

Review article

Global Research Trends in Anterior Cruciate Ligament Reconstruction

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Abstract: Anterior cruciate ligament (ACL) reconstruction remains one of the most frequently performed procedures in orthopaedic sports medicine. While traditionally focused on surgical techniques and graft selection, recent research has increasingly addressed rehabilitation strategies, return-to-sport outcomes, and psychological determinants of recovery. Bibliometric analysis provides a comprehensive approach to evaluating research trends and identifying emerging areas of interest in this field. A bibliometric analysis was conducted in the Scopus database to identify publications on ACL reconstruction from 2020 to 2026. Studies were retrieved using predefined search criteria, and bibliographic data were analyzed using VOSviewer software to assess publication trends, keyword co-occurrence, and thematic clustering. A total of 2316 publications were included in the analysis. Scientific output increased steadily over the study period, reflecting growing research interest. Keyword co-occurrence analysis identified four major thematic clusters: clinical and surgical management, return to sport (RTS) and psychological factors, graft selection and revision surgery, and rehabilitation and functional recovery. A notable shift toward patient-centered outcomes was observed, with increasing prominence of keywords related to functional performance and psychological readiness. This bibliometric analysis highlights a clear evolution in ACL reconstruction research toward a multidisciplinary and patient-centered approach. Future research should focus on integrating surgical, functional, and psychological factors to optimize return-to-sport outcomes and long-term patient recovery.

Keywords: ACL reconstruction, bibliometric analysis, sports medicine, rehabilitation, return to sport

1. Introduction

Anterior cruciate ligament (ACL) injuries are among the most common knee ligament injuries, particularly among athletes participating in pivoting sports such as soccer, basketball, and handball. These injuries frequently occur during rapid deceleration, cutting maneuvers, or changes of direction that place substantial mechanical stress on the knee joint [1].

ACL rupture often results in knee instability, decreased functional performance, and an increased risk of secondary intra-articular injuries, including meniscal tears and cartilage damage. If left untreated, these injuries may contribute to the development of early knee osteoarthritis [2].

ACL reconstruction is widely considered the gold standard surgical treatment for restoring knee stability and enabling patients to RTS activities. Over the past decades, significant improvements have been made in arthroscopic surgical techniques, graft fixation strategies, and postoperative rehabilitation protocols [3,4].

Despite these advancements, several important challenges remain regarding optimal graft selection, rehabilitation strategies, and safe return-to-sport decision-making. Consequently, the scientific literature addressing ACL reconstruction has expanded considerably in recent years [5-7].

Bibliometric analysis has emerged as an important methodological tool for evaluating scientific productivity and identifying research trends within a specific field. By analyzing publication patterns, collaboration networks, and keyword relationships, bibliometric studies provide valuable insights into the evolution of scientific research.

Given the rapid expansion of ACL reconstruction literature in recent years, understanding the main research trends and thematic directions has become increasingly important. Despite the growing volume of scientific literature on ACL reconstruction, the overall structure and thematic evolution of research in this field remain insufficiently explored. In particular, there is limited bibliometric evidence that maps the relationships among surgical reconstruction techniques, rehabilitation strategies, and return-to-sport outcomes.

A comprehensive bibliometric analysis can therefore provide valuable insights into the main research trends and emerging directions in ACL reconstruction literature.

Despite continuous advances in surgical techniques and graft selection, successful anterior cruciate ligament reconstruction extends beyond restoring mechanical knee stability. Increasing evidence suggests that long-term outcomes are strongly influenced by rehabilitation quality, neuromuscular recovery, return-to-sport readiness, and patient-reported outcome measures [8,9]. Consequently, contemporary ACL research has progressively evolved from a predominantly surgery-focused perspective toward a more comprehensive approach that integrates functional recovery, psychological factors, and individualized rehabilitation strategies [10,11].

In parallel, return-to-sport assessment has emerged as one of the most actively investigated areas in ACL reconstruction research [10,12]. Although numerous rehabilitation protocols and functional testing batteries have been proposed, considerable variability persists regarding return-to-sport criteria and clinical decision-making [13,14,15]. Furthermore, growing attention has been directed toward psychological determinants of recovery, including fear of reinjury, confidence, and readiness to resume athletic participation [16,17]. Understanding how these themes have evolved is essential for identifying current research priorities and future directions within the field of ACL reconstruction.

