



## RESEARCH ARTICLE

# Femoroacetabular Impingement and Labral Tear: From the Most Highly Cited Articles to Research Interests

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**Objective:** To highlight the characteristics of the most highly cited articles and propose the research interests over the past decades in the field of femoroacetabular impingement (FAI) and labral tear.

**Methods:** The ISI Web of Science database (Clarivate Analytics, New York, the United States) was utilized for the identification of articles on 15 December 2020. FAI and labral tear-related articles (1138 articles) were retrieved, of which the 100 most-cited articles (top 100) were identified. Subsequent analysis included citation density (citations/article age), authorship, institution, journal, geographic distribution, level of evidence, and theme.

**Results:** The number of citations per article ranged from 66 to 1189 with a mean of 163.31. The majority of articles were published in the United States (all articles/top 100 = 655/57) and Switzerland (85/22). University of Bern (n = 10) was the most prolific institution. The journal with the most of articles was *Arthroscopy: The Journal of Arthroscopic and Related Surgery*. The most prolific coauthor (all articles) or first authors (top 100) was Domb (n = 109) and Philippon (n = 6), respectively. The evidence with the most articles is level IV (n = 41). The top three most popular topics of research article were outcomes of surgery (n = 23), imaging diagnosis (n = 18), and comparison of surgery (n = 8). The top four most prevalent themes of review were labral tears (n = 3), FAI (n = 3), comparison of surgery imaging diagnosis, and outcomes of surgery (both n = 2). Six keywords with the newest average publication year, including FAI syndrome (average publication year = 2019.50), patient-reported outcomes (2019.43), femoroplasty (2018.60), clinical outcomes (2018.17), borderline dysplasia (2018.00), and capsule (2018.00). Five keywords with the highest average citations, including outcome (average citations = 88.50), alpha angle (58.00), complications (55.86), revision hip arthroscopy (49.00), and systematic review (46.14).

**Conclusions:** Outcomes research is the most popular research interest and patient-reported outcome instruments might be further and widely used in the emerging articles in the near future. The field of FAI and labral tear has shown an obvious trend of development and is steadily evolving. It could be predicted that there will be an increasing number of publications in the following years, with the United States and Switzerland maintaining leadership in this field.

**Key words:** Femoroacetabular impingement; FAI; Labral tear; Research interests; Bibliometric analysis

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## Introduction

Bibliometric analysis is a serviceable and efficient tool to quantitatively evaluate the performance and characteristics of publications<sup>1</sup>. In the past several years, this method has been widely used in various research areas<sup>2,3-12</sup>. Citation analysis is the main methodology of bibliometric analysis. A citation is the acknowledgement that one article uses another as a reference. The number of citations is not only an indicator of the impact of an article on the scientific community but also forms the basis of journal impact factor (IF) generation<sup>5</sup>.

Femoroacetabular impingement (FAI) is a well-known clinical syndrome deriving from morphologic alterations of the acetabulum or femur and is the common cause of hip pain and limited hip range of motion<sup>13-18</sup>. The prevalence of labral tears in patients with hip or groin pain has been reported to be 22%–55%<sup>19</sup>. It has been reported that acetabular labral tears were closely related to FAI<sup>13,20</sup>. Specifically, abnormal articular burden and increased pressure caused by FAI resulted in the development of labral tears, cartilage delamination, and eventual secondary oosthritis<sup>16,21</sup>. The term FAI was firstly coined and developed by the Ganz group<sup>15,22</sup>; subsequently an exponential rise of publications about FAI further extended its recognition<sup>23</sup>.

The citation analysis, one of the key methodologies of bibliometrics, has been utilized to analyze the 50 most-cited articles for femoroacetabular impingement and hip arthroscopy by Simon *et al.* in 2014<sup>24</sup>. However, a comprehensive bibliometric analysis on FAI and lateral tear remains scarce. Thus, in this study, we conducted the comprehensive bibliometric analysis to assess the 100 most-cited articles in the field of FAI, with the aim to highlight the characteristics of these highly cited articles and propose the research interests over the past decades.

## Materials and Methods

### Study Design

This study used a bibliometric method to analyze the articles on FAI and lateral tear. The 100 top cited articles were enrolled and analyzed in accordance with the method for bibliometrics<sup>3,5,7,8,10-12</sup> and offer the doctors more classical articles compared to the bibliometric papers that only focused on the top 25<sup>25,26</sup> or 50<sup>4,9,24</sup> articles in a specific field.

### Search Strategy

Articles related to FAI and lateral tear were retrieved by searching the ISI Web of Science database (Clarivate Analytics, NY, USA), comprising the Web of Science (WOS) Core Collection, BIOSIS Citation Index, MEDLINE, Russian Science Citation Index, SciELO Citation Index, and KCI-Korean Journal Database. The search terms utilized were the following: (femoroacetabular impingement OR femoral acetabular impingement OR FAI) AND (labrum OR labral) AND (tear OR tears OR lesion OR lesions). There is no language limitation in the search.

The search was implemented on 15 December 2020 and yielded 1138 results in total. Those articles were subsequently

analyzed *via* VOS viewer 1.6.15 (a program operated by the Centre for Science and Technology Studies at Leiden University, Leiden, Netherlands)<sup>6</sup>. For further selection, two well-trained reviewers (the first author and the second author in the author list) reviewed and chose the eligible articles according to eligibility criteria, respectively. And the 100 most-cited papers were listed for data extraction. Any disagreements between the two reviewers were discussed by the group until a final consensus was reached. Finally, the previously mentioned two strategies were integrated into further analysis (Fig. 1).

### Eligibility Criteria

The inclusion criteria were as follows: (i) basic or clinical research papers of any type (original article, review, meta-analysis, case report, and so on) which were associated with FAI and lateral tear. Exclusion criteria were as follows: (i) research theme or content not considered FAI and lateral tear as the main research subject.

