

Analysis of Global Trends and Research Frontiers in Functional Movement Screening and Lower-Limb Neuromuscular Control Using Citespace

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How to cite this paper: Kuang, H.Y., Wang, L.H., Cao, X.A., Su, W., Li, X.R., Li, X.C. and Zhou, Y. (2026) Analysis of Global Trends and Research Frontiers in Functional Movement Screening and Lower-Limb Neuromuscular Control Using Citespace. *Journal of Biosciences and Medicines*, 14, 296-308.

<https://doi.org/10.4236/jbm.2026.1410021>

Received: August 1, 2026

Accepted: October 23, 2026

Published: October 26, 2026

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Abstract

Objective: This bibliometric study evaluates global research output, intellectual structure, and dynamic hotspots in Functional Movement Screen (FMS) and lower-limb neuromuscular control. It aims to offer quantitative evidence to advance interdisciplinary practice in orthopedic rehabilitation and sports medicine in China. **Methods:** Relevant studies (2000-2026) were extracted from the Web of Science Core Collection. CiteSpace (6.4.R1) was applied to analyze institutional, national, and author collaboration patterns, alongside keyword co-occurrence, timeline dynamics, and burst terms. **Results:** Global publication volume expanded in distinct stages over the past two decades. Geographically, the United States, China, and Australia emerged as the principal knowledge producers, with leading academic medical centers anchoring international research networks. Keyword clustering has revealed a core knowledge framework centered on dynamic joint control, dynamic balance, anterior cruciate ligament (ACL) injuries, and return to sport. Analysis of emerging terms indicates that early research was highly focused on the prediction of sports injury risk and the screening of basic movement patterns; in recent years (2020-2026), “trunk,” “muscle activation,” and “mechanisms” have emerged as high-intensity research frontiers. **Conclusion:** The global research para-

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digim has shifted from screening macro-level movement patterns to a deeper exploration of multidimensional dynamic postural control mechanisms; FMS serves as a movement-quality screening tool whose predictive validity for injury is interpreted alongside neuromuscular measures; and the coordination of the “trunk-core-lower limb” holistic kinetic chain represents an important area for future academic growth.

Keywords

Functional Movement Screening, Lower Extremities, Neuromuscular Control, Sports Injuries, Anterior Cruciate Ligament, Bibliometrics

1. Introduction

The Functional Movement Screen (FMS), first proposed by Cook *et al.* in the late 1990s, is a systematic screening tool used to assess the quality of an individual's fundamental movement patterns and to identify movement compensations, physical asymmetries, and anatomical limitations [1]. In the fields of human movement science and clinical rehabilitation, “Lower Extremity Neuromuscular Control” refers to the central nervous system's ability to coordinate the various muscle groups of the lower extremities to maintain joint dynamic stability, postural balance, and efficient energy transfer [2] [3]. Extensive clinical and sports practice has shown that inadequate lower extremity neuromuscular control, muscle imbalance, and bilateral movement asymmetry are risk factors for lower extremity sports injuries (such as anterior cruciate ligament injuries, knee dynamic instability, and ankle sprains) [4] [5]. As a qualitative and semi-quantitative method for assessing movement quality, the Functional Movement Screen (FMS) provides practical clinical insights into gross movement limitations and compensation patterns. However, while optimal movement patterns rely on neuromuscular coordination, current evidence regarding the direct predictive validity of FMS scores for lower-limb injury risk and its linear correlation with fine biomechanical or EMG parameters remains mixed and actively debated in literature [6]. Therefore, an in-depth exploration of the intrinsic relationship and synergistic application between the Functional Movement Screen and lower-limb neuromuscular control is of great significance for predicting the risk of sports injuries, conducting precise clinical rehabilitation assessments, and implementing scientifically grounded athletic training.

In recent years, interdisciplinary research on functional movement screening and lower-limb neuromuscular control has developed rapidly on the international stage, with the number of published papers showing a phased growth trend. Recent research on movement screening has transitioned from qualitative descriptions to objective, technology-driven evaluations. By leveraging electromyography (EMG), gait analysis, and biomechanical metrics, investigators can now quantify lower-limb neuromuscular control across diverse groups, including elite ath-

letes, injured individuals, and fall-prone older adults [7] [8]. Academic inquiry has concurrently broadened to examine dynamic joint instability mechanisms, post-ACL reconstruction neuromuscular adaptations, and objective criteria for return-to-sport clearance [9] [10]. However, this rapid accumulation of multi-disciplinary evidence presents a practical hurdle: the sheer volume and fragmentation of published data make it difficult for clinicians and sports scientists to map core intellectual structures or track emerging global trends efficiently.