The present study aimed to address the following research questions (RQ):

- RQ1: What are the main research trends and thematic clusters in the scientific literature on ACL reconstruction between 2020 and 2026?
- RQ2: What are the most influential keywords and research topics shaping the contemporary scientific landscape of ACL reconstruction research?

2. Materials and Methods

2.1. Data Source

The bibliographic dataset used in this study was retrieved from the Scopus database. Scopus was selected because it represents one of the largest multidisciplinary databases of peer-reviewed scientific literature and provides extensive coverage of journals in the fields of sports medicine, orthopedics, and rehabilitation research. Furthermore, Scopus provides structured bibliographic information and citation data that facilitate advanced bibliometric analyses and network visualization.

2.2. Search Strategy

The bibliographic search was conducted in the Scopus database on March 10, 2026. The search was performed in the title, abstract, and keyword fields using the following query: TITLE-ABS-KEY ("anterior cruciate ligament reconstruction" OR "ACL reconstruction"). AND TITLE-ABS-KEY (rehabilitation OR physiotherapy OR "physical therapy" OR "return to sport"). The search was limited to publications indexed between January 2020 and March 2026 to capture recent developments in ACL reconstruction research. The search strategy was designed to identify studies addressing anterior cruciate ligament reconstruction (ACLR) and its associated rehabilitation and return-to-sport outcomes.

2.3. Study selection

The initial database search retrieved 7,052 publications from Scopus. After applying the predefined inclusion criteria—publication years between 2020 and 2026, document types limited to articles and review papers, and English language—2,316 publications were retained for the final bibliometric analysis. Conference papers, editorials, notes, and letters to the editor were excluded to ensure scientific relevance and methodological consistency. The study selection process is summarized in Figure 1.

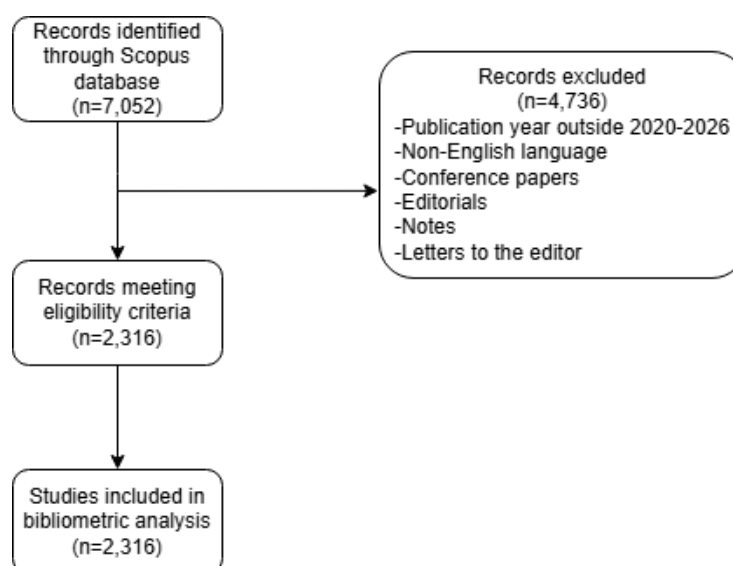


Figure 1. PRISMA flow diagram of the study selection process. A total of 7,052 records were identified through the Scopus database search. After applying the predefined eligibility criteria, 2,316 publications were retained for the final bibliometric analysis.

2.4. Data Extraction

Bibliographic information, including authors, titles, keywords, affiliations, publication year, and country of origin, was exported from Scopus in CSV format. The extracted dataset was subsequently used for bibliometric mapping and network visualization.

2.5. Bibliometric Analysis

The dataset was analyzed using VOSviewer software (version 1.6.19). VOSviewer is widely used for constructing and visualizing bibliometric networks. The following analyses were performed:

- Keyword co-occurrence analysis
- Cluster analysis
- Overlay visualization
- Density visualization
- Country collaboration network analysis

A minimum occurrence threshold was applied to identify the most relevant keywords within the dataset. Based on this threshold, the most frequently occurring keywords were selected to generate network visualizations and thematic clusters.