### Data Extraction

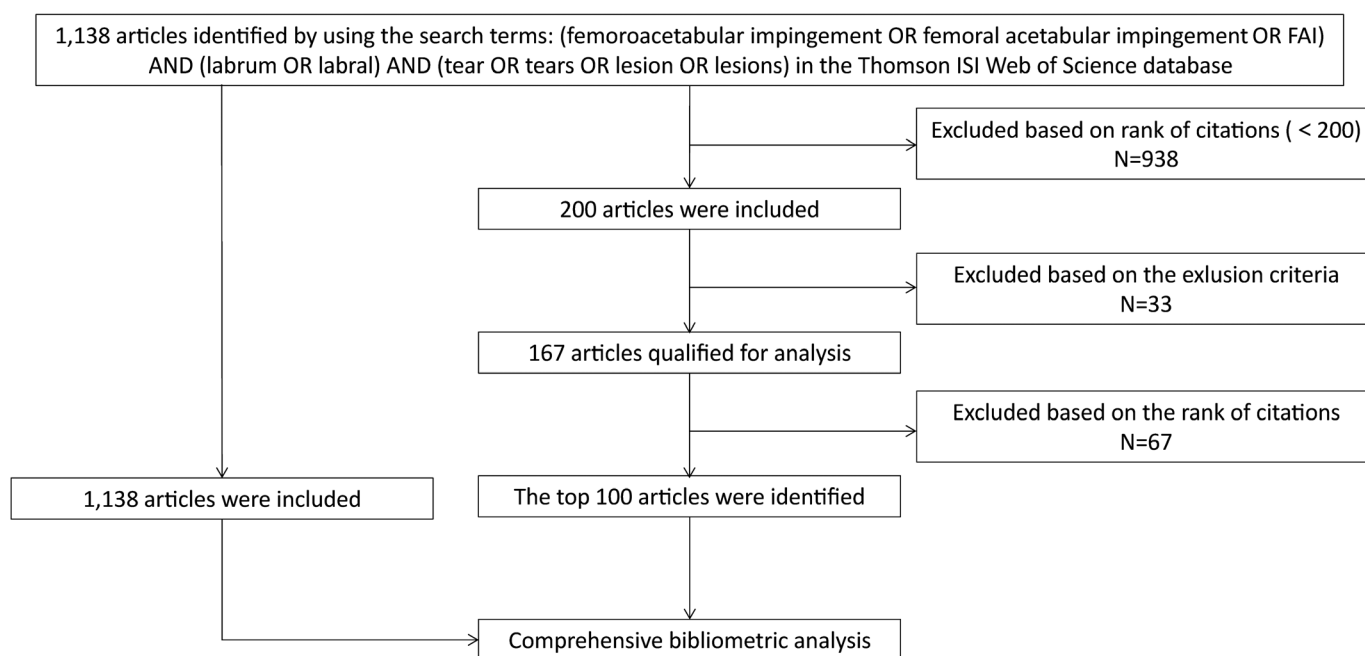
The following information was extracted for the 100 most-cited articles: (i) title; (ii) type of article; (iii) publication year; (iv) first author; (v) journal name and impact factor (IF) in 2019; (vi) country; (vii) institution; (viii) theme; (ix) level of evidence (the evidence review of Canadian Task Force on Preventive Health Care [the CTFPHC's evidence review]); (x) citations; (xi) citation density (citations/article age). For the previously retrieved 1138 articles: (i) title; (ii) author keywords; (iii) publication years.

If an article has multiple countries or institutions, the affiliation of the first author was utilized. In the same way, if the first author has multiple institutions, the affiliation of the corresponding author was used.

### Statistical Analysis

The bibliometric software Vosviewer was used to analyze the previously retrieved 1138 articles. Nine hundred and twenty-seven author keywords were extracted. To simplify the figure of the author's keywords co-occurrence network, a limitation with minimum number of occurrences of the keywords was set (threshold = 4). The higher occurrence of keywords, the larger circle in the co-occurrence network. Moreover, a blue to yellow gradient was used to show the mean publication years of a certain author's keywords.

The Shapiro–Wilk test was utilized to test the distribution of individual variables for normality. Normally distributed data were presented as mean  $\pm$  standard deviation. The Kruskal–Wallis H test was used to evaluate differences between the publication year and the total number of citations. Comparison between means of citations was determined by using one-way analysis of variance (ANOVA), and post-hoc testing was implemented when necessary. The Mann–Kendall trend test was performed to test time-dependent trends. Spearman rank or Pearson tests correlation between variables.  $P < 0.05$  was considered to be statistically significant. Analysis was performed using GraphPad Prism 8, R 4.0.2 (GraphPad Software inc., San



**Fig. 1** Flow chart illustrating the procedure of allocation of articles.

Diego, CA, USA) and IBM SPSS Statistics 22.0 (IBM inc., NY, USA).

## Results

### Top Articles

The 100 most-cited articles are shown in Table S1. The number of citations per article ranged from 66 to 1189 with a mean of 163.31. The Kruskal–Wallis H test showed a significant difference between the publication year and the total number of citations ( $P \leq 0.001$ ). The publication items were obviously increased over the past decades (Fig. 2A). The publication years of the top 100 articles was showed in Fig. 2B, in which publication years with the most publications were 2011 ( $n = 12$ ). Citation density ranged from 5.06 to 79.27 per article. The top 10 articles with largest citation density were listed in Table 1. A gentle increasing trend between the citation density and the publication year was demonstrated (Fig. 3), but no significant difference between the citation density and the publication year was found by Mann–Kendall test ( $z = 1.0454$ ,  $P = 0.2959$ ).

### Journals

Twenty-two different journals in which the top 100 articles were published are listed in Table 2. Sixty-one percent of the articles were published in the top three journals in the table, including *Arthroscopy: The Journal of Arthroscopic and Related Surgery* ( $n = 28$ , IF = 4.325), *American Journal of Sports Medicine* ( $n = 17$ , IF = 5.810), and *Clinical Orthopaedics and Related Research* ( $n = 16$ , IF = 4.329).

### Countries

Within the 100 most-cited papers, there were eight countries of origin (Fig. 4B). The United States was leading the way ( $n = 57$ ), followed by Switzerland ( $n = 22$ ), Canada ( $n = 9$ ), and the United Kingdom ( $n = 8$ ). Australia, Italy, the Netherlands, and New Zealand each only contributed one paper, respectively. Countries with five or more papers on the field of FAI and lateral tear were shown in Fig. 4A. The top four countries of papers' origin were the United States ( $n = 655$ ), Switzerland ( $n = 85$ ), the United Kingdom ( $n = 83$ ), and Canada ( $n = 69$ ).

