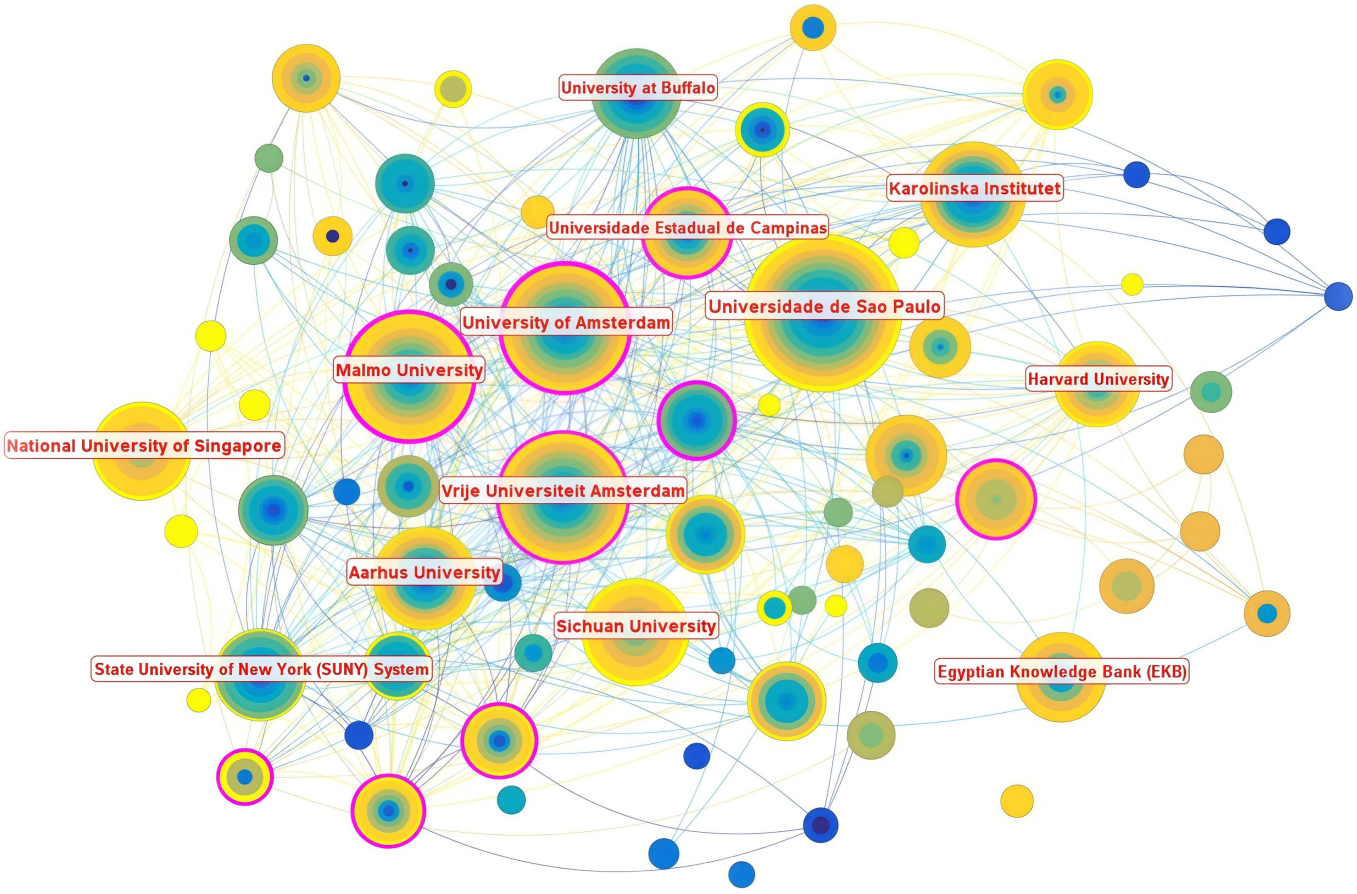


FIGURE 8. Institutions collaboration network map. This network visualisation illustrates the co-authorship relationships among contributing institutions. Nodes represent individual institutions, with node size corresponding to the total number of publications. Links between nodes indicate collaborative relationships, where line thickness reflects the strength of cooperation. The purple rings around some nodes represent betweenness centrality; thicker rings indicate higher centrality, identifying these institutions as key hubs in the research collaboration network.

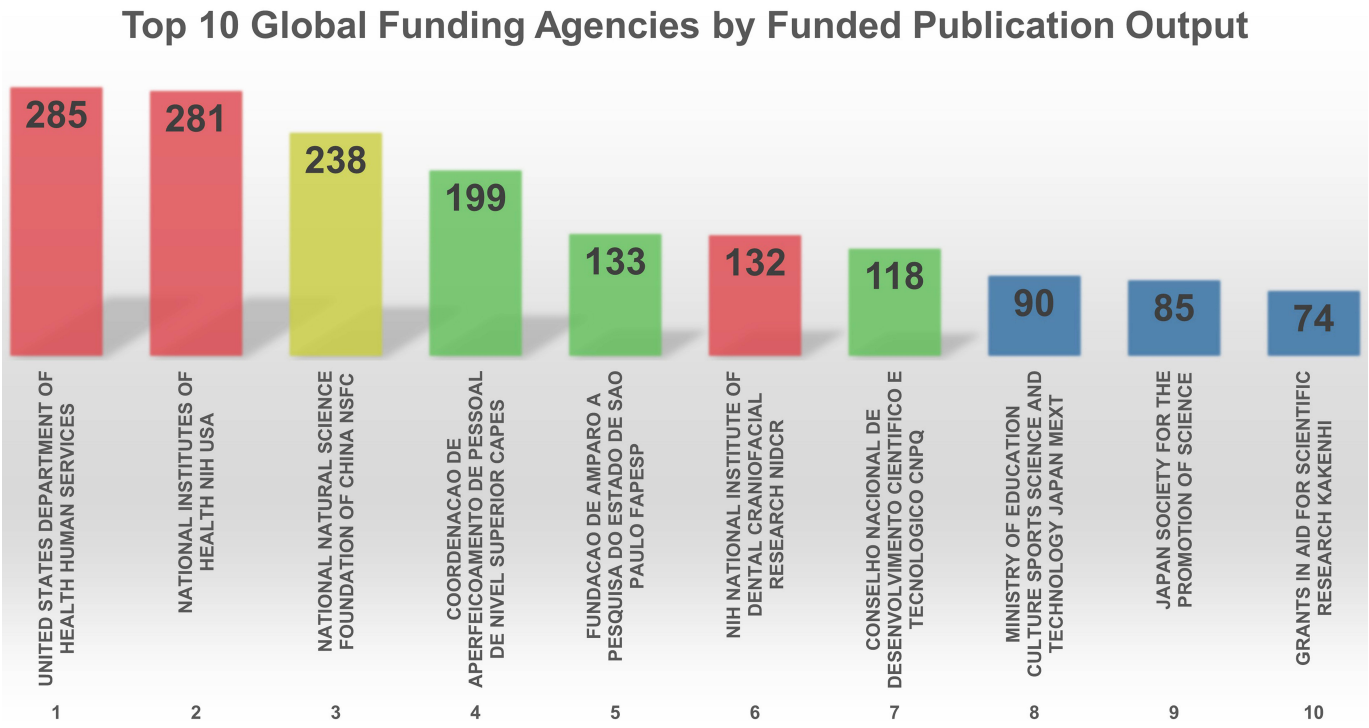


FIGURE 9. Top 10 global funding agencies by funded publication output. Bar height represents the total number of supported publications. Colours indicate funding countries: red—United States; yellow—China; green—Brazil; blue—Japan.

Chinese institutions are among the global leaders in publication output.

3.7 Keyword analysis

Keyword frequency reflects research trends in a specific field and indicates increasing research attention [41]. As shown in Fig. 10, "temporomandibular disorders" was the most frequently occurring keyword (1624 occurrences), followed by "pain" (1208 occurrences) and "orofacial pain" (812 occurrences), which is consistent with the search strategy used in this study.

A total of 11,399 original keywords were identified. After setting the minimum occurrence threshold at 72, 100 high-frequency keywords were retained for analysis. As shown in Fig. 11, the research content was divided into four major clusters, with strong interconnections among them, indicating a high level of interdisciplinarity. Cluster 1 (red) represents a cluster of pain assessment and comorbidity research. Cluster 2 (green) represents temporomandibular joint structural disorders and diagnostic studies. Cluster 3 (blue) represents epidemiological characteristics, risk factors, and psychological comorbidities. Cluster 4 (yellow) represents clinical treatment, rehabilitation, and evidence-based interventions. Representative keywords are listed in Table 5.

The keyword burst analysis map (Fig. 12) reveals temporal changes in research hotspots. Based on burst strength ranking, "follow-up" (10.87) and "risk factors" (9.57) were major research hotspots during 2016–2019, indicating that early studies primarily focused on long-term prognosis and risk factor analysis. In recent years, keywords such as "artificial intelligence" (7.75), "pain management" (7.23), "etiology" (5.97), and "oral behaviors" (5.05) have shown strong burst signals, suggesting that research is progressively shifting toward multifactorial integration, personalized medicine, and intelligent diagnosis and treatment.

The keyword timeline view (Fig. 13) further reveals the dynamic evolution of research themes, identifying five major clusters: "#0 temporomandibular joint", "#1 temporomandibular disorders", "#2 myofascial pain", "#3 chronic pain", and "#4 replacement". From 2016 to 2019, keyword nodes across all five clusters were densely distributed, indicating a period of increased research activity and diversification of thematic subtopics within the field.

Over time, clusters #3 and #4 contained fewer nodes than the other clusters, suggesting that recent research hotspots remain primarily concentrated in the first three clusters. For example, topics such as artificial intelligence (AI) in cluster #0 and oral behaviors in cluster #1 continue to receive sustained attention.

The keyword prediction map (Fig. 14) shows the observed frequencies of selected high-frequency keywords from 2020 to 2025, as well as their projected trends after 2026. The results indicate an increasing trend for "anxiety", suggesting that psychological factors may play an increasingly important role in TMD research. In addition, "diagnostic criteria" and "validity" are also predicted to increase, indicating that future studies may further emphasize the standardization of diagnostic criteria and the assessment of research reliability, with a gradual shift toward standardized measurement systems.

4. Discussion

4.1 Research trends

The number of publications in the field of TMDs and associated pain has shown an upward trend (Fig. 2), indicating a sus-

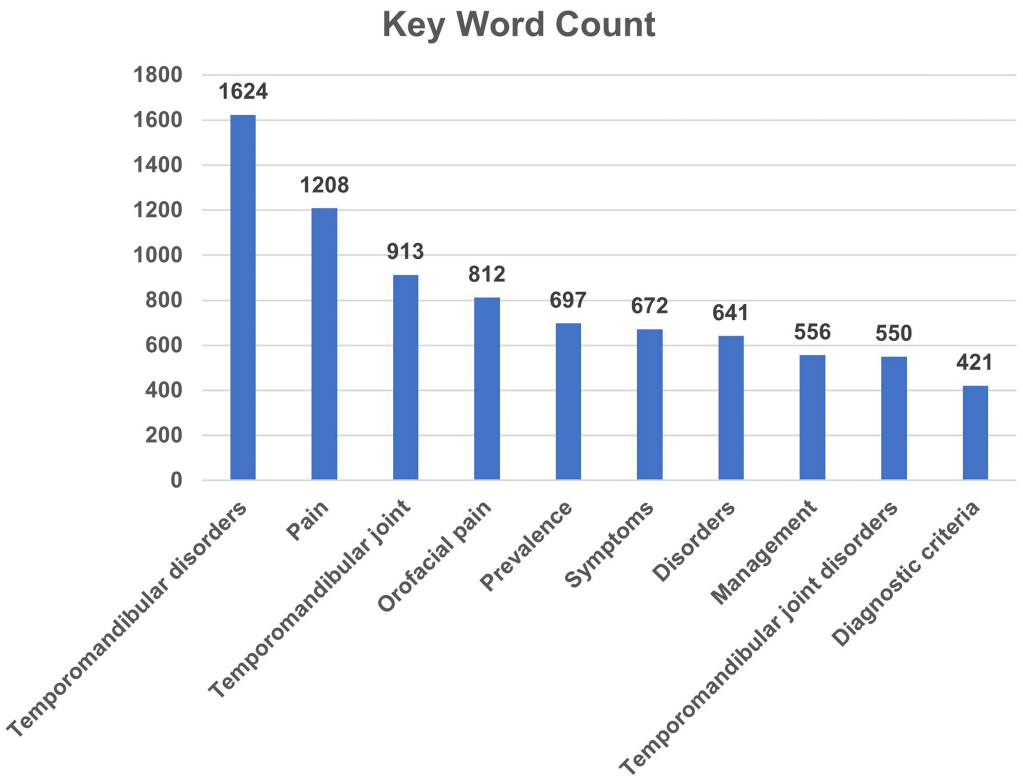


FIGURE 10. Top 10 high-frequency keywords. This bar chart shows the frequency of the top 10 keywords identified in the included literature. The horizontal axis represents the keywords, and the vertical axis indicates the number of occurrences.

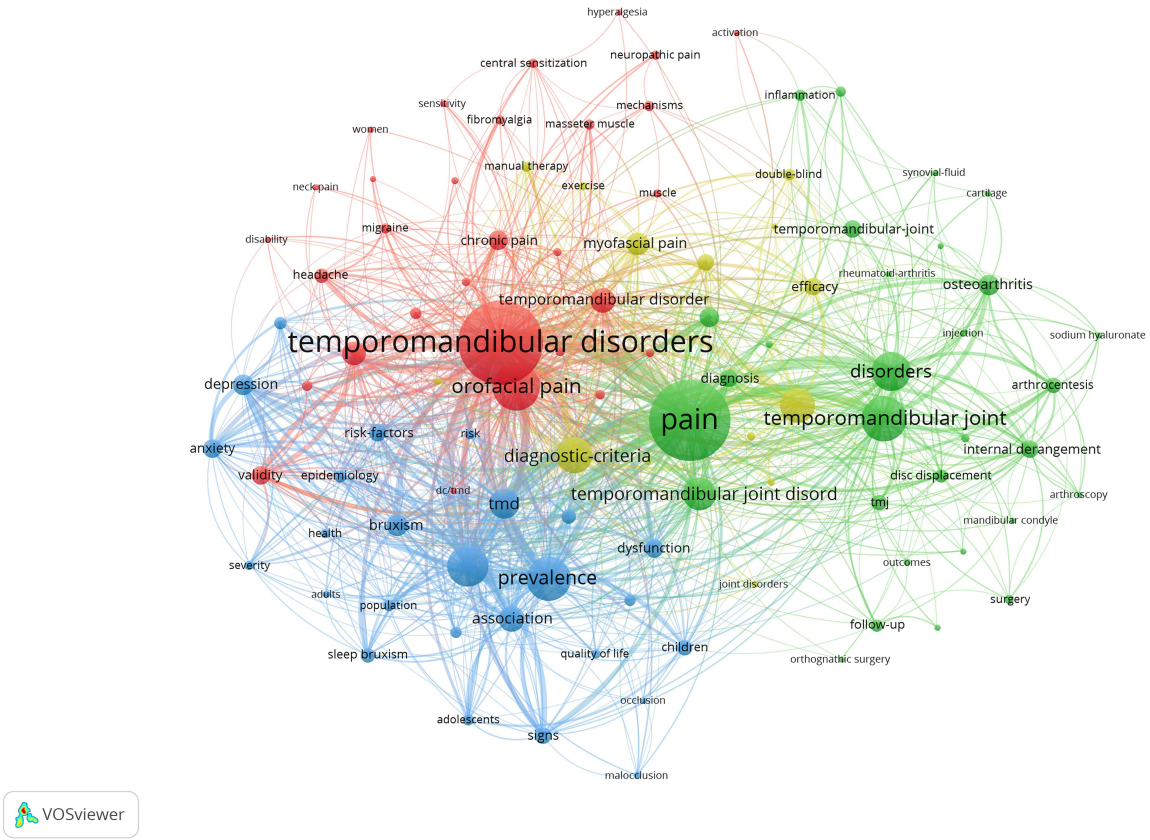


FIGURE 11. Keywords collaboration clustering map. This network map visualises keyword co-occurrence relationships. Each node represents a keyword, with node size indicating its frequency of occurrence in the literature. Node colours denote distinct thematic clusters, and connecting lines reflect the co-occurrence strength between keywords. The analysis identifies four main thematic clusters in the network.

TABLE 5. Top 10 keywords of each cluster.

Keywords	Cluster	Links	Total Link Strength	Occurrences	Average Publication Year	Average Citations	Average Normalized Citations
Cluster 1							
Temporomandibular disorders	1	99	7675	1624	2021.6492	15.6123	1.1441
Orofacial pain	1	98	4117	812	2021.7245	15.4145	1.1642
Temporomandibular disorder	1	99	1792	387	2021.7494	15.7364	0.9753
Reliability	1	94	2044	367	2021.5886	16.2888	1.0441
Chronic pain	1	97	1372	290	2021.3966	21.4655	1.2800
Validity	1	87	1643	276	2021.8623	20.1196	1.2975
Headache	1	85	1127	205	2020.9854	17.1512	1.0253
Facial pain	1	91	798	158	2021.2089	16.0443	1.0984
Migraine	1	82	745	140	2020.95	16.8857	1.0190
Cluster 2							
Pain	2	99	7028	1208	2021.6966	13.7689	1.0256
Temporomandibular joint	2	99	3272	772	2021.6049	14.1127	0.9687
Disorders	2	99	2989	643	2021.535	12.6081	0.8435
Temporomandibular joint disorders	2	98	2528	534	2022.1423	13.0449	1.0317
Osteoarthritis	2	95	1394	309	2021.6667	17.3042	1.1704
Joint	2	97	1572	289	2021.1834	14.4983	0.9283
Diagnosis	2	97	1235	261	2021.6513	13.1341	0.8221
Internal derangement	2	89	1286	259	2021.3938	16.8842	1.1771
Temporomandibular-joint	2	89	808	250	2021.2000	12.4640	0.7352
Arthrocentesis	2	84	1081	229	2021.7817	15.4498	1.1535
Cluster 3							
Prevalence	3	99	4323	746	2021.5496	16.6421	1.0965
Symptoms	3	99	4152	684	2021.1594	18.3977	1.096
TMD	3	98	2694	482	2021.5622	17.0332	1.2669
Association	3	96	2293	390	2021.6333	19.6564	1.2438
Bruxism	3	92	1850	329	2021.8784	20.6505	1.5875
Depression	3	94	1905	307	2021.456	18.6221	1.2411
Dysfunction	3	94	1597	281	2021.1388	16.2776	1.1103
Anxiety	3	90	1642	265	2022.0566	16.0075	1.3303
Risk-factors	3	94	1532	259	2020.4208	27.8378	1.3442
Signs	3	90	1617	244	2021.0123	19.9713	1.2460
Cluster 4							
Diagnostic-criteria	4	97	3147	591	2022.0491	13.3249	1.1506
Management	4	99	2708	572	2021.8147	13.9441	1.0141
Myofascial pain	4	96	1749	341	2021.2405	17.8974	1.1598
Efficacy	4	96	1261	248	2021.7218	15.6532	1.0660
Therapy	4	96	1094	235	2021.6383	13.0511	0.9253
Double-blind	4	85	735	156	2021.5513	17.8077	1.2054
Manual therapy	4	84	763	134	2022.2388	15.7388	1.2290
Systematic review	4	91	573	107	2022.2056	26.5047	1.7964
Exercise	4	86	585	106	2021.6604	16.2547	1.2179
Occlusal splint	4	78	492	95	2022.0211	12.7684	1.1543

TMD: temporomandibular disorders.

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2016 - 2026
follow-up	2016	**10.87**	2016	2018	
risk-factors	2016	**9.57**	2016	2019	
mendelian randomization	2024	**9.47**	2024	2026	
oppera prospective cohort	2016	**9.4**	2016	2018	
artificial intelligence	2024	**7.75**	2024	2026	
pain management	2018	**7.23**	2024	2026	
research diagnostic criteria	2016	**6.97**	2016	2018	
trigger points	2016	**6.93**	2021	2023	
facial-pain	2016	**6.91**	2016	2018	
randomized clinical trial	2016	**6.42**	2016	2018	
population	2016	**6.27**	2016	2017	
clinical-trial	2018	**6.2**	2018	2020	
etiology	2023	**5.97**	2023	2026	
rheumatoid-arthritis	2016	**5.8**	2016	2019	
sex-differences	2017	**5.51**	2017	2018	
treatment need	2016	**5.44**	2016	2018	
pressure pain	2016	**5.36**	2016	2019	
oral parafunctions	2016	**5.27**	2016	2019	
proinflammatory cytokines	2017	**5.24**	2017	2019	
joint disorders	2017	**5.21**	2023	2024	
range	2023	**5.12**	2023	2026	
reduction	2018	**5.12**	2022	2023	
closed lock	2016	**5.11**	2016	2018	
hospital anxiety	2020	**5.05**	2020	2021	
oral behaviors	2021	**5.05**	2024	2026	

FIGURE 12. Top 25 keywords with the strongest citation bursts. This figure presents the top 25 keywords with the strongest citation burst strength. For each keyword, the table lists its year of first occurrence, burst strength, and the start and end years of the burst period. The horizontal timeline visualises the duration of each burst, where blue segments indicate periods of stable citation activity and red segments mark the burst periods.

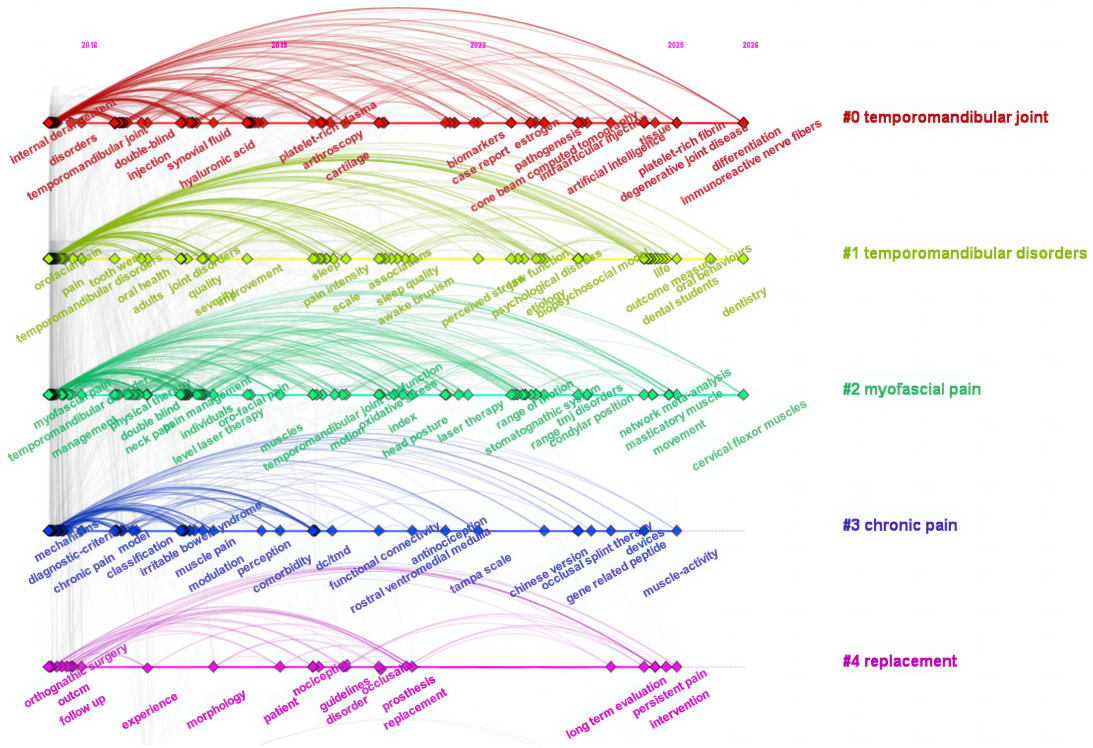


FIGURE 13. Timeline view of keyword clusters. This timeline map visualises the evolution of keyword clusters over time. Each coloured line represents a distinct thematic cluster, including #0 temporomandibular joint, #1 temporomandibular disorders, #2 myofascial pain, #3 chronic pain, and #4 replacement. The horizontal axis represents the publication year, and the diamonds represent individual keywords, with their positions indicating their emergence period. The connecting lines illustrate the thematic continuity and evolution within each cluster, revealing how research topics have developed and expanded over the years.

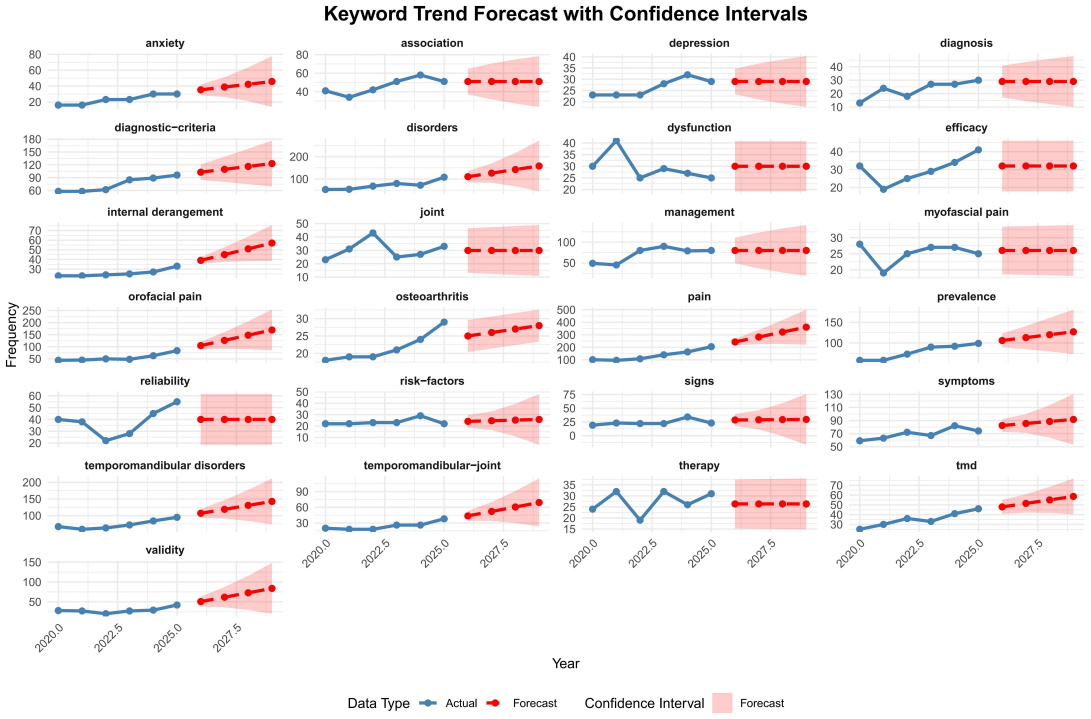


FIGURE 14. Keyword trend forecast with confidence intervals. The figure presents time-series frequency trends and future forecasts for selected core keywords in the field. Blue lines represent the actual observed frequency of each keyword from 2020 to 2025. Red points and lines show the predicted frequency trends from 2026 to 2028, with shaded pink areas indicating the 95% confidence intervals of the forecasts.

tained increase in research interest. This trend may be related to the growing clinical demand for the diagnosis and treatment of TMJ disorders, as well as greater increasing awareness of these conditions among clinicians and researchers. In addition, the integration of emerging technologies, such as AI and radiomics with dentistry has facilitated interdisciplinary collaboration, further expanding the research scope and exploratory potential of this field.

As shown in Table 1 and Fig. 9, the United States ranked first in publication output and received higher levels of government research funding than other countries. This may be attributed to the emphasis placed by the U.S. government on the development of this field, as well as growing recognition of insufficient TMD-related education in dental schools and long-standing issues such as inconsistent diagnostic criteria and heterogeneous treatment strategies [42]. China, as a developing country in Asia, ranked third in publication output; however, its relatively low average number of citations per article and H-index indicate that further efforts are needed to enhance research depth and international collaboration to improve academic impact.

Among the ten most productive research institutions worldwide (Fig. 8), Universidade de São Paulo ranked first and accounted for approximately one-third of Brazil's total publication output, making it a key institution representing Latin American scientific contributions in global academic communication. Lobbezoo F was identified as a core author in the field of TMJ-related disorders and associated pain, with a primary research focus on bruxism [43, 44].

In summary, research interest in this field continues to increase, although the global research landscape remains highly heterogeneous. Strengthening international academic exchange and interdisciplinary collaboration is therefore essential to further promote high-quality development of research in TMD and associated pain.

4.2 Keyword analysis

Based on the integrated results of keyword clustering, burst detection, and temporal evolution analyses, current research hotspots in TMD and associated pain mainly focus on two areas: (1) aetiological factors, behavioral influences, and pain management; and (2) the application of AI aimed at improving clinical diagnosis and treatment.

4.2.1 Multifactorial mechanisms and integrated management of TMD and associated pain

TMDs and associated pain represent a major research focus in orofacial medicine, with their onset and progression jointly influenced by multiple factors. From an aetiological perspective, two-sample Mendelian randomisation analyses have confirmed that malocclusion [45], sleep disorders, anxiety and depression [46, 47], smoking [48], and autoimmune diseases [49] are important risk factors for TMD [50]. In addition, oral parafunctional behaviours, such as tooth clenching and abnormal mandibular posture [51, 52], are also closely associated with the development of TMD. Among sleep-related factors, evidence supporting an association between TMD and obstructive sleep apnea remains limited [53]. However, high-quality polysomnography-based studies have shown that sleep bruxism is not significantly associated with TMD and may even exhibit a negative association, which differs markedly from findings based on self-reported or clinical assessments. Experimental studies have further demonstrated that experimentally induced TMD-like pain can reduce sleep bruxism activity, a phenomenon consistent with the pain adaptation model [54, 55], suggesting a complex bidirectional interaction between behavioral factors and pain processes.

From a clinical perspective, conservative therapy remains the cornerstone of the initial management of TMD and mainly includes physical therapy, pharmacological treatment, exercise therapy, and laser analgesia [56–60]. Notably, Engel's biopsychosocial (BPS) model [61] proposes that disease development results from the interaction of biological, psychological, and social factors, with TMD essentially reflecting an imbalance in this multidimensional regulatory system [62]. Within this theoretical framework, patients with myofascial pain syndrome, one of the major subtypes of TMD, can achieve significant pain relief following guided and self-management interventions based on the BPS model [63]. Cognitive reappraisal, as an emotion-regulation strategy, accounts for 49% of the variance in the effect size of pain relief and may alleviate TMD and associated pain via a serial mediation pathway involving anxiety and oral parafunctional behaviours, providing new mechanistic insights into psychosomatic interventions for TMD and offering an important direction for further research [64].

In summary, accumulating evidence indicates that effective management of TMD and associated pain requires the integration of multiple dimensions, including aetiological factors, behavioural patterns, and psychological status. Therefore, self-management, psychological counselling, and education [50] play crucial roles in treatment strategies for TMD [65].

4.2.2 Advances in AI-based imaging analysis and precision diagnosis of TMD

AI is a broad technological discipline in which machine learning represents a core methodology, comprising two main branches: traditional machine learning and deep learning. Deep learning, which has evolved from traditional machine learning, has become an important component of AI through the use of deep neural network architectures [66].

In the field of TMD, traditional machine learning methods, such as the Least Absolute Shrinkage and Selection Operator (LASSO) model [67], are used to build predictive models based on manually extracted clinical or imaging features, including indicators derived from Cone-Beam Computed Tomography (CBCT). These methods enable the identification of key risk factors and the screening of high-risk populations, thereby supporting early risk assessment and the development of preventive strategies.

In contrast, deep learning methods do not depend on manually engineered features and can automatically learn hierarchical image representations through multilayer convolutional architectures. These methods have been widely applied to TMJ structure segmentation, lesion classification, and the detection of disc displacement and perforation [68]. Overall, these

two approaches differ in their application domains and can be complementary.

Magnetic Resonance Imaging (MRI)-based deep learning models have shown promising performance in automated diagnostic tasks, with reported accuracies ranging from 70% to 99% [68]. Convolutional neural networks (CNNs) are the most commonly used architectures in TMJ imaging analysis, among which U-Net and UNet++ are primarily used for image segmentation tasks [68, 69]. For disc position assessment, MobileNetV2 and ResNet have demonstrated favourable performance compared with other models [70]. In MRI-based lesion analysis, ResNet-18, Inception v3, and EfficientNet-B4 have achieved accuracies ranging from 70% to 73%, together with acceptable sensitivity and specificity [71].

Additionally, Generative Adversarial Network (GAN)-based deep learning frameworks, in which TransUNet is used as the generator to synthesise T2-weighted (T2w) MRI images from proton density-weighted (PDw) images, may help reduce MRI scanning time in patients with TMD while maintaining image quality [72]. CNN-based approaches have also been applied to the automated detection of TMJ osteoarthritis (TMJOA) using CBCT images [73]. Among the different models evaluated, including Sparse Variational Autoencoder (SVA), Light Gradient Boosting Machine (LightGBM), Extreme Gradient Boosting (XGBoost), and You Only Look Once (YOLO), YOLO has shown strong performance in detection tasks. Furthermore, biomarkers are increasingly being investigated for their potential roles in the auxiliary diagnosis, disease monitoring, and personalised management of TMD [74, 75].

Compared with single-modality deep learning models, multimodal approaches have shown improved diagnostic performance. For example, in screening for TMJ degenerative osteoarthritis, the combined use of panoramic and lateral cephalometric radiographs allows integration of complementary diagnostic information from both imaging modalities, thereby improving diagnostic performance [76]. Furthermore, multimodal models that incorporate structured clinical information, such as limited mouth opening and joint clicking, together with imaging features as joint model inputs, may further enhance classification performance [77]. The integration of CBCT-based radiomics with salivary or serum biomarkers may also enable a more precise diagnosis of osteoarthritis [78].

These developments highlight an emerging trend in dental diagnostics, whereby AI may achieve diagnostic performance previously attainable only through specialist interpretation or more expensive diagnostic procedures by leveraging routinely acquired imaging data and readily available clinical indicators. However, clinical metadata cannot fully compensate for the loss of structural information caused by spatial downsampling or image cropping in imaging datasets [77]. The integration of AI with radiomics, biomarkers, and multimodal data fusion is therefore expected to become an important direction for the future precision diagnosis of TMD [79].

Furthermore, the application of AI in TMDs is not limited to imaging-based diagnosis. Some studies have used decision trees and deep neural networks (DNNs) to construct predictive models based on clinical and haematological parameters for forecasting long-term treatment outcomes in patients with TMD [80]. In addition, artificial neural networks (ANNs), combined with SHapley Additive exPlanations (SHAP)-based explainable AI methods, have been applied to identify and quantitatively analyse the key factors influencing the quality of adverse event reporting in randomised controlled trials of TMD treatment [81].

Although some studies have reported relatively high diagnostic accuracy, several limitations remain in the clinical translation of AI for TMD. AI models often function as "black boxes", making it difficult to interpret the contribution of individual features to diagnostic decisions, while small sample sizes may lead to overfitting and reduced generalisability. In addition, the lack of external validation, the limited availability of high-quality multicentre datasets, and data heterogeneity further restrict their clinical applicability [77, 78, 80]. Future studies should therefore focus on constructing large multicentre datasets, performing external validation, and applying explainable artificial intelligence (XAI) approaches to improve model robustness, generalisability, and clinical utility. Ultimately, the value of AI models depends not only on their algorithmic performance, but also on their interpretability and effective integration into clinical workflows.

5. Limitations of the study

However, several limitations should be acknowledged in this study. First, only the Web of Science database was used as a data source. Although it is highly authoritative, its coverage is limited; future studies should include searches across multi-databases to ensure more comprehensive data retrieval. Second, some recently published high-quality studies may not have been included due to indexing delays, and citation counts are time-dependent, which may affect the temporal accuracy and completeness of the findings. Third, only English-language publications were included in this study, which may lead to underrepresentation of research outputs from non-English-speaking regions and may introduce potential bias in the geographic distribution analysis.

6. Conclusions

This study shows that research on TMDs and associated pain has exhibited a continuous upward trend. The global research landscape is highly polarised, with the United States maintaining a leading position. China has a substantial publication output; however, there is still room for improvement in research depth, academic impact, and international collaboration.

Research on TMDs and associated pain is shifting from single-symptom management towards a multidimensional intervention model that integrates aetiological, behavioural, and psychological factors. At the same time, the application of AI is providing new tools and approaches for imaging diagnosis, risk prediction, and personalised intervention. In future, the integration of multifactorial management strategies with intelligent diagnostic technologies is expected to further enhance clinical outcomes and management efficiency in TMD.

AVAILABILITY OF DATA AND MATERIALS

All datasets utilised and analysed in this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

XFY, BWZ, HRC and HX—conceptualization. HRC and HX—formal analysis, visualisation, and original draft preparation. HRC and YL (0000-0001-7557-4015)—data curation. HX and YL (0000-0002-4640-3396)—software analysis. BWZ—manuscript review and editing. XFY and BWZ—funding and supervision. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

ACKNOWLEDGMENT

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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