3. Results

3.1 Publication Trends

The annual scientific production related to ACL reconstruction demonstrated a progressive increase between 2020 and 2026 (Figure 2). The number of publications increased steadily during the analyzed period, reflecting growing scientific interest in ACL injuries, surgical reconstruction techniques, and postoperative rehabilitation strategies

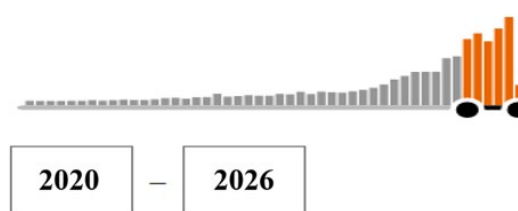


Figure 2. Annual scientific production related to ACL reconstruction between 2020 and 2026.

3.2 Keyword Analysis

A total of 30 keywords met the inclusion criteria for the co-occurrence analysis (Table 1). The most frequent keywords included:

Table 1. Most frequent keywords in ACL reconstruction literature

Keyword	Occurrences	Total Link Strength
anterior cruciate ligament	443	561
anterior cruciate ligament reconstruction	342	330
rehabilitation	301	438
acl	265	405
return to sport	231	360
knee	223	359
acl reconstruction	206	234
reconstruction	69	121
biomechanics	68	99
return to sports	61	95
return to play	54	82
psychological readiness	48	101
aclr	45	63
muscle strength	45	65
sports medicine	45	79

Keyword	Occurrences	Total Link Strength
meniscus	43	56
physical therapy	43	73
soccer	41	64
knee injuries	35	42
arthroscopy	33	56
autograft	31	66
osteoarthritis	31	46
quadriceps	31	54
revision	31	56
acl-rsi	27	59
outcomes	26	54
pediatric	26	50
adolescent	25	51
allograft	25	57
quadriceps tendon	23	50

Legend: ACL - Anterior cruciate ligament; ACL reconstruction - Anterior cruciate ligament reconstruction; ACLR - Anterior cruciate ligament reconstruction; ACL-RSI - Anterior cruciate ligament - Return to sport index.

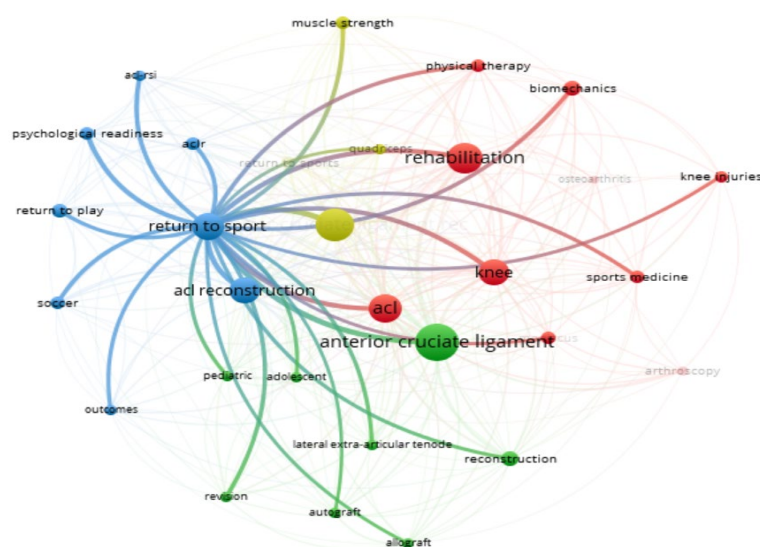


Figure 3. Network visualization of keyword co-occurrence generated using VOSviewer.

Figure 3 illustrates relationships between frequently occurring keywords in the literature. Each node represents a keyword, with node size proportional to its frequency. Colors indicate distinct thematic clusters, while the connecting lines reflect co-occurrence links between keywords.

3.3 Keyword Network Visualization

The keyword co-occurrence network is presented in Figure 4, illustrating the relationships between frequently occurring research topics. The identified clusters represent groups of closely related keywords that frequently co-occur in the scientific literature, reflecting the main research directions in ACL reconstruction studies. A more detailed and comprehensive representation of the network structure is provided in Figure 4.

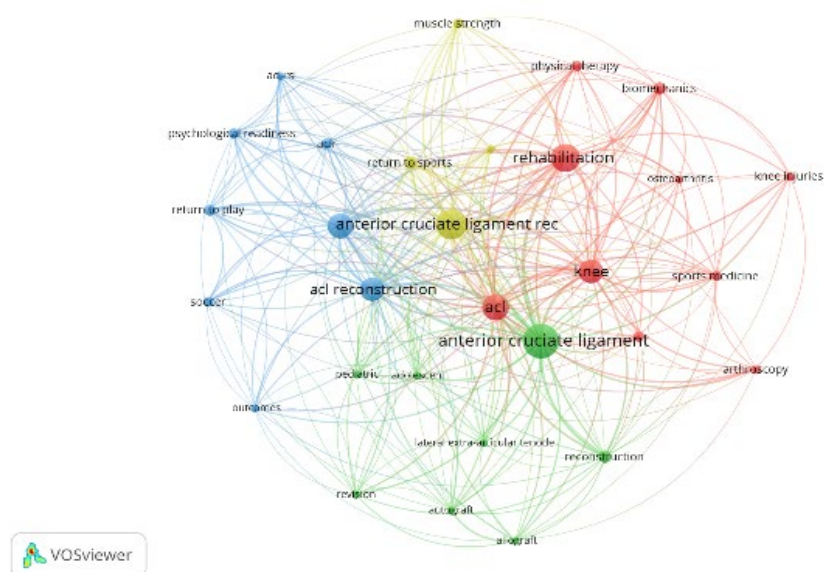


Figure 4. Full network visualisation of keyword co-occurrence generated using VOSviewer.

3.4 Overlay Visualization

The overlay visualization map highlights the temporal evolution of research topics in ACL reconstruction literature (Figure 5). Recent keywords such as "return to sport," "psychological readiness," and "ACL-RSI" have increased in recent years, indicating emerging research interest in postoperative functional recovery.

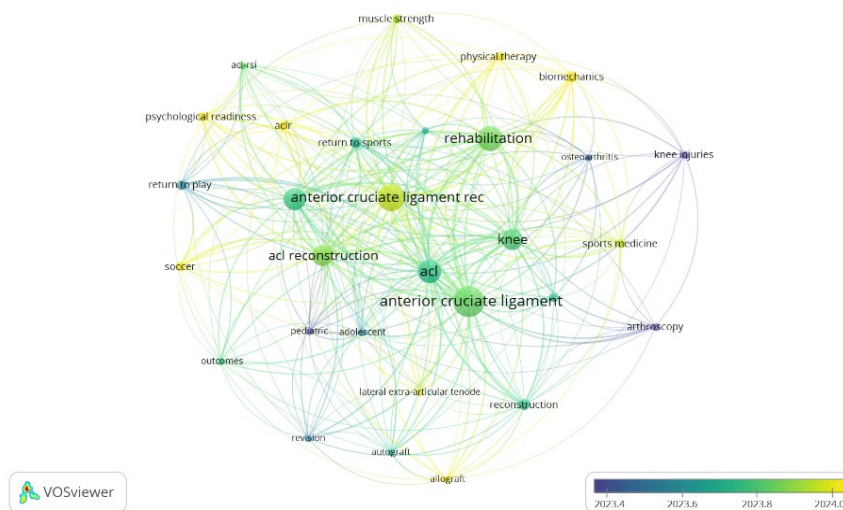


Figure 5. Overlay visualization map illustrating the temporal evolution of keywords generated using VOSviewer.

Keywords are color-coded according to their average year of appearance, ranging from earlier (blue) to more recent (yellow). This visualization highlights emerging research trends, particularly the increasing focus on RTS, psychological readiness, and functional recovery.

3.5 Density Visualization

The density visualization map illustrates the concentration of the most influential research themes in the field (Figure 6). Keywords related to ACL reconstruction, rehabilitation, and return to sport demonstrate the highest density values.

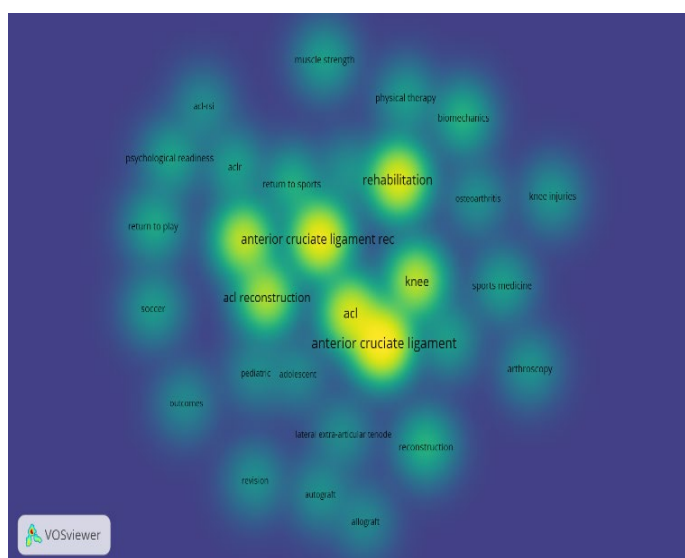
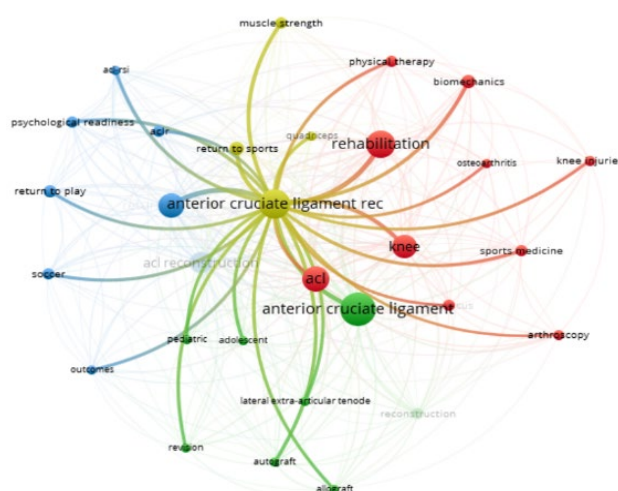


Figure 6. Density visualization of keyword co-occurrence generated using VOSviewer.

The density map represents the concentration of research topics within the field. Areas with higher keyword frequency are displayed in warmer colors (yellow), while less frequent topics appear in cooler colors (green to blue), indicating the most intensively studied themes.

3.6 Cluster Analysis

Four major thematic clusters were identified in the keyword co-occurrence network, reflecting the principal directions of contemporary research in ACL reconstruction between 2020 and 2026.



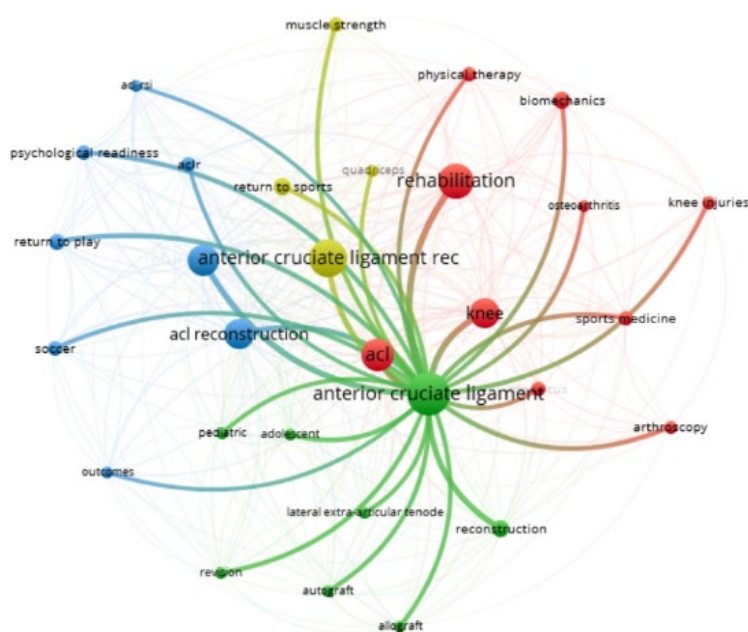
Cluster 1. Clinical and Surgical Aspects of ACL Injuries

The largest cluster was associated with the clinical and surgical management of ACL injuries. The most representative keywords within this cluster included knee, arthroscopy, meniscus, osteoarthritis, knee injuries, and sports medicine. The prominence of these terms reflects the central role of arthroscopic surgery in ACL reconstruction. Arthroscopic techniques allow precise graft placement, improved visualization of intra-articular structures, and reduced surgical morbidity compared with open procedures [3].

In addition, the presence of keywords related to meniscus and osteoarthritis highlights the close association between ACL rupture and secondary intra-articular

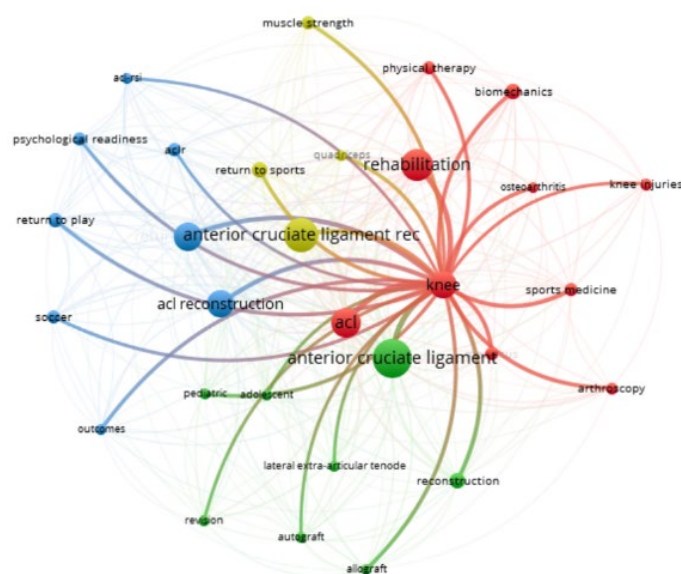
The second cluster focused on return-to-sport outcomes following ACL reconstruction. Keywords within this cluster included return to sport, return to play, psychological readiness, and ACL-RSI. Returning athletes to their previous level of sport represents one of the primary objectives of ACL reconstruction. However, several studies have demonstrated that only a proportion of athletes successfully return to their pre-injury level of performance following surgery [5,12].

Psychological factors such as fear of reinjury, lack of confidence, and perceived knee instability have increasingly been recognized as critical determinants of return-to-sport success [6,16]. Consequently, psychological assessment tools such as the ACL-RSI scale have been developed to assess psychological readiness and assist clinicians in determining the safe timing for RTS. This cluster, therefore, highlights the growing importance of psychological and functional evaluation in postoperative ACL management.



The third cluster was associated with graft selection and revision surgery. Representative keywords included autograft, allograft, quadriceps tendon, and revision. The presence of these terms reflects the continuing debate regarding the optimal graft choice for ACL reconstruction. Autografts such as hamstring tendons and bone-patellar tendon-bone grafts remain widely used because of their favorable biomechanical characteristics and clinical outcomes [4].

However, quadriceps tendon grafts have gained increasing popularity in recent years due to promising biomechanical properties and reduced donor-site morbidity [19-22]. The presence of the keyword revision highlights the clinical challenges associated with graft failure and persistent knee instability following reconstruction. Research in this area, therefore, focuses on improving graft selection strategies and reducing the risk of revision surgery.



Cluster 4. Rehabilitation and Functional Recovery

The fourth cluster focused on postoperative rehabilitation and functional recovery following ACL reconstruction. Keywords included rehabilitation, muscle strength, biomechanics, and physical therapy. Rehabilitation represents a critical component of successful ACL reconstruction, as it aims to restore knee stability, neuromuscular control, and muscle strength [23].

Quadriceps strength recovery has been identified as one of the most important predictors of functional outcomes and safe RTS [24,25]. Modern rehabilitation protocols increasingly emphasize criterion-based progression rather than purely time-based milestones. Objective functional criteria are now commonly used to guide rehabilitation progression and determine readiness for RTS [13,26].

3.7 Country Collaboration Network

The country collaboration analysis identified 23 countries meeting the inclusion threshold (Figure 7). The United States demonstrated the highest number of publications and collaboration links. European countries, including the United Kingdom, Germany, France, and Italy, formed strong collaborative research networks. Asian countries such as China and Japan also contributed significantly to ACL reconstruction research.

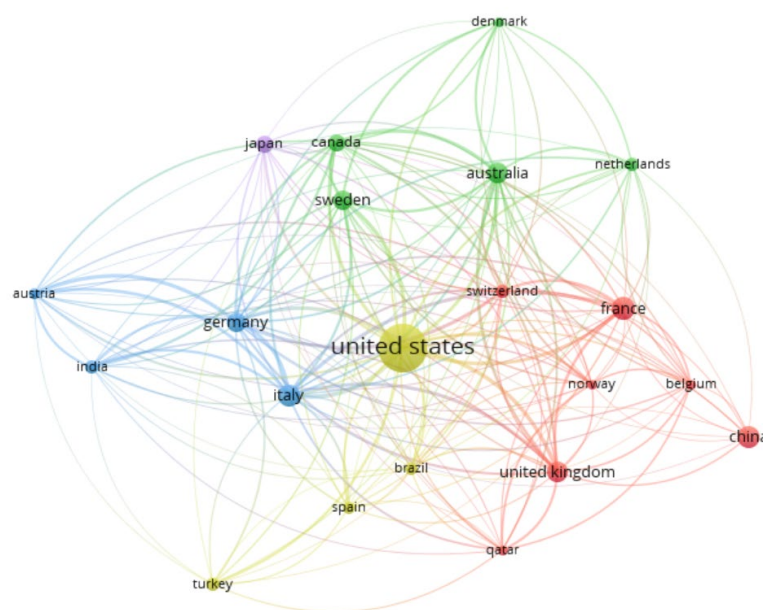


Figure 7. An international collaboration network between countries based on co-authorship analysis.

The map displays collaborative relationships between countries contributing to ACL reconstruction research. Node size reflects publication output, while links indicate co-authorship connections, highlighting the central role of leading countries in global research networks.

4. Discussion

4.1 Principal Findings

This bibliometric analysis demonstrates a consistent and progressive increase in scientific production related to ACL reconstruction between 2020 and March 2026, reflecting sustained global interest in optimizing both surgical techniques and patient outcomes.

Beyond this quantitative growth, the most relevant finding lies in the qualitative evolution of research themes. While traditional topics such as graft selection and sur-

gical techniques remain well represented, there is a clear shift toward a more comprehensive and multidisciplinary approach. Increasing attention is being directed toward rehabilitation strategies, functional recovery, and psychological readiness for RTS.

This evolution is consistent with contemporary rehabilitation frameworks, which increasingly define successful ACL reconstruction through a multidimensional perspective that integrates physical recovery, patient-reported outcomes, psychological readiness, and safe return-to-sport participation [8,10]. Recent consensus statements, including the PANTHER Symposium ACL Injury Return-to-Sport Consensus Group, have emphasized that graft integrity and objective knee stability alone do not adequately reflect treatment success, highlighting the importance of functional performance, psychological readiness, and patient-reported outcomes in postoperative evaluation [15,11].

This transition reflects a broader change in the conceptual definition of “successful” ACL reconstruction. Historically, success was primarily assessed using objective measures such as graft integrity, joint stability, and absence of complications. However, contemporary literature emphasizes that these parameters alone are insufficient to capture patient outcomes, as return to pre-injury levels of sport and performance has emerged as a critical endpoint [5,8,12,27].

4.2 Evolution of Research Trends

The bibliometric findings highlight a progressive diversification of research topics over the study period. Early research in ACL reconstruction was predominantly centered on biomechanical properties, fixation methods, and graft survival. In contrast, more recent studies increasingly explore functional, behavioral, and psychological dimensions of recovery [6].

The growing prominence of keywords such as “return to sport,” “psychological readiness,” and “rehabilitation” suggests a paradigm shift toward patient-centered and outcome-oriented research. This shift is supported by accumulating evidence demonstrating that physical recovery does not necessarily translate into successful RTS. Indeed, several studies have shown that a substantial proportion of patients do not return to their pre-injury level of activity despite satisfactory surgical outcomes, with psychological barriers playing a major role [5,6,12,16].

This evolution mirrors broader developments within sports medicine, where successful ACL reconstruction is increasingly evaluated using multidimensional outcome frameworks rather than isolated surgical endpoints [11,15]. Contemporary research emphasizes that return-to-sport decisions should integrate objective functional recovery, patient-reported outcomes, and psychological readiness, reflecting a more holistic understanding of recovery after ACL injury [15]. The increasing visibility of these themes within the bibliometric network supports the notion that ACL research is progressively adopting a patient-centered perspective [9,10,14,17].

In parallel, the importance of neuromuscular control, movement quality, and objective functional testing has been increasingly recognized as key determinants of safe RTS [13]. These findings suggest that ACL research is moving toward a more integrative model that combines biomechanical, functional, and psychological components [9,10].

4.3 Clinical Implications

The evolution of research trends observed in this study has direct implications for clinical practice. ACL reconstruction should no longer be considered an isolated surgical event but rather one element within a comprehensive continuum of care [28].

A multidisciplinary approach is essential [14], involving close collaboration between surgeons, physiotherapists, and, when appropriate, sports psychologists. Rehabilitation should be structured, progressive, and criterion-based rather than solely time-based. The use of objective return-to-sport criteria, including strength testing, functional performance, and movement quality assessment, has been shown to significantly reduce the risk of reinjury [29].

However, these criteria are not yet universally standardized, highlighting an important gap between research and clinical implementation.

The absence of universally accepted return-to-sport criteria remains one of the most frequently discussed challenges in contemporary ACL literature. Considerable variability persists regarding the selection of functional tests, strength thresholds, timing of return-to-sport decisions, and the integration of psychological assessment into clinical practice. This heterogeneity may contribute to inconsistent outcomes across studies and highlights the need for greater consensus regarding evidence-based return-to-sport decision-making [8,9,10,14,15].

In addition, psychological readiness should be systematically evaluated [17], as fear of reinjury and lack of confidence may delay or prevent RTS, even in the presence of adequate physical recovery. Overall, these findings support a shift toward personalized, patient-centered management strategies aimed at optimizing long-term outcomes rather than focusing solely on short-term surgical success.

4.4 Strengths of the Study

This study has several notable strengths. First, it provides a contemporary overview of ACL reconstruction research, including publications up to March 2026, thereby capturing the most recent developments in the field.

Second, the use of VOSviewer enabled advanced visualization of keyword co-occurrence networks, facilitating the identification of meaningful thematic clusters and relationships between research topics.

Third, the identification of four distinct thematic clusters provides a structured and interpretable framework for understanding current research priorities. This clustering approach allows not only the description of existing trends but also the identification of emerging areas of interest.

Finally, the bibliometric methodology offers an objective and reproducible means of analyzing large volumes of scientific literature, minimizing subjective interpretation.

4.5 Limitations

Despite its strengths, this study has several limitations that should be acknowledged. First, the analysis was restricted to the Scopus database, which may have excluded relevant publications indexed in other databases, such as Web of Science or PubMed. Moreover, because the search strategy intentionally combined terms related to ACL reconstruction with rehabilitation-oriented concepts such as physiotherapy and return-to-sport, the findings should be interpreted as reflecting rehabilitation-focused ACL research rather than the entire body of ACL reconstruction literature.

Second, bibliometric analyses are inherently dependent on database indexing and author-selected keywords. Variability in terminology and indexing practices may influence the identification of clusters and the interpretation of research trends. Third, only English-language publications were included, which may introduce language bias and limit the global representativeness of the findings. Finally, the year 2026 was only partially represented, as the analysis included publications indexed up to March 2026. Consequently, the total scientific output for that year may be underestimated.

4.6 Future Research Directions

The findings of this study highlight several important directions for future research. First, further investigation is needed to better understand the role of psychological factors in return-to-sport outcomes and to develop standardized tools for assessing psychological readiness.

Second, there is a need to establish consensus on objective return-to-sport criteria and to validate these criteria across different patient populations and levels of athletic participation.

Third, the development of personalized rehabilitation protocols represents a promising area of research. Advances in technology, including wearable devices and artificial intelligence, may facilitate real-time monitoring and individualized adaptation of rehabilitation programs.

Finally, future bibliometric studies could incorporate multiple databases and longitudinal analyses to provide a more comprehensive and dynamic understanding of research evolution in ACL reconstruction.

5. Conclusions

This bibliometric analysis provides a comprehensive overview of global research trends in ACL reconstruction between 2020 and 2026. The findings highlight the multidisciplinary nature of contemporary ACL research, integrating surgical innovation, rehabilitation science, biomechanics, and psychological assessment.

Future research should continue to focus on optimizing rehabilitation strategies and improving return-to-sport decision-making to enhance long-term outcomes for patients undergoing ACL reconstruction.

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Abbreviations

The following abbreviations are used in this manuscript:

ACL	Anterior Cruciate Ligament
ACL-RSI	Anterior Cruciate Ligament-Return to Sport Index
ACLR	Anterior Cruciate Ligament Reconstruction
AI	Artificial Intelligence
RCT	Randomized Controlled Trial
RQ	Research Question
RTS	Return to Sport
TLS	Total Link Strength

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