### Institutions

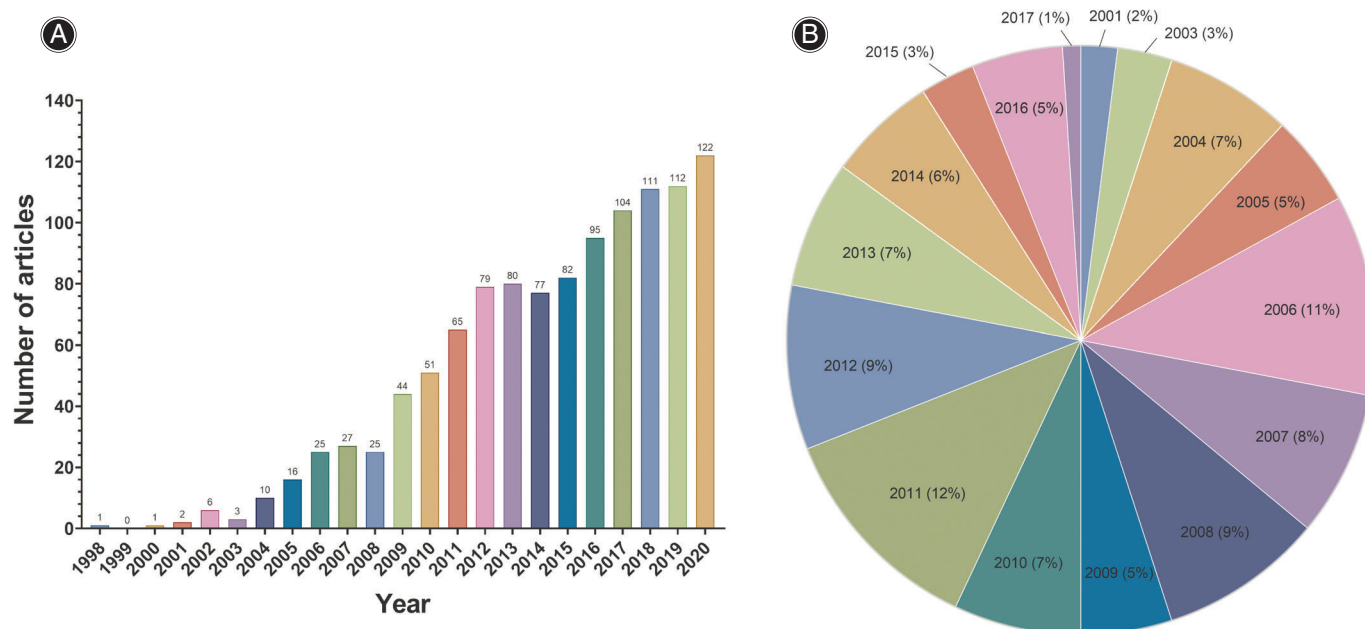
The 100 most-cited articles were published by a total of 53 institutions independently or cooperatively. Among these articles, 18 institutions contributed two or more articles. The most prolific institution was University of Bern ( $n = 10$ ), and other institutions were shown in Fig. 5.

### Authors

Coauthors with the top 10 number of highly cited papers and first authors with two or more articles in the 100 most-cited articles were listed in Table 3. The most prolific coauthor or first authors was Domb ( $n = 109$ ) and Philippon ( $n = 6$ ), respectively.

### Level of Evidence

There were 73 clinical articles identified, and the levels of evidence among them were showed in Fig. 6. The evidence with the most articles in the 100 most-cited articles was level IV ( $n = 41$ , mean citations = 197.6). Followed by level III ( $n = 23$ , mean citations = 157.9), level II ( $n = 5$ , 104.0), and level V ( $n = 4$ , 188.5). Interestingly, no clinical article had



**Fig. 2** Time distribution of all articles (A) and the 100 most-cited articles (B). (A) The number of publications per year showed a growth trend. (B) A majority of the 100 most-cited articles were published in 2011.

**TABLE 1** Top 10 articles with largest citation density

Rank	Paper	Publication year	Citations	Citations rank	Citation density
1	Hip morphology influences the pattern of damage to the acetabular cartilage: Femoroacetabular impingement as a cause of early osteoarthritis of the hip	2005	1189	1	79.27
2	The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): An international consensus statement	2016	261	12	65.25
3	Prevalence of Femoroacetabular Impingement Imaging Findings in Asymptomatic Volunteers: A Systematic Review	2015	187	31	37.40
4	Survivorship and Outcomes 10 Years Following Hip Arthroscopy for Femoroacetabular Impingement	2017	102	57	34.00
5	Trends in Hip Arthroscopy Utilization in the United States	2013	226	21	32.29
6	Anterior femoroacetabular impingement Part II: Midterm results of surgical treatment	2004	513	3	32.06
7	Arthroscopic Debridement Versus Refixation of the Acetabular Labrum Associated With Femoroacetabular Impingement Mean 3.5-Year Follow-up	2012	243	18	30.38
8	Complications and Reoperations During and After Hip Arthroscopy: A Systematic Review of 92 Studies and More Than 6,000 Patients	2013	212	24	30.29
9	Femoroacetabular impingement and the cam-effect: A MRI-based quantitative anatomical study of the femoral head-neck offset	2001	574	2	30.21
10	Trends and Demographics in Hip Arthroscopy in the United States	2013	204	27	29.14

level I evidence. No significant difference has been found among these levels of evidence in the one-way ANOVA ( $P = 0.5649$ ).

#### Themes and Keywords Analysis

As for the article type, there were 77 articles, 22 reviews, and one meta-analysis among the 100 most-cited papers. The top four most prevalent themes of review were labral tear

( $n = 3$ ), FAI ( $n = 3$ ), comparison of surgery, imaging diagnosis, and outcomes of surgery (both  $n = 2$ ). The top three most popular topics of research article were outcomes of surgery ( $n = 23$ ), imaging diagnosis ( $n = 18$ ), and comparison of surgery ( $n = 8$ ). And details of the themes among specific articles or reviews were presented in Fig. 7.

One hundred and five keywords have occurred at least four times. These keywords were clustered into 11 subsets

with different colors in Fig. 8A and Fig. 8B. Femoroacetabular impingement, labral tear, and hip arthroscopy were at the convergence point. The top 30 keywords ranked by average publication year were listed in Table S2. Six keywords had an average publication year larger than or equal to 2018, including femoroacetabular impingement syndrome (average publication year = 2019.50), patient-reported outcomes (2019.43), femoroplasty (2018.60), clinical outcomes (2018.17), borderline dysplasia (2018.00), and capsule (2018.00). Top 30 keywords in all articles ranked by average citations were listed in Table S3. Five keywords with average citations greater than

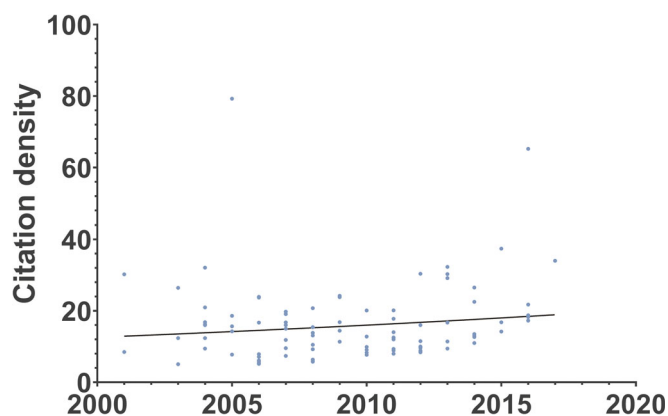
45, including outcome (average citations = 88.50), alpha angle (58.00), complications (55.86), revision hip arthroscopy (49.00), and systematic review (46.14).

### Discussion

The number of citations of a specific article is often regarded as a bibliometric indicator of influence within authors, journals, and themes of research<sup>27-30</sup>. In this study, we evaluated all articles, especially the 100 most-cited articles, on FAI and labral tear by using the bibliometric analysis, aiming to highlight the characteristics of the higher citations articles and provide research interests on the field of FAI and labral tear in the past or currently.

The 100 most-cited articles in the field of FAI and labral tear were identified with a mean of 163.31 citations (range, 66 to 1189), which is smaller than the fields of orthopaedic surgery<sup>12</sup>, burns<sup>3</sup>, and spine deformity<sup>8</sup>. As is showed in Fig. 2A, the earliest papers on the topic were published in 1998. And since 2003, the number of articles per year was increased obviously. This was because that FAI is a relatively young research field and was prosperous after the concept of FAI was fully developed by Ganz *et al.* in 2003<sup>23</sup>. Even though the citation density is increased every year, time accumulation effect is not enough for these articles to accumulate the citations compared with mean citations of the top 100 articles in other fields.

The oldest article in the top 50 articles on FAI and arthroscopy was published in 1987, while the oldest paper in the 100 most-cited articles on FAI and labral tear was

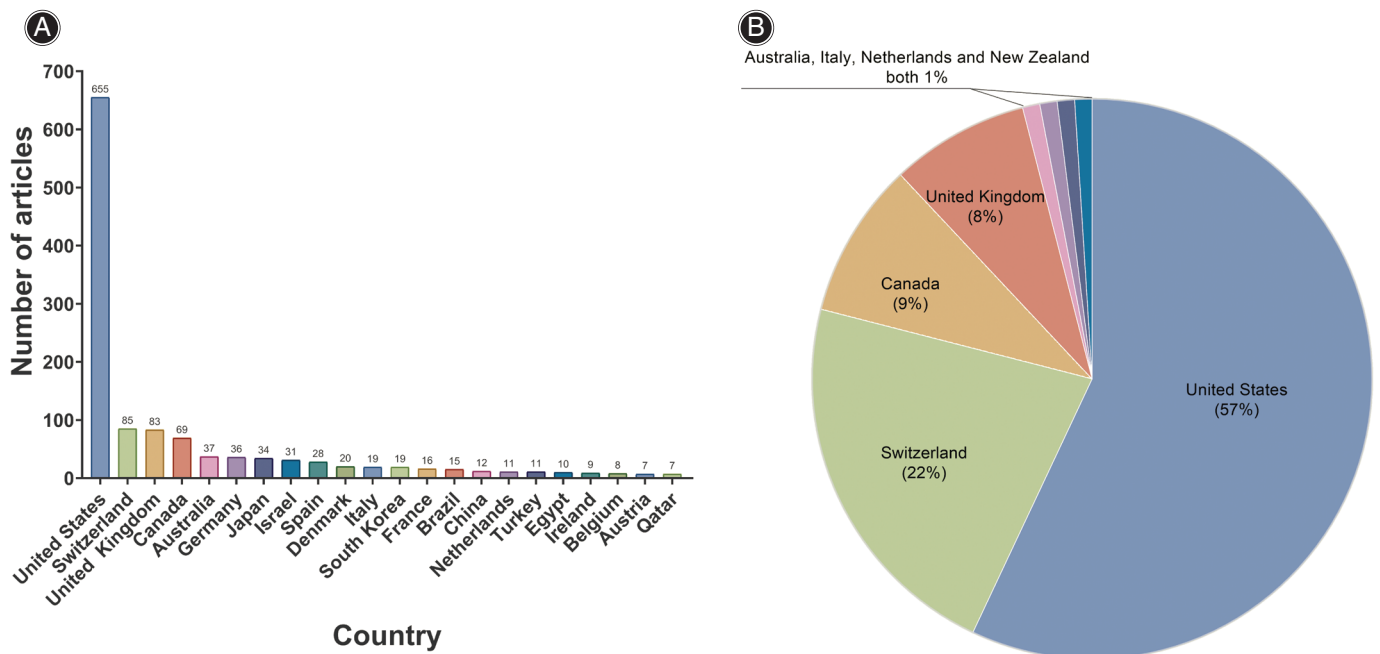


**Fig. 3** Time-dependent citation density trend. The citation density showed a gentle increasing trend.

**TABLE 2** Journal in which the top-cited 100 articles were published

Journal	Country	IF (2019)	Number of articles	Total Citations
Arthroscopy: The Journal of Arthroscopic and Related Surgery	United States	4.325	28	126.79
American Journal of Sports Medicine	United States	5.810	17	13.53
Clinical Orthopaedics and Related Research	United States	4.329	16	204.81
Journal of Bone and Joint Surgery: American Volume	United States	4.578	8	208.88
Journal of Bone and Joint Surgery: British Volume*	United Kingdom	4.306	6	372.83
Radiology	United States	7.931	4	206.75
Clinics in Sports Medicine	United States	2.227	3	84.67
American Journal of Roentgenology	United States	3.013	2	81.50
Current Reviews in Musculoskeletal Medicine	United States	-	2	98.50
Knee Surgery, Sports Traumatology, Arthroscopy	Germany	3.16	2	105.50
British Journal of Sports Medicine	United Kingdom	12.68	1	261.00
European Radiology	Germany	4.101	1	113.00
Journal of Arthroplasty	United States	3.709	1	226.00
Journal of Orthopaedic & Sports Physical Therapy	United States	3.839	1	76.00
Journal of Orthopaedic Research	United Kingdom	2.728	1	235.00
Journal of Orthopaedic Trauma	United States	1.897	1	161.00
Journal of Pediatric Orthopaedics	United States	1.909	1	69.00
Journal of the American Academy of Orthopaedic Surgeons	United States	2.286	1	154.00
Orthopade	Germany	0.823	1	76.00
Physical Therapy	United States	3.140	1	86.00
Pm&R	United States	1.821	1	71.00
Skeletal Radiology	United States	1.618	1	116.00

\* Renamed as **Bone & Joint Journal** after 2013.



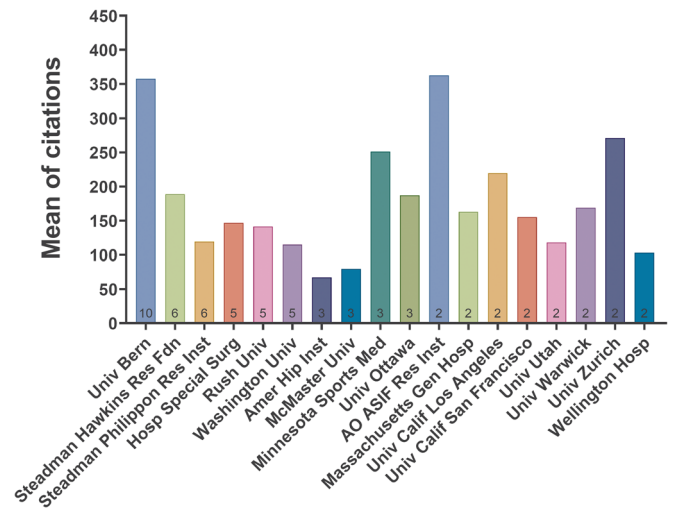
**Fig. 4** Geographical distribution of all articles (A) and the 100 most-cited articles (B). (A and B) Two figures showed that more than half articles came from the United States and the country with the second largest number of articles was Switzerland.

published in 2001. FAI and labral tear is a relatively new area of research. The mean of citation of top 50 articles between the older list and our study is increased from 182.7 to 242.9. *Arthroscopy: The Journal of Arthroscopic and Related Surgery* became the journal with the most number of articles in the new list, while *Clinical Orthopaedics and Related Research*, which was the most prolific journal in the previous list, only ranked three.

This study revealed that the United States is the greatest contributor of articles and Switzerland ranked number two both in all articles (Fig. 4A) and in the top 100 articles (Fig. 4B). The same phenomenon of the contribution of the United States can be seen in other fields<sup>4,9-11,31</sup>. The consideration of leadership of the United States in various scientific research fields is an expected result. Notably, 16 of the involved 22 journals are from United States (Table 2), while it is reported that U.S. reviewers having a significant preference for U.S. papers<sup>32</sup>.

*Arthroscopy: The Journal of Arthroscopic and Related Surgery* came to be the journal that published the maximum number of papers (n = 28), which was different from the previous study<sup>24</sup>. Two influential journals in the field of FAI and labral tear, *American Journal of Sports Medicine* and *Clinical Orthopaedics and Related Research*, published a comparable number of papers on the top 100 articles (17 vs 16 papers).

The University of Bern was the institution with the most articles in top 100 cited articles, followed by Switzerland (Fig. 5). Interestingly, the top eight articles<sup>18,33-39</sup> in our



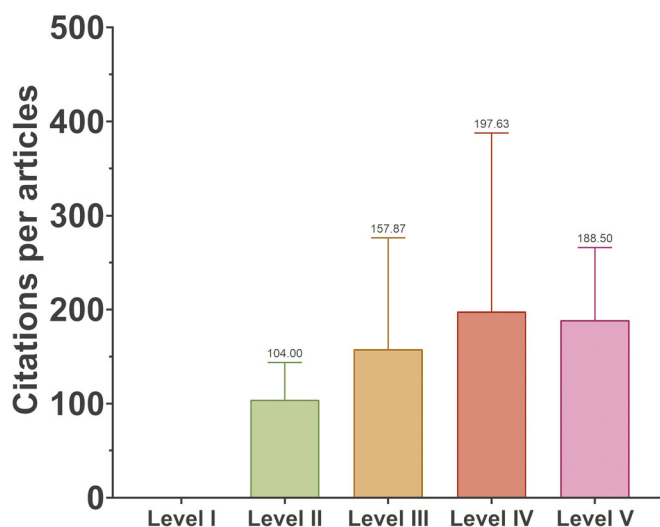
**Fig. 5** Institutions of the 100 most-cited articles. The University of Bern was the institute with most articles (n = 10), followed by Steadman Hawkins Research Foundation and Steadman Philippon Research Institute, both with six articles.

list all originated from Switzerland and five of these articles were affiliated with the University of Bern. It can be explained by the fact that Ganz, as a pioneer in the field of FAI, was from Switzerland and was affiliated to the University of Bern. He and his team have made the concept of FAI

**TABLE 3** Coauthors with the top 10 number of papers in all articles and first authors with two or more articles in the 100 most-cited articles

All articles			The 100 most-cited articles			
Rank	Author	Number of papers	Author	Number of papers	Rank of paper*	Citations per articles
1	Domb, B. G.	109	Philippon, M. J.	6	14, 17, 28, 43, 50, 74	173.33
2	Philippon, M. J.	76	Beck, M.	2	1, 3	851
3	Nho, S. J.	45	Ito, K.	2	2, 42	362.5
4	Kelly, B. T.	42	Espinosa, N.	2	5, 49	229.5
5	Leunig, M.	33	Beaule, P. E.	2	19, 30	215
6	Maldonado, D. R.	34	Frank, R. M.	2	39, 88	116
7	Briggs, K. K.	33	Nepple, J. J.	2	70, 97	75.5
8	Perets, I.	32	Domb, B. G.	2	98, 99	66
9	Ganz, R.	30				
10	Lall, A. C.	31				

\* Rank of paper in the 100 most-cited articles.



**Fig. 6** Mean citations based on level of evidence. Within 73 clinical articles in the 100 most-cited articles, more than half of the articles (n = 41) were level IV evidence with mean citations is 197.6, followed by level III (n = 23), level II (n = 5), and level V (n = 4). However, no clinical article was level I evidence. Fig. 7: Themes distribution. Within the 100 most-cited articles, labral tear (n = 3), FAI (n = 3), comparison of surgery, imaging diagnosis, and outcomes of surgery (both n = 2) were the top four most prevalent themes of review. Outcomes of surgery (n = 23), imaging diagnosis (n = 18), and comparison of surgery (n = 8) were the top three most popular topics of research. MR, magnetic resonance.

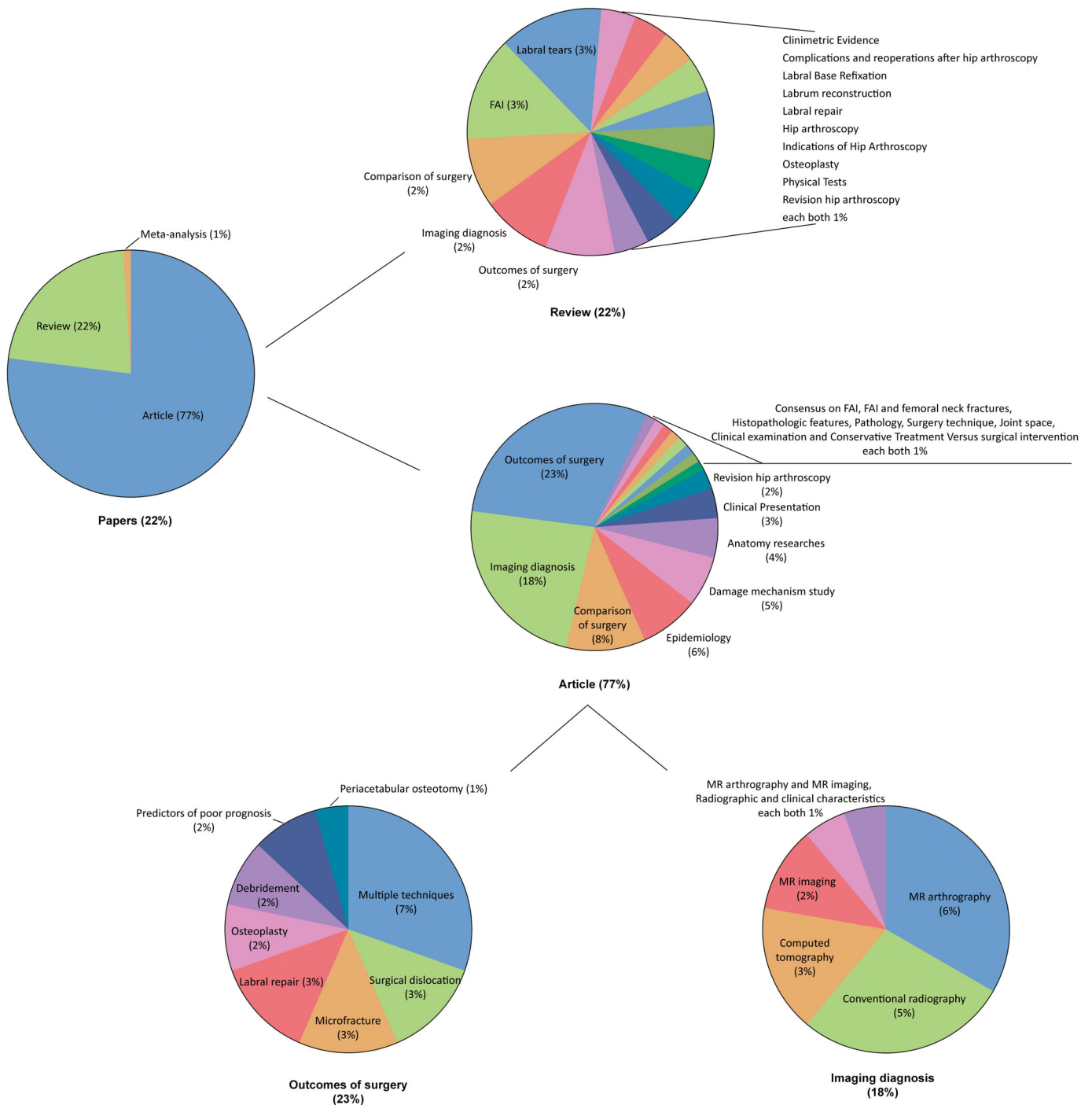
becoming internationally accepted as a common cause of hip pain and dysfunction<sup>15,23,40,41</sup>.

The article with the largest citations (n = 1189) and the largest citation density (n = 79.27) was written in Switzerland by Beck, titled “Hip morphology influences the pattern of damage to the acetabular cartilage – Femoroacetabular impingement

as a cause of early osteoarthritis of the hip” which was published on *Journal of Bone and Joint Surgery-British Volume* in 2005. This case research article mainly focused on the damage mechanisms of FAI, stating that “During movement the labrum is crushed between the acetabular rim and the femoral neck causing degeneration and ossification. Both cam and pincer impingement lead to osteoarthritis of the hip. Labral damage indicates ongoing impingement and rarely occurs alone.”<sup>18</sup>

The article with the second largest citation density is a consensus statement on the diagnosis, treatment principles, and key terminology relating to FAI syndrome and was published in the *British Journal of Sports Medicine* in 2016. The third largest citation density paper was published in *Arthroscopy: The Journal of Arthroscopic and Related Surgery* in 2015<sup>42</sup>. By reviewing the findings of radiographic, CT, or MRI scans, it was concluded that FAI morphologic features and labral injuries were common in asymptomatic patients<sup>43</sup>. The rest of the top 10 articles with largest citation density is listed in Table 1.

Philippon was the only first author owning as many as six items on the 100 most-cited articles list and ranked second as the coauthor among all authors in this field. He reported a new technique for arthroscopic rim trimming of pincer-type femoroacetabular impingement and labral repair through the lateral arthroscopic portal in 2006<sup>44</sup>, reviewed the management of femoroacetabular impingement-osteoplasty technique, reported 37 revisions of hip arthroscopies in 2007<sup>16,45</sup>, analyzed the outcomes of 28 professional hockey players who underwent arthroscopic labral repair and were treated for femoroacetabular impingement in 2010<sup>46</sup>, shared increased alpha angles as a measure of cam-type impingement in 2013<sup>47</sup>, and evaluated the hip fluid seal of acetabular labrum in several pathological conditions in 2014<sup>48</sup>. Domb, another pioneer in this area, was the author with the greatest number of articles with co-authorship in the all-articles list and possessed two articles on the 100 most-cited articles list<sup>49,50</sup>.

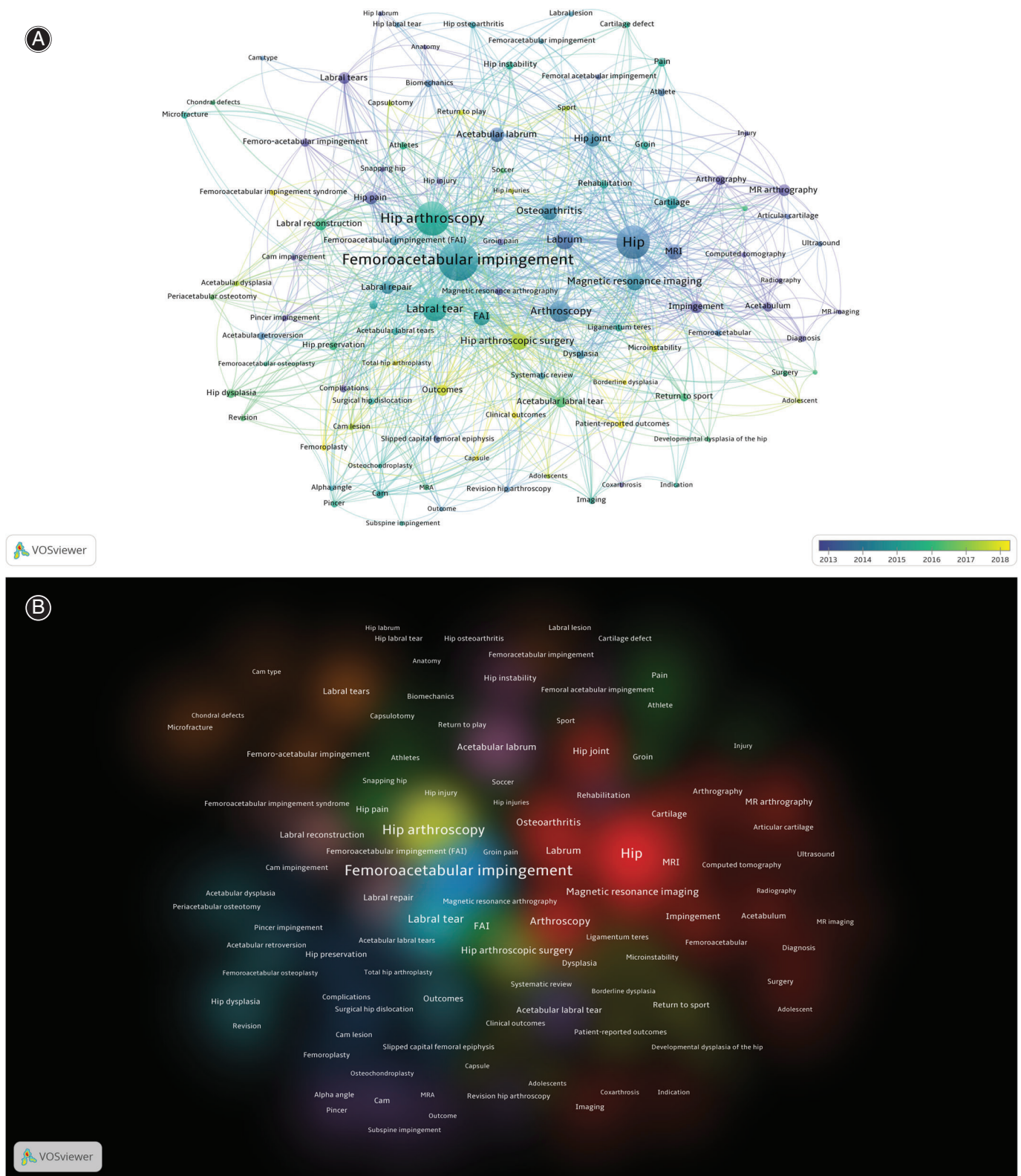


**Fig. 7** Themes distribution

The most popular level of evidence was level IV, with 41 of the 73 clinical studies belonging to this classification. The same result was reported in other orthopaedic studies<sup>4,7,11</sup>. However, there is no publication belonging to level of evidence I in the 100 top-cited articles list. The possible reason is that the earlier studies usually applied

uncontrolled case series or observational research as the main approaches to explore clinical questions. There have been a number of articles published on high-level evidence in recent years<sup>51,52</sup>, but not enough time accumulation for these articles to possess higher citations to become one of the 100 most-cited articles. It also suggests





**Fig. 8** Network analysis of keywords among all articles. (A) overlay visualization, (B) cluster visualization. Of the 927 keywords in 1138 articles, 105 keywords occurred at least four times as shown in the Figure. The size of the circles presents the occurrences of terms. A blue-yellow gradient showed the keywords changed over time.

that more high-level evidence studies are required to be designed in the field.

The 100 most-cited articles consist of 77 research articles, 22 review articles (including 15 reviews and seven systematic reviews), and one meta-analysis. The mean citation per article for review articles was 119.68 times, while for research articles were 176.43 times. Research articles have higher mean citations than that of review articles. The seven systematic reviews respectively ranked 24, 31, 56, 64, 92, and 96 in the top 100 most-cited articles. While systematic reviews are highly cited more than original research papers, this was not apparent in this study. Surgery research (including outcomes of surgery and comparison of surgery) was the most popular theme in both the research articles and review articles. The research objective was mainly focused on surgical dislocation, microfracture, labral debridement, labral repair, proximal femoral osteoplasty, predictors of poor prognosis, and periacetabular osteotomy.

Surgical dislocation technique was first introduced by Ganz in 2001 and it provided an all-round view of femoral head, labrum, and acetabulum without the risk of avascular necrosis<sup>40</sup>. Three articles mainly focused on this approach in our list. Taking advantage of this technique, surgeons can easily probe the location of labral lesion.

The first documented surgical treatment for labral tears was labral debridement. Surgical debridement was reported to relieve symptoms and slow or halt progression toward degenerative joint disease in patients with FAI<sup>53,54</sup>, and the selective debridement reported a favorable outcome by both 5-year and 10-year follow-up<sup>55,56</sup>. However, several studies reported that patients with labral debridement probably end up with osteoarthritis and a high reoperation rate due to the loss of the labrum to sustain the joint stability<sup>57,58</sup>.

After the significance of the labrum was fully recognized and the techniques were developed, the preservation of torn labrum has become the better choice for patients in most cases. Labral repair is reported significantly better than debridement among Harris Hip Score, 12-item short form survey, and visual analogue pain scores<sup>59-61</sup>. Meanwhile, labral tears are often associated with femoral or acetabular chondral injuries<sup>39</sup>. This may explain why three articles in our list mainly focused on microfracture.

It was reported that patients who underwent arthroscopic debridement with femoral osteoplasty (excision of impingement lesion) had a higher proportion of excellent/good results compared with the controls and a significant improvement in the overall quality of life<sup>62,63</sup>. In addition, periacetabular osteotomy was also reported as an effective way to treat the acetabulum with symptomatic anterior femoral acetabular impingement because of acetabular retroversion<sup>35</sup>.

Diagnosis is the second popular theme for articles and reviews in the 100 most-cited papers. Arthroscopy, as the gold standard, is a diagnostic therapeutic approach for FAI and labral tear, but it is only used for patients without an explicit diagnosis after careful history assessment, physical test, and radiographic exam<sup>64</sup>. Therefore, diagnostic imaging

usually is widely used, mainly including magnetic resonance arthrography (MRA), magnetic resonance imaging (MRI), computed tomography (CT), and conventional radiography (anteroposterior view of the pelvis, Dunn view, and cross-table lateral view).

Conventional radiography can perform a specific measurement of femoral head and acetabulum to diagnose FAI and subtle developmental dysplasia of the hip (DDH)<sup>21,65</sup>. Alpha angle is regarded as an important radiological measurement to determine cam-type impingement<sup>23</sup>. It was reported that alpha angle was a prognostic variable and increased alpha angle could be used to predict progression of FAI to labral tear<sup>66,67</sup>. However, it has faced questions of its utility to diagnose FAI and is no longer used in isolation<sup>23</sup>. CT scans are unable to detect labral tears reliably<sup>68,69</sup>, but the cross-over sign along with ischial spine projection is used to diagnose acetabular retroversion is being diagnosed by 3D CT scans<sup>23</sup>.

Standard MRI has only 30% sensitivity and 36% accuracy on diagnosis of labral tears due to it producing underestimation of labral pathology and false-positive results<sup>68,70</sup>. But while the radial-sequence MRI of single hip has been used to diagnose the labral tear, the sensitivity and accuracy has been improved<sup>71,72</sup>.

Compared to MRI, MRA can produce better results, the sensitivity and accuracy increased to 90% and 91% after joint distention, respectively<sup>70,73</sup>. However, compared with surgical findings, MRA still have a limited sensitivity (range from 60% to 100%) and accuracy (range from 44% to 100%)<sup>19</sup>. These studies showed that arthroscopy is still the gold standard of diagnosis<sup>68</sup>.

A network analysis of all the articles showed the interest of research relevant to the field of FAI and labral tear (Fig. 8). "Overlay visualization" was applied to identify author keywords of importance and give relative impact to each keyword based on its calculated value. The keywords could be considered as substitutions of scientific ideas.

"Patient-reported outcomes" is the keyword with the newest average publication year rather than femoroacetabular impingement syndrome. "Clinical outcomes" is one of the newest keywords and "Outcome" is the keyword with highest citations in the network analysis. Meanwhile, the outcomes of surgery are the most popular theme in the 100 most-cited articles. In addition, "Femoroplasty," "Borderline dysplasia," and "Capsule" are also some of the newest keywords and "Alpha angle," "Complications," "Revision hip arthroscopy," and "Systematic review" are the keywords with the higher citations in the network analysis.

With the development of surgical techniques and an increase in the patients treated with these techniques, it is important to evaluate the outcomes of current interventions<sup>74</sup>. The higher number of articles with outcomes research, the higher requirements for instruments to evaluate the index of outcomes.

Patient-reported outcome instruments are widely used to evaluate the patients' activities of daily life and hip pain

and functional outcomes, mainly including Harris Hip Score (HHS), Modified HHS, Merle d'Aubigne Hip Score, 12-item modified Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index, Non-Arthritic Hip Score (NAHS), and Hip Outcome Score (HOS)<sup>74</sup>.

It was reported that only three patient-reported outcome instruments (the HOS, NAHS, and the modified WOMAC Osteoarthritis Index) have shown “clinimetric evidence” (rigor of rating scales and indexes for the description of clinical phenomena) to support their use in measuring outcomes of patients with FAI and labral pathology and that HOS is the most proven instrument<sup>74</sup>. Patient-reported outcome instruments allow surgeons to pay more attention to the problems of patients and have been widely utilized in research and clinical practice<sup>75,76</sup>.

In this study, we present a comprehensive bibliometric analysis of the network analysis of keywords among all articles, themes of the 100 most-cited articles, and other important information in these articles that may provide useful evidence in revealing scientific research interests. In summary, outcomes research is the most popular interest of past and current research, and patient-reported outcome instruments might be further and widely used in the emerging articles in the near future.

There are several limitations to this study. Firstly, although a bibliometric analysis has been utilized to identify the 100 most-cited articles, some influential articles published recently have not had enough time to accumulate high citations and were therefore not included. Second, the 100 most-cited articles were identified in the Web of Science database, while citations from other databases, such as the world's largest academic search engine Google Scholar<sup>77</sup>, were not included. Third, the number of citations of articles could be affected by its publication year because of time-accumulation effect, with the most recent articles being at a disadvantage<sup>5,11</sup>. Fourth, “the snowball effect”<sup>11</sup> and self-

citations may have influenced the citations. Finally, remote papers were less possible to be cited because of the “obliteration by incorporation” phenomenon<sup>7</sup>.

### Conclusion

This article performed a comprehensive bibliometric analysis of publication time, geographical distribution, authorship, research themes, keywords, and levels of evidence of articles in the field of FAI and labral tear research. And it is demonstrated that outcomes research is the most popular interest of research and patient-reported outcome instruments might be further and widely used in emerging articles in the near future. The field of FAI and labral tear has been shown as an obvious trend that is steadily evolving. It could be predicted that there will be an increasing number of publications in the following years, with the United States and Switzerland maintaining leadership in this field.

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### Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

**Table S1.** The 100 most-cited articles on FAI and lateral tear.

**Table S2.** Top 30 keywords in all articles ranked by average publication year.

**Table S3.** Top 30 keywords in all articles ranked by average citations.

### References

- Moed HF. New developments in the use of citation analysis in research evaluation. *Arch Immunol Ther Exp (Warsz)*, 2009, 57: 13–18.
- Zupic I, Cater T. Bibliometric methods in management and organization. *Organ Res Methods*, 2015, 18: 429–472.
- Joyce CW, Kelly JC, Sugrue C. A bibliometric analysis of the 100 most influential papers in burns. *Burns*, 2014, 40: 30–37.
- Huo Y-q, Pan X-h, Li Q-b, et al. Fifty top-cited classic papers in orthopedic elbow surgery: a bibliometric analysis. *Int J Surg*, 2015, 18: 28–33.
- Kim HJ, Yoon DY, Kim ES, Lee K, Bae JS, Lee J-H. The 100 most-cited articles in neuroimaging: a bibliometric analysis. *Neuroimage*, 2016, 139: 149–156.
- Bang CS, Lee JJ, Baik GH. The most influential articles in helicobacter pylori research: a bibliometric analysis. *Helicobacