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Global research status of anterior cruciate ligament reconstruction: a bibliometric analysis

Tianping Zhou[1], Yihong Xu[1], Aiai Zhang[2], Lan Zhou[3], Qing Zhang[1], Zhou Ji[1] and Weidong Xu[1]

[1]Department of Joint Surgery and Sports Medicine, Shanghai Changhai Hospital of Navy Medical University, Shanghai, P.R.China
[2]Department of Burn Surgery, Shanghai Changhai Hospital of Navy Medical University, Shanghai, P.R.China
[3]School of Kinesiology, Shanghai University of Sport, Shanghai, China

*(T Zhou and Y Xu contributed equally to this work)

Correspondence should be addressed to W Xu
Email
xuweidongch@163.com

- *Purpose:* The aim of this study is to comprehensively analyze the publications of anterior cruciate ligament reconstruction (ACLR) research and display the current research status in this field.
- *Methods:* Articles regarding ACLR research published before October 7, 2021, were downloaded from the Web of Science Core Collection. Excel 2016 and Bibliometric website were used to analyze the annual article trends and international cooperation network. CiteSpace V and VOSviewer were used to perform co-occurrence and citation analyses for journals, institutions, authors, cocitation authors and keywords. Burst keyword detection was also performed with CiteSpace V.
- *Results:* A total of 12 223 ACLR articles were identified. *The American Journal of Sports Medicine* (1636 publications, 92,310 citations), the Pennsylvania Commonwealth System of Higher Education (624 publications, 25,304 citations) and Freddie H. Fu (321 publications, 15,245 citations) were journals, institutions and authors with the most publications and citations, respectively. Patellar tendon was the keyword with the most occurrences (1618 times) and return to sport was the keyword with the most burst strength (burst strength: 46.99).
- *Conclusion:* ACLR-related publications showed a rapid increasing trend since 1990. A large number of articles have been published by authors from different institutions and countries, some of which have gained great academic influence. Based on keyword analysis, patellar tendon is identified as the research hotspot and return to sport is identified as the current research frontier.

Keywords

- anterior cruciate ligament reconstruction
- bibliometrics
- hotspots
- frontiers
- CiteSpace
- VOSviewer

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Introduction

Most patients suffering from anterior cruciate ligament (ACL) injuries, especially athletes and physically active populations desiring to return to physical activities, need surgical reconstruction (1). In fact, the number of anterior cruciate ligament reconstruction (ACLR) surgeries performed annually has increased to over 100 000 and continues to increase (2). However, despite great progress made in ACLR research, many controversies and problems still remain (3). No clear consensus has been reached about the most suitable graft, femoral tunnel drilling technique and graft fixation method in ACLR (4). Besides this, the influence of ACLR on the progress of knee osteoarthritis is still in dispute (5). According to epidemiological studies, ACL tears are one of the most common and serious injuries in professional sports, especially basketball and soccer, with ACLR being the main treatment (6, 7). Despite progress in the past decades, ACLR has not been perfect enough to enable athletes to fully return to prior level of play without negative consequences. With a considerable morbidity and improvable surgical methods, ACLR has always been a focus of sports medicine. Currently, thousands of articles have been published regarding ACLR. While most of the articles involve clinical research or are reviews, few studies have attempted to statistically analyze the data of these publications.

Bibliometric analysis is a mathematical and statistical method used to analyze the metrological characters of

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research literature in a certain field (8). Analytic tools include CiteSpace, Pajek, UCINET, VOSviewer and so on, with CiteSpace being the most popular. CiteSpace was initially developed by Chaomei Chen in 2004 (9). It has been widely used in many research fields to examine knowledge structures, transition patterns and emerging trends. A number of bibliometric studies have recently been published in high-impact journals (10, 11, 12). However, few bibliometric articles exist in the ACLR research field. The purpose of this study is to perform a bibliometric analysis of publications about ACLR in the past decades using CiteSpace V (Drexel University, Philadelphia, PA, USA), VOSviewer (Leiden University, Leiden, Netherlands) and Excel 2016 (Microsoft Corporation, USA) to display the present research status and hotspots as well as identify possible research frontiers in this research field.

Methods

Data collection

Data from the literature were retrieved from the Web of Science Core Collection (WoSCC) on October 7, 2021. The data retrieval strategy was as follows: Topic: (anterior cruciate ligament reconstruction) OR Topic: (ACL reconstruction) OR Topic: (anterior cruciate ligament surgery) OR Topic: (ACL surgery) AND LANGUAGE=English; indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC; time span: 1900–2021. No restrictions regarding document type were applied. A total of 12 223 English research articles among 15 111 papers were obtained after a thorough screening. The 'Full Records and Cited References' records were uploaded to CiteSpace V and VOSviewer in the format of 'plain text'. The flowchart of the literature election is shown in Fig. 1.

Statistical analysis

Information on annual publications and journals was obtained from the WoSCC literature analysis reports. The publication trend and cooperative relations between countries was analyzed with the help of Bibliometric (https://bibliometric.com). Occurrence and citation analysis of journals/institutions/authors, reference cocitation analysis and burst keyword detection were performed by CiteSpace V. VOSviewer was used to perform overlay visualizations of keywords.

Results

Scientific output analysis

A total of 12 223 articles were published in the past decades, with annual publications presented in Fig. 2.

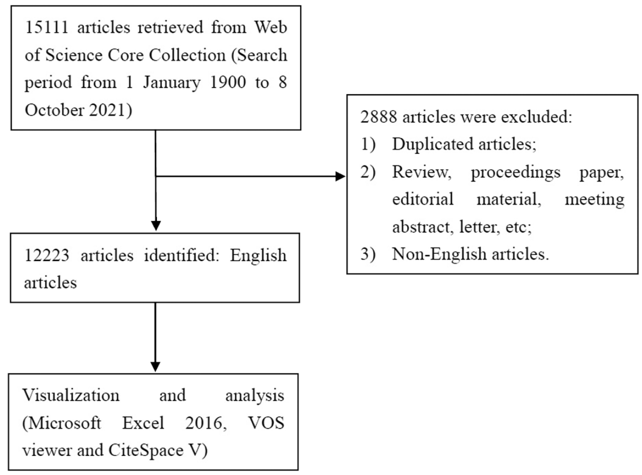

Figure 1
Flowchart of the literature selection.

The research on ACLR dated back to 1963, and only a few articles were published during the first two decades. Overall, the number of papers published annually rose sharply since 1990. A total of 6602 institutions from 94 countries contributed research papers in the ACLR field. Of all the contributing countries, the USA published the highest number of papers (5012 publications) with a lot of collaboration with other countries, which can be judged from the co-occurrence frequency between countries. The contribution and international cooperation between different countries are clearly displayed in Fig. 3, with the size of the sectors representing the frequencies of co-occurrence and the sector connections representing the cooperation relationships. Besides this, the top three funding agencies, namely the United States Department of Health and Human Services (994 publications), the National Institutes of Health (984 publications) and the National Institute of Arthritis and Musculoskeletal and Skin Diseases (719 publications), were all from the USA, despite the fact that only 27.5% of all the articles were funded by foundations. The top 10 institutions are listed in Table 1,

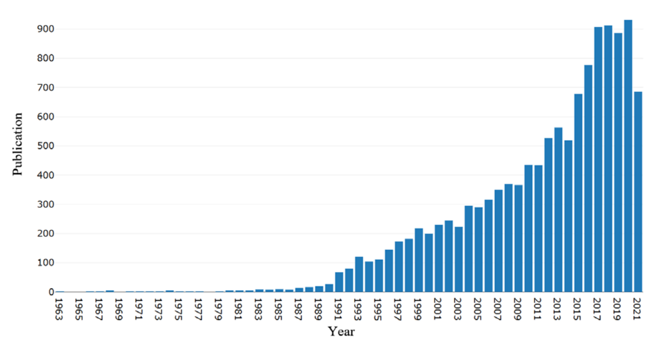

Figure 2
The number of articles regarding ACLR published annually.

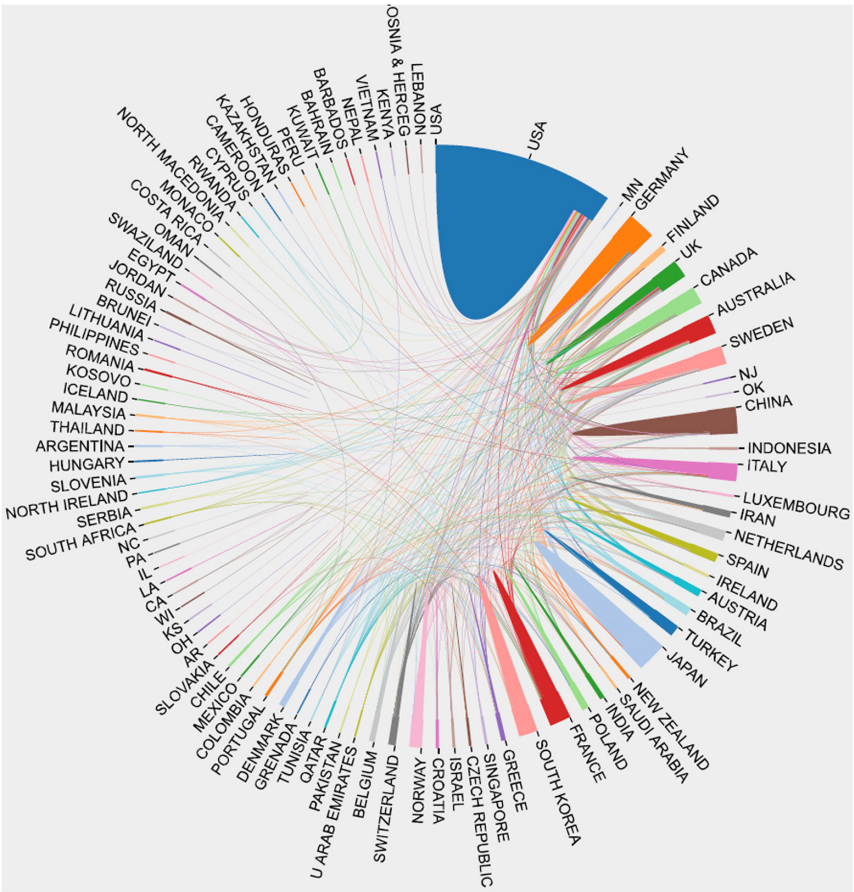

Figure 3
The contribution and international cooperation between different countries in ACLR field.

with the Pennsylvania Commonwealth System of Higher Education ranked first with 624 publications.

In total, 823 academic journals have published articles on ACLR. The top 10 journals in this research field are shown in Table 1. *The American Journal of Sports Medicine* published the highest number of papers (1636 publications, 13.39%), followed by *Knee Surgery, Sports Traumatology, Arthroscopy* (1563 publications, 12.79%) and *Arthroscopy: the Journal of Arthroscopic and Related Surgery* (1094 publications, 8.95%). Over 26 389 authors made contributions to ACLR research. The top 10 authors are ranked in Table 1, and Freddie H. Fu was the most productive author publishing 321 articles.

Academic influence and citation analysis

Academic influence could be quantitatively evaluated with indicators such as total citations, impact factor and H-index, although they would be influenced by factors like excessive self-citation which has become a major issue in scientific research (13). The impact factors of journal refer to the 2020 Journal Citation Report, and the H-index is calculated according to the method of John-Hirsch (14). The top 10 periodicals, institutions and authors in terms of total citations are listed in Table 2. *The American Journal of Sports Medicine*, the Pennsylvania Commonwealth System of Higher Education and Freddie H. Fu were journals, institutions and authors with the most citations, respectively. Citation analysis has become a useful method to determine the core and fundamental information of a certain knowledge network (15). Articles with top 10 citations in ACLR research field are listed in Table 3. The most cited paper was published in *The American Journal of Sports Medicine* in 2016, with a citation of 422.

Analysis of keywords and burst keywords

Generally, keywords are the representation of an article's main idea or thesis. Therefore, the research trends and hotspots could be easily discovered with the help of a keyword analysis (16). Of 16 204 keywords identified, including author keywords and plus ones, the overlay visualization of top 150 keywords are shown in Fig. 4. The size of the label and the circle of an item is determined by the weight of the item. The higher the weight of an item, the larger the label and the circle of the item. The color of an item is determined by the mean time of occurrence. Lines between items represent links. A color bar is shown in the bottom right corner of the visualization. By default, colors range from blue to green to yellow symbolizing

Table 1 Top 10 contributive journals, institutions and authors in the ACLR field.

Rank	Journals		Institutions		Authors	
	Name	Count (%)	Name	Count (%)	Name	Count (%)
1	*The American Journal of Sports Medicine*	1636 (13.39%)	Pennsylvania Commonwealth System of Higher Education	624 (5.10%)	Freddie H. Fu	321 (2.63%)
2	*Knee Surgery, Sports Traumatology, Arthroscopy*	1563 (12.79%)	University of Pittsburgh	577 (4.72%)	LaPrade RF	149 (1.22%)
3	*Arthroscopy: The Journal of Arthroscopic & Related Surgery*	1094 (8.95%)	University of California	325 (2.66%)	Musahl V	138 (1.13%)
4	*Knee*	432 (3.53%)	Harvard University	305 (2.50%)	Engebretsen L	130 (1.06%)
5	*Orthopaedic Journal of Sports Medicine*	378 (3.10%)	Hospital for Special Surgery	282 (2.30%)	Zaffagnini S	123 (1.01%)
6	*Journal of Orthopaedic Research*	286 (2.34%)	Ohio State University	192 (1.57%)	Spindler KP	108 (0.88%)
7	*Arthroscopy Techniques*	247 (2.02%)	Mayo Clinic	191 (1.56%)	Karlsson J	102 (0.83%)
8	*Archives of Orthopaedic and Trauma Surgery*	239 (1.96%)	La Trobe University	163 (1.33%)	Snyder-Mackler L	99 (0.81%)
9	*Journal of Bone and Joint Surgery, American Volume*	236 (1.93%)	University of North Carolina	163 (1.33%)	Irrgang JJ	96 (0.79%)
10	*Journal of Knee Surgery*	215 (1.76%)	University of Oslo	156 (1.28%)	Hewett TE	95 (0.78%)

the passage of time from far to near. Of all the keywords, patellar tendon (occurrences: 1618, average occurrence time: 2010.15), follow-up (occurrences: 1327, average occurrence time: 2011.98) and rehabilitation (occurrences: 1133, average occurrence time: 2011.07) were top three keywords and identified as research hotspots. Besides, the keywords 'Return (return to sport)' and 'risk (risk factors)' were higher-weighted terms of those whose average occurrences time passed 2017.

Burst keywords (Fig. 5) are also analyzed with CiteSpace to comprehensively understand the evolution of research hotspots. A total of 10 keywords with strong citation bursts are found from 2011 to 2021, with return (burst strength: 46.99), risk (burst strength: 35.23) and meniscus (burst strength: 13.21) being the most distinct burst keywords.

Discussion

The annual changes in the number of articles related to ACLR clearly display the development status and trend of academic output in this field. The earliest study related to ACLR in the WOS core collection dates back to the 1960s, although this is still not the first study in this area. In fact, the first ACLR was performed by Hey Groves in 1917 (17). In 1963, Kenneth Jones reported on a new surgical procedure for ACLR with the middle third of the patellar tendon, which had a significant impact and was the first paper included in this study (18). In the early 1990s, the advent of arthroscopy greatly changed the surgical approach for ACLR and gradually replaced traditional open surgery as the current mainstream (19). The emergence of arthroscopy technology has brought many new research directions such as the surgical approach, the location of bone tunnel opening and graft fixation, greatly promoting the scientific output about ACLR (20, 21, 22). Currently, the academic output of ACLR remains at a high level, with about 900 articles published annually.

The academic output in ACLR requires close cooperation between countries, institutions, authors and journals and even financial funds. The USA contributes the highest proportion of academic output and the most international cooperation, demonstrating its undisputed status as a scientific power. Interestingly, only 27.5% of the research was funded by grants, and the top three grants were all from the USA, indicating the country's huge investment in this field. In this study, the cumulative number of publications, adding together the number of first organization/author and the number of non-first organization/author, is used to evaluate the academic output of authors and institutions. Although this indicator shows good differential validity, it has to be admitted that it ignores the difference between the contributions of the first author and non-first authors in the same study and therefore needs to be improved. According to the research results, the Pennsylvania Commonwealth System of Higher Education and Freddie H. Fu are the institutions and authors with the most output respectively, while *The American Journal of Sports Medicine* is the journal with the most published articles.

In addition, this study has evaluated and analyzed leading authors, institutions and journals in the field of ACLR in terms of academic impact. In this study, total citations, impact factor and H-index were used to comprehensively evaluate the academic influence of relevant journals, institutions and authors. Besides this, in view of the increasingly serious problem of excessive self-citations, self-citation rates of journals, institutions and authors were also assessed (21). In this study, *The American Journal of Sports Medicine*, the Pennsylvania Commonwealth System of Higher Education and Freddie H. Fu are the journals, institutions and authors with the greatest academic influence, respectively. According to the research results of Martin Szomszor *et al.*, the median self-citation rate of highly cited authors in the clinical

Table 2 Top-cited journals, institutions and authors in the ACLR field.

	Journals				Institutions				Authors			
Rank	Source	Citation	Self-citation rate	Impact factor (2020)	Organizations	Citation	Self-citation rate	H-index	Name	Citation	Self-citation rate	H-index
1	*The American Journal of Sports Medicine*	92 310	10.98%	6.20	Pennsylvania Commonwealth System of Higher Education	25 304	12.31%	83	Freddie H. Fu	15 245	11.97%	67
2	*Arthroscopy: The Journal of Arthroscopic & Related Surgery*	40 468	9.53%	4.77	University of Pittsburgh	24 659	12.42%	82	Savio L-Y. Woo	6442	3.63%	39
3	*Knee Surgery, Sports Traumatology Arthroscopy*	38 322	16.09%	4.34	Hospital for Special Surgery	10 493	5.69%	56	Lars Engebretsen	6302	5.76%	46
4	*Journal of Bone and Joint Surgery American Volume*	17 844	2.22%	5.28	Harvard University	11 821	7.04%	56	Timothy Hewett	6126	6.12%	38
5	*Clinical Orthopaedics and Related Research*	10 529	0.97%	4.18	Ohio State University	6844	7.07%	43	Robert LaPrade	4826	10.07%	41
6	*Journal of Orthopaedic Research*	9643	4.00%	3.49	Sahlgrenska University Hospital	6543	6.63%	42	Kurt Spindler	4481	7.12%	38
7	*Journal of Orthopaedic & Sports Physical Therapy*	7700	3.47%	4.75	University of Vermont	5867	3.27%	35	Kate E Webster	4171	6.88%	32
8	*Knee*	6206	3.79%	2.20	University of Delaware	5989	11.92%	41	Volker Musahl	4064	11.66%	38
9	*The Journal of Bone and Joint Surgery* British volume	6136	1.45%	End in 2012	University of Cincinnati	5773	4.62%	37	Lynn Snyder-Mackler	4533	13.88%	38
10	*Archives of Orthopaedic and Trauma Surgery*	3811	5.17%	3.07	La Trobe University	5630	9.11%	38	Julian Feller	3968	5.24%	31

Table 3 The top 10 cited articles on ACLR.

Rank	Year	Authors	Title	Journal	Citations
1	2016	Sanders T L	Incidence of Anterior Cruciate Ligament Tears and Reconstruction: A 21-Year Population-Based Study	*The American Journal of Sports Medicine*	422
2	2016	Kyritsis P	Likelihood of ACL Graft Rupture: Not Meeting Six Clinical Discharge Criteria Before Return to Sport is Associated With a Four Times Greater Risk of Rupture	*British Journal of Sports Medicine*	363
3	2015	Sonnery-Cottet B	Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up	*The American Journal of Sports Medicine*	342
4	2014	Mall N A	Incidence and Trends of Anterior Cruciate Ligament Reconstruction in the United States	*The American Journal of Sports Medicine*	320
5	2014	Paterno M V	Incidence of Second ACL Injuries 2 Years After Primary ACL Reconstruction and Return to Sport	*The American Journal of Sports Medicine*	315
6	2014	Webster K E	Younger Patients Are at Increased Risk for Graft Rupture and Contralateral Injury After Anterior Cruciate Ligament Reconstruction	*The American Journal of Sports Medicine*	279
7	2012	Magnussen R A	Graft Size and Patient Age Are Predictors of Early Revision After Anterior Cruciate Ligament Reconstruction With Hamstring Autograft	*Arthroscopy: The Journal of Arthroscopic & Related Surgery*	266
8	2012	Paterno M V	Incidence of Contralateral and Ipsilateral Anterior Cruciate Ligament (ACL) Injury After Primary ACL Reconstruction and Return to Sport	*Clinical Journal of Sport Medicine*	259
9	2011	Kim S	Increase in Outpatient Knee Arthroscopy in the United States: A Comparison of National Surveys of Ambulatory Surgery, 1996 and 2006	*Journal of Bone and Joint Surgery, American Volume*	248
10	2011	Ardern C L	Return to the Preinjury Level of Competitive Sport After Anterior Cruciate Ligament Reconstruction Surgery Two-thirds of Patients Have Not Returned by 12 Months After Surgery	*The American Journal of Sports Medicine*	235

medical field is 8.68% (13). Similarly, this article found that the self-citation rate of most journals, institutions and authors were around 8%. However, the self-citation rates of *Knee Surgery, Sports Traumatology Arthroscopy* is as high as 16%, much higher than other top 10 journals, which is worth discussing and paying attention to.

The top 10 cited articles in ACLR research field were identified with citation analysis. All of the studies have been published since 2010, with citations of more than 200. Six articles were published on *The American Journal of Sports Medicine*. With respect to the contents of the 10 literatures, five of them are about the occurrence and risk factors of reinjuries or revisions after primary ACLR. Based on a 12-month follow-up of 36 ACLR patients and 39 healthy controls, Paterno *et al.* found that the risk of reinjury after primary ACLR was 15 times higher than that of the control group and the risk of ACL reinjury in female patients was four times higher than that in male patients (22). Paterno also found that the incidence of second ACL injury after ACLR remained nearly six times higher than that of healthy controls 2 years after surgery (23). Another three studies found that patient age, graft size and readiness to return to sport all influenced the incidence of reinjury after ACLR (24, 25, 26). Three of top 10 cited articles are epidemiological studies about the occurrence of ACL injury and reconstruction. According

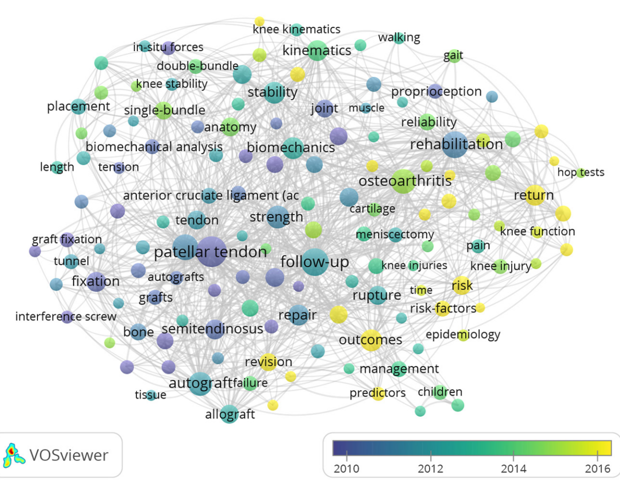

Figure 4
Overlay visualization of keywords on ACLR.

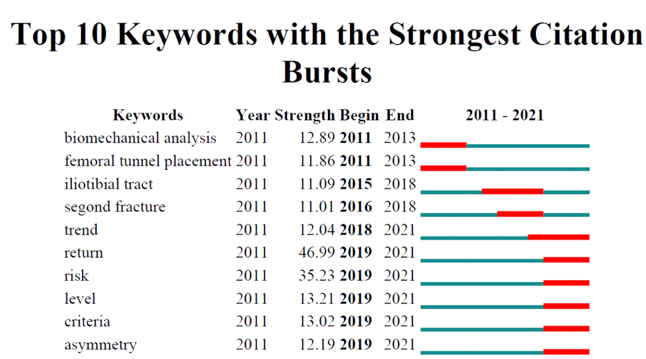

Figure 5
Top 10 keywords with the strongest citation bursts in the ACLR field from 2011 to 2021. The green line represents the time period from 2011 to 2021. The period of each burst keyword is plotted by the red line.

to the results of these studies, the incidence of ACLR in the USA increased from 32.9 per 100 000 person-years to 43.5 per 100 000 person-years between 1994 and 2006, and the portion of outpatient ACLR increased from 43% to 95%, indicating the rapid growth of ACLR in the USA (27, 28, 29). Only one of the top 10 cited articles displayed good short-term follow-up outcomes of combined ACLR and anterolateral ligament reconstruction with a lower rate of reinjury and significantly improved subjective knee score after surgery (30). The contents of these highly cited literatures commendably reflect the phased research achievements in the research field of ACLR.

According to the results of keyword analysis, patellar tendon is the keyword with the highest frequency (1618 times), indicating that research related to patellar tendon has the highest proportion in the ACLR research area. Thus, patellar tendon is considered to be the biggest research hotspot in ACLR research field. With respect to articles about patellar tendon, Freddie H. Fu publishes the most literatures (73 papers) and the Pennsylvania Commonwealth System of Higher Education makes the most contribution (133 papers). The annual literatures on patellar tendon maintain a high level between 2006 and 2017 and add up to 68.5% of the total articles about patellar tendon, which suggests that this research hotspot has lasted for a long time. After a review of these literatures, it is considered that most of them are about the comparison of the clinical outcomes between patellar tendon and hamstring tendon, while no significant difference in clinical outcomes is identified between the two grafts (31, 32).

In addition, this study has identified return (return to sport, RTS) as keywords with most burst strength, which is considered as the latest research frontier. In fact, there are 300 literatures with RTS as the keyword, of which 91.3% are published after 2015. Webster KE publishes the most literatures (23 articles) and the La Trobe University contributes the most (29 articles). In these studies, the influencing factors and test battery of returning to sport are the two most concerned questions (33, 34).

In fact, there are still many keywords or research directions about ACLR which are of great interest to researchers. A total of 466 articles have examined issues related to the femoral canal, most of which have focused on the selection of the femoral tunnel position. Anatomic single-bundle footprint is the most common point for the femoral tunnel creation (35). One of the most controversial issues in this field is the comparison of clinical outcomes between anatomic single-bundle ACLR and anatomic double-bundle ACLR (36). Femoral tunnel shapes, including oval-shaped tunnels and rectangular ones, are relatively new research topics based on the theory that the ACL is connected to the femur with a ribbon-like attachment (37). Currently, there are only 21 studies on femoral tunnel shape problems, and Shino K is the main researcher with seven articles. Some studies suggest that the clinical results of this new technique may be better than that of traditional anatomic single-bundle ACLR, but long-term follow-up studies are still lacking (38). Studies on meniscus-related problems in ACLR have also attracted the attention of scientists, but it has been studied in the previous literature (10). Long-term follow-up after ACLR is an important issue, but there are still few high-quality long-term follow-up studies. Most of the reported outcomes are between 10 and 18 years, and only five studies are followed for more than 20 years. Filbay S *et al.* conducted the longest follow-up study about ACLR, which identified reduced self-reported knee function and single-leg hop performance 4 years after ACLR as prognostic factors for worse 32- to 37-year outcomes (39).

As the first attempt to apply bibliometrics methods in analyzing scientific output of ACLR research, the article also has some limitations. First, in order to maintain the accuracy of analyzing results and avoid the influence of unrelated articles, the authors have not extended the retrieval strategy of this study. As a result, a small number of articles regarding ACLR may be missed. Besides, limited by the design of CiteSpace V, burst keywords were identified by the default algorithm, with variation of frequency of burst keywords not shown in this article. There is no doubt that results of this study will be more reasonable if this problem was solved. In addition, as the keywords are always chosen by the authors, they might not necessarily represent the research questions of the papers and be misleading. In this study, all the keywords including both author keywords and keywords-plus which are keywords added by the editors of the database according to the topic of the article are analyzed, which can avoid misleading to some extent. In order to avoid the misdirection caused by author keywords in scientific research, many scientists suggest that authors use standard and scientific keywords to mark papers (40, 41). Possible improved algorithms of bibliometric analysis in the future may also be favorable to solving this problem. Finally, since items analyzed by VOSviewer were terms or keywords extracted from publications, meanings of results have to be interpreted by professional scholars. Thus, implications of terms discussed in the study will probably not be accepted by everyone. The authors have tried to interpret terms of research hotspots and frontiers with the most common meanings.

Conclusion

In conclusion, the scientific output of ACLR research was comprehensively analyzed with the help of CiteSpace V and VOSviewer. Great progress has been made with regard to ACLR in the past decades. The USA made the greatest contribution to ACLR research. *The American Journal of Sports Medicine* (16 361 133 publications, 92

310 citations, 13.83%), Pennsylvania Commonwealth System of Higher Education (624 publications, 25,304 citations), USA (5012 publications, 25,304 citations) and Freddie H Fu (321 publications, 15 245 citations) were journals, institutions, countries and authors with the most publications and citations, respectively. Patellar tendon is identified as research hotspot and return to sport is identified as current research frontier.

ICMJE Conflict of Interest Statement
The authors declare that they have no competing interests.

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