Qualitative narrative reviews often struggle to objectively synthesize large body of literature due to their reliance on subjective interpretation. In contrast, bibliometrics applies mathematical and statistical models to deconstruct field-specific knowledge structures and map publication trends quantitatively [11]. Within this analytical framework, CiteSpace—developed by Chaomei Chen—is widely adopted for mapping domain evolution [12]. By building co-occurrence networks, temporal clusters, and citation bursts, the software allows researchers to systematically identify leading research teams, key theoretical turning points, and emerging frontiers [12]. Currently, although standalone reviews on FMS or neuromuscular control are common, there remains a relative scarcity of articles that treat the two as a symbiotic whole, adopt a global, multicenter perspective, and conduct systematic visualometric analysis and identification of cutting-edge trends in high-quality SCIE research literature spanning 26 years (2000-2026). As a result, the macro-level evolutionary trends and international cutting-edge landscape in this interdisciplinary research field remain unclear in China, which to some extent limits the innovative development of related translational medicine and rehabilitation practices domestically.

To this end, this study selected the Science Citation Index Expanded (SCIE) database from the Web of Science Core Collection as its data source and, using the CiteSpace (6.4.R1) visualization software, conducted an in-depth bibliometric analysis of global research literature published between 2000 and 2026 on functional movement screening and lower-limb neuromuscular control. By mapping collaboration networks among countries/regions, publishing institutions, and core authors, this study identifies leading global research forces; through keyword co-occurrence analysis, clustering timeline views, and emergent term detection, it maps out the core knowledge structure, analyzes the evolution of research hotspots, and focuses on predicting future academic frontiers. By quantifying global bibliometric trends, this study provides empirical groundwork to connect sports science, clinical orthopedics, and rehabilitation medicine in China. Practically, these insights can help establish localized research networks, advance behavioral movement frameworks, and guide the integration of digital health technologies for smart movement interventions.

2. Materials and Methods

2.1. Materials Source

Literature for this bibliometric analysis was retrieved from the SCIE within the

Web of Science Core Collection using the search terms below: TS = ((“Functional Movement Screen*” OR “FMS” OR “Movement Pattern*”) AND (“Lower Extremity” OR “Lower Limb” OR “Knee” OR “Ankle” OR “Hip”) AND (“Neuromuscular Control” OR “Muscle Strength” OR “Asymmetry” OR “Muscle Imbalance” OR “Stability”)) to conduct a subject-based search, covering the period from 2000 to March 30, 2026. Literature screening was conducted strictly in accordance with the inclusion and exclusion criteria, and the results were obtained through independent dual-review.

Studies were considered eligible if they met three primary criteria: 1) peer-reviewed original research or review articles published in English; 2) a explicit focus on functional movement screening, movement quality, or lower-limb neuromuscular control; and 3) evaluation of movement mechanics or injury risks across healthy individuals, athletic cohorts, or patients undergoing lower-extremity rehabilitation. Literature was screened out if it met any of the following conditions: duplicate records across search queries; non-article document types (e.g., conference proceedings, book reviews, letters, or early access notes); or publication dates falling outside the 2000-2026 threshold.

The initial database search returned 529 records. After removing 9 non-empirical publication items during preliminary data cleaning, 520 studies progressed to sequential title, abstract, and full-text evaluation. Two reviewers (H.K. and L.W.) independently assessed all records. To satisfy topical eligibility, studies had to combine movement pattern screening (such as the FMS) with lower-limb neuromuscular, postural, or biomechanical evaluations. Discrepancies during the review were settled through mutual consensus or referred to a third senior author (Y.Z.) for final decision. Following complete screening, 420 articles fulfilled all eligibility criteria and were compiled for final bibliometric mapping.

2.2. Analytical Tools

Visual mapping was performed using CiteSpace (version 6.4.R1) [13] to evaluate the structural properties and evolutionary dynamics of the domain. Author and institutional collaboration networks were constructed to identify key research clusters and cross-institutional ties. Keyword co-occurrence and thematic clustering analyses were subsequently conducted to map the core intellectual landscape and isolate research hotspots. Finally, timeline overlays were integrated with keyword burst detection to trace historical evolutionary pathways and highlight emerging frontiers.

2.3. Research Methods

Prior to network construction, retrieved bibliographic records were deduplicated and standardized according to CiteSpace operational protocols. The refined dataset was subsequently analyzed across a 2000-2026 observation window using 1-year time slices. Nodes were parameterized to represent authors, institutions, and keywords, with edge weights calculated via Cosine similarity metrics. The node

selection threshold was governed by a g-index scale factor of $K = 8$, while remaining parameters were retained at software default values. Quantitative evaluation of node centralities and inter-node connection densities enabled the mapping of foundational research teams, dominant topical clusters, and emerging development trends in functional movement screening and lower-limb neuromuscular control.

3. Results

3.1. Literature Search Results

The literature identification and selection pipeline is depicted in **Figure 1**. An initial query returned 529 records. Following preliminary data cleaning that filtered out 9 non-article items, the remaining entries underwent title, abstract, and full-text screening. This evaluation phase excluded 99 topically irrelevant studies and 1 duplicate record, leaving 420 eligible publications for bibliometric mapping.

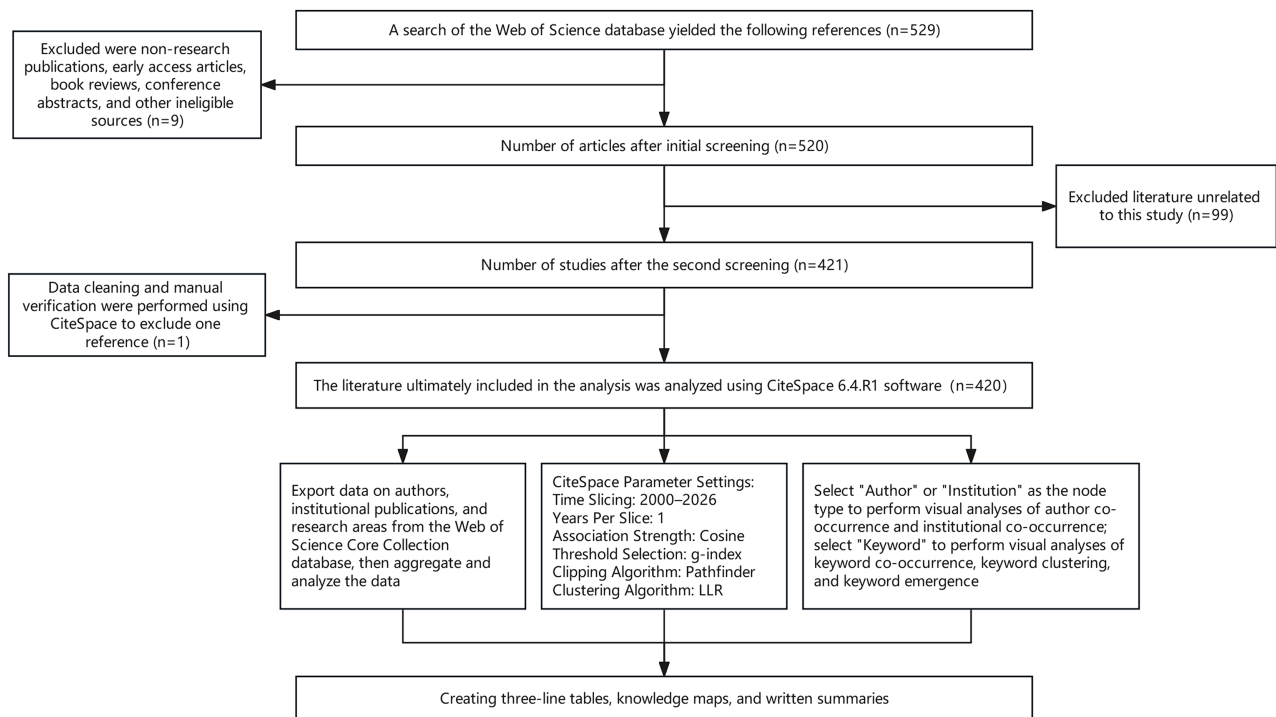


Figure 1. Flowchart of the literature screening and analysis process.

3.2. Statistics on Annual Publication Volume

Between 2000 and 2026, a total of 420 relevant studies were identified, establishing a robust literature base for domain mapping. Temporal trajectory analysis indicates that scholarly interest in functional movement screening and lower-limb neuromuscular control began accelerating around 2005, triggering a rapid expansion in both annual output and thematic scope. This expansion culminated in a concentrated publication surge from 2005 to 2015. Although annual volume sub-

sequently moderated, publishing activity has maintained a steady baseline in recent years. See **Figure 2**.

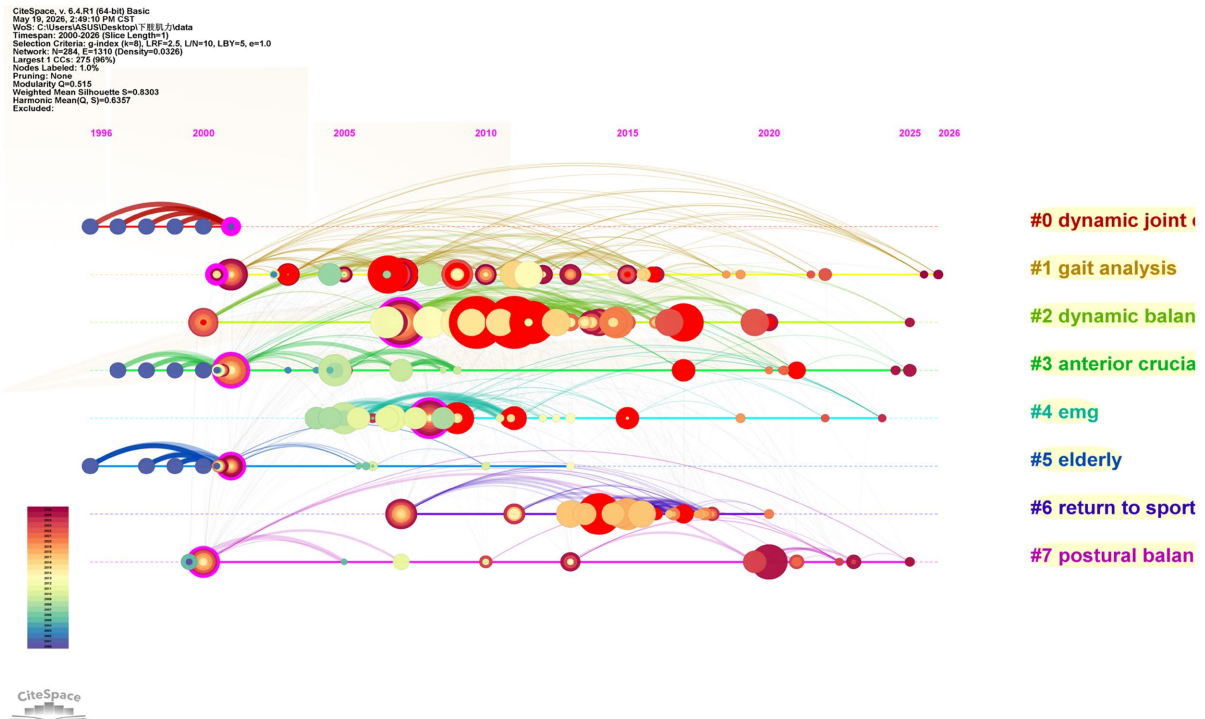


Figure 2. Trends in the number of publications on functional movement screening and lower limb neuromuscular control research.

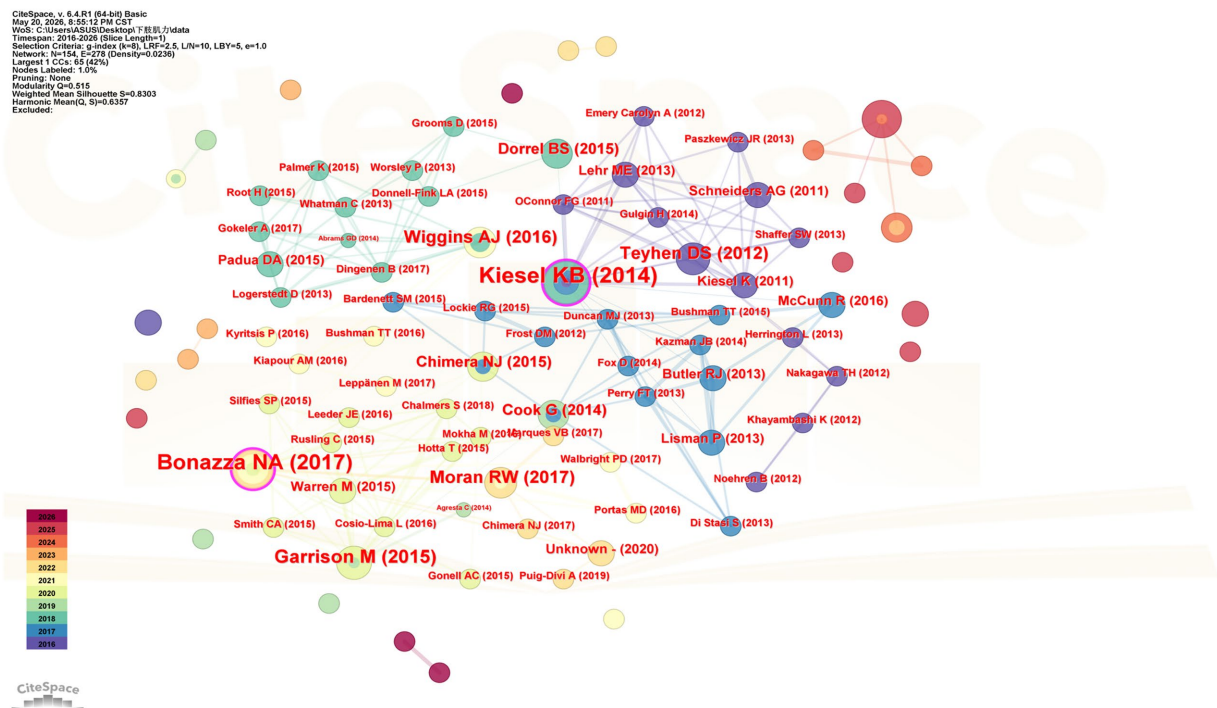


Figure 3. Co-occurrence network of functional movement screening and lower-limb neuromuscular control in the literature.

3.3. Analysis of Institutional Information

Co-citation mapping of core documents (Figure 3) reflects a distributed research structure anchored by several prominent academic clusters. Primary network hubs are represented by landmark publications from the University of Louisville and U.S. Army-Baylor University (Kiesel K, 2011; Kiesel KB, 2014), supplemented by military and regional clinical research from the U.S. Army Medical Research and Development Command (Teyhen DS, 2012) and Texas medical institutions (Garrison M, 2015). International and broader academic links are anchored by the University of Mississippi (Bonazza NA, 2017) and the University of Melbourne (Moran RW, 2017). High inter-node connectivity across these primary hubs highlights an established cross-institutional knowledge base driving research in functional movement screening and lower-limb neuromuscular control.

3.4. Keyword Analysis

3.4.1. Keyword Co-Occurrence Analysis

The keyword co-occurrence topology exhibits dense inter-node connectivity and pronounced modularity. The literature branches into several main clusters: a module anchored by “anterior cruciate ligament” and “return” addresses postoperative rehabilitation and return-to-sport clearance, whereas a cluster centered on “performance” and “reliability” focuses on the psychometric validation of movement screening and athletic performance forecasting. Furthermore, peripheral subnetworks comprising “low back pain,” “stability,” and “movement” indicate targeted avenues of inquiry into regional and population-specific neuromuscular control, complemented by a distinct radial, star-shaped module representing a specialized niche field. Chromatic temporal mapping across the 2000-2026 timeframe reveals that green and yellow nodes represent core concepts consolidated between 2010 and 2018. Conversely, red and dark-red peripheral nodes reflect high scholarly activity over the past five years, underscoring a contemporary shift toward muscle strength evaluation, population-tailored balance control, and the biomechanical mechanisms underlying low back pain. See Table 1.

Table 1. Top 15 high-frequency keywords in the literature on functional movement screening and lower-limb neuromuscular control.

Keyword	Frequency	Centrality	Year of first occurrence
performance	60	0.36	2007
kinematics	53	0.19	2008
anterior cruciate ligament	46	0.21	2001
injury	44	0.11	2007
knee	41	0.13	2001
stability	40	0.17	2007
muscle strength	39	0.44	2000
reliability	38	0.15	2000

Continued

strength	38	0.07	2009
walking	33	0.03	2007
movement patterns	31	0.04	2009
neuromuscular control	28	0.12	2010
lower extremity injury	26	0.08	2014
risk	26	0.06	2012
risk factors	26	0.04	2007

3.4.2. Keyword Cluster Analysis

Keyword clustering via the Log-Likelihood Ratio (LRR) algorithm yielded seven major thematic modules (#0 - #4 and #6 - #7). Network evaluation metrics confirmed a robust modular structure ($Q = 0.515$, exceeding the 0.3 threshold) and high internal homogeneity ($S=0.8303$, exceeding 0.7). Topologically, cluster #0 (“dynamic joint control”) occupies the central position of the network, acting as an integrative hub linked to surrounding domain clusters. Surrounding modules fall into two principal functional domains: assessment-focused topics—comprising #1 (“gait analysis”) and #4 (“EMG”) on the upper-left quadrant alongside #2 (“dynamic balance”) at the apex—form the foundation of biomechanical and neuromuscular evaluation; conversely, #3 (“anterior cruciate ligament,” lower-left) and #6 (“return to sport,” right) directly target lower-limb injury mechanisms and clinical rehabilitation outcomes.

Concurrently, cluster #7 (“postural balance”) forms a distinct peripheral module, highlighting targeted interest in postural control and stability evaluation. Representative node distributions reveal a clear temporal evolution across clusters: cluster #2 (“dynamic balance”) is anchored by foundational, highly cited literature such as Kiesel [14] *et al.*, whereas cluster #6 (“return to sport”) encapsulates recent high-impact inquiries, exemplified by Padua [15] *et al.* Collectively, these seven thematic modules synthesize the domain’s intellectual architecture, mapping a continuous continuum from injury etiology and biomechanical profiling to neuromuscular control and post-injury management. See **Figure 4** and **Table 2**.

Table 2. Cluster analysis of keywords in the literature on functional movement screening and lower limb neuromuscular control.

Freq	Degree	Centrality	Label	Year	ClusterID
60	46	0.25	performance	2007	2
53	54	0.29	kinematics	2008	4
46	58	0.2	anterior cruciate ligament	2001	3
44	30	0.03	injury	2007	1
41	40	0.08	knee	2001	1
40	30	0.06	stability	2007	6
39	51	0.37	muscle strength	2000	7
38	32	0.07	reliability	2000	2

Continued

38	24	0.03	strength	2009	4
33	25	0.03	walking	2007	1
31	26	0.03	movement patterns	2009	1
28	36	0.04	neuromuscular control	2010	2
26	32	0.06	lower extremity injury	2014	2
26	27	0.03	risk	2012	2
26	21	0.03	risk factors	2007	2

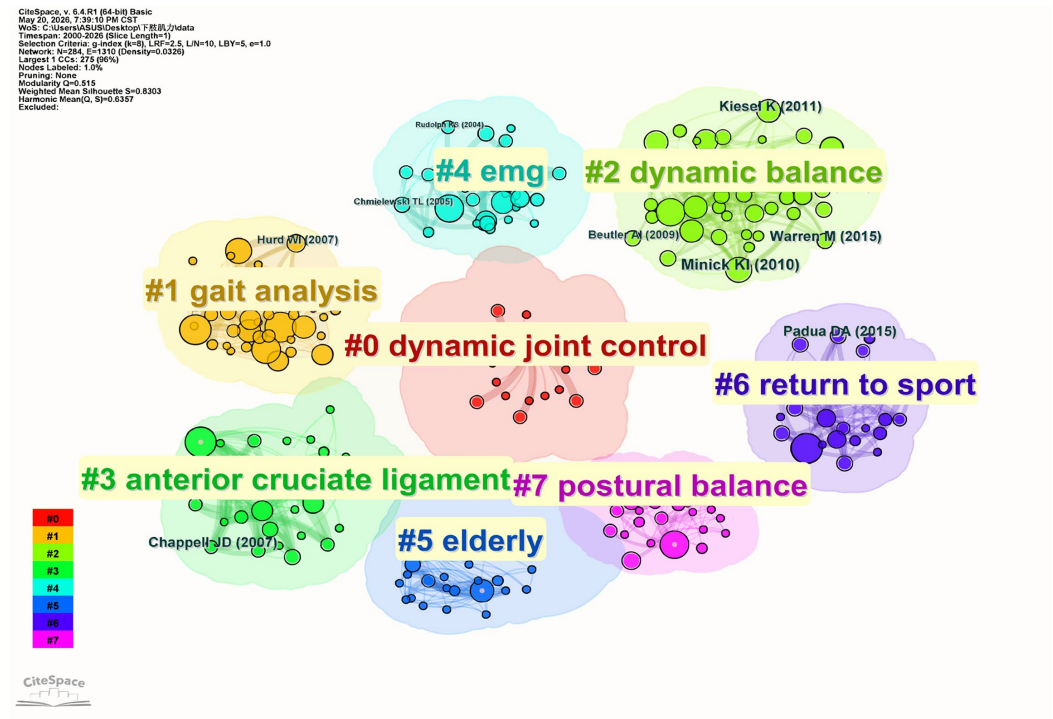


Figure 4. Clustering map of keywords from the literature on functional movement screening and lower limb neuromuscular control.

3.4.3. Keyword Burst Detection Analysis

Keyword burst detection via CiteSpace isolated the 16 primary terms with the highest emergence intensities between 2000 and 2026 (**Figure 5**). Peak burst magnitudes were led by “injury” (intensity = 5.48), followed by “neuromuscular control” (4.90), “risk” (4.40), “fundamental movements” (4.27), “biomechanical measures” (4.14), and “dynamic stability” (3.35). Chronologically, research priorities evolved across three distinct phases. Early inquiries (2001-2007) prioritized baseline stability metrics, typified by “dynamic stability.” Studies between 2010 and 2016 shifted toward muscle mechanics and joint pathology, as marked by bursts in “neuromuscular control,” “knee injury,” and “quadriceps strength.” Subsequently, the 2015-2019 period reflected a deliberate pivot toward quantitative biomechanical profiling and postoperative recovery, driven by terms such as “biomechanical measures” and “reconstruction.”

Based on a further analysis of recent emerging trends (2020-2026), there has been a significant shift in the current cutting-edge research topics in this field. “Return” (2020-2026), “Injury” (2021-2023), “risk” (2021-2026), “mechanisms” (2021-2026), “trunk” (2023-2026), and “muscle activation” (2024-2026) have emerged as the most prominent research trends over the past five years. Among these, the emergence periods for “risk,” “mechanisms,” “trunk,” and “muscle activation” all extend through 2026, indicating that the field is currently in a phase of highly active academic growth. This phased evolution clearly reveals that the research focus in this field is gradually shifting from traditional single-injury assessment toward an in-depth exploration of the biomechanical mechanisms of injury risk, trunk core control, and multidimensional neuromuscular function assessment for return to sport.

Top 16 Keywords with the Strongest Citation Bursts

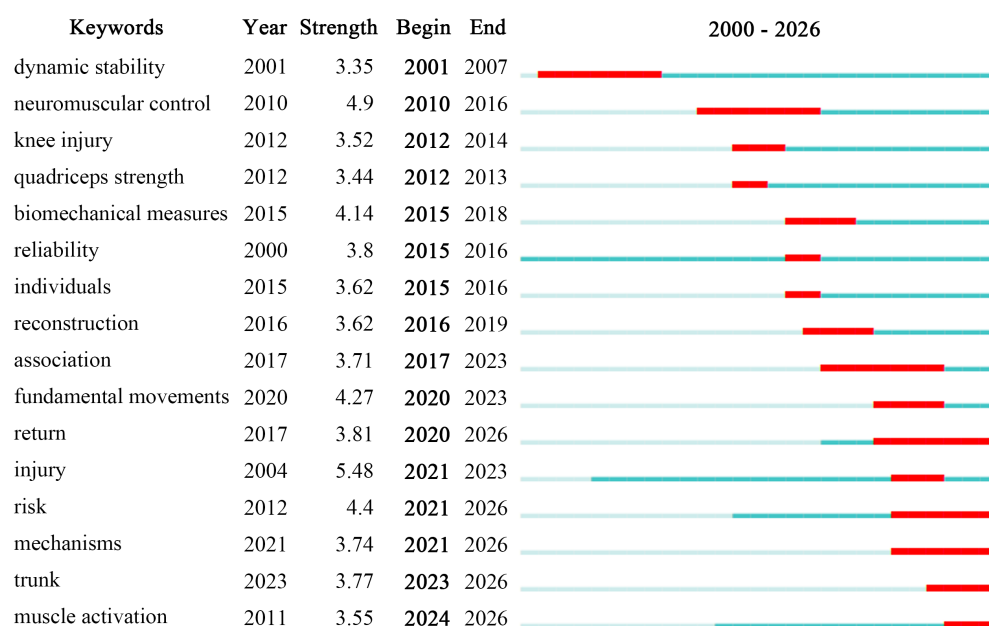


Figure 5. Top 16 keywords with the strongest citation bursts.

4. Discussion

4.1. From Screening Based on Single-Motion-Pattern Performance to a Deeper Understanding of Multidimensional Dynamic Joint and Postural Balance Control Mechanisms

Visual analysis indicates that research on the FMS and neuromuscular control of the lower limbs has evolved from early validity and reliability testing and descriptions of movement performance to interdisciplinary biomechanical explorations of dynamic joint control and overall postural balance mechanisms. In the keyword co-occurrence network, the high frequency and strong emergence of “performance,” “reliability,” and “fundamental movements” underscore the FMS’s central role as a classic screening tool for evaluating fundamental movement patterns

and identifying biomechanical compensations.

The prominence of central hub clusters—specifically “#0 dynamic joint control,” “#2 dynamic balance,” and “#7 postural balance”—reflects an ongoing integration between macroscopic FMS performance metrics and microscopic neuromuscular function. By synthesizing kinematic tracking with electromyographic (EMG) profiling, recent inquiries extend beyond qualitative clinical ratings toward the quantitative modeling of neural activation strategies and kinetic chain coordination under dynamic loading. This progression marks a fundamental paradigm shift within the field, transitioning from observational movement screening to the elucidation of underlying neuromuscular control mechanisms.

4.2. Clinical Translational Applications of Lower Limb Neuromuscular Control in the Prevention of Specific Sports Injuries and Full-Cycle Return to Sport

The thematic trajectory establishes ACL and knee injury management as a primary clinical translational focus. Core keywords (“anterior cruciate ligament,” “knee”) intersect with early-to-mid stage terms (“knee injury,” “quadriceps strength”) and align with clusters #3 (“anterior cruciate ligament”) and #6 (“return to sport”). This convergence delineates a comprehensive continuum: injury risk identification, targeted neuromuscular conditioning, postoperative functional recovery, and return-to-sport clearance. Given that impaired lower-extremity neuromuscular control predisposes individuals to primary and secondary ACL tears, movement screens such as the FMS provide objective detection of aberrant compensatory mechanics. Contemporary inquiries increasingly prioritize precise quantification of rehabilitation milestones and criteria-based return-to-play decisions, advancing evidence-based standards in sports medicine and orthopedic rehabilitation.

4.3. Cross-Regional Kinetic Chain Coordination and Micro-Muscle Activation Patterns Have Emerged as New Frontier Trends Driving the Field’s Development

Keyword burst dynamics over the past five years highlight a distinct trajectory in contemporary research, transitioning from localized segmental evaluations toward holistic kinetic chain mechanics and refined motor control. Bursts in terms such as “return,” “risk,” “mechanisms,” “trunk,” and “muscle activation” delineate key developmental priorities. Focus has expanded beyond isolated lower-extremity biomechanics (e.g., the knee and shank) to encompass integrated “trunk-core-lower limb” dynamic interactions. Proximal trunk stability directly governs segmental alignment and alters distal load distribution during dynamic tasks. Concurrently, the persistence of “muscle activation” underscores a growing emphasis on neurophysiological metrics—such as activation onset timing, coordination profiles, and central motor regulation—to resolve compensatory movement mechanics. Combining multidimensional biomechanics with systemic motor

control will continue to shape future research inquiries.

Project Support

Yunnan Medical Health College 2025 University-Level Student Research Projects (2025X009).

Author Contributions

Conceptualization, Hongyan Kuang, Lihui Wang and Yun Zhou; methodology, Xuang Cao and Xuechun Li; validation, Hongyan Kuang, Lihui Wang, and Xuang Cao; formal analysis, Wei Su and Xuechun Li; investigation, Hongyan Kuang and Lihui Wang; writing—original draft preparation, Hongyan Kuang and Lihui Wang; writing—review and editing, Xuechun Li and Yun Zhou; visualization, Hongyan Kuang and Lihui Wang; supervision, Xuang Cao; project administration, Xuang Cao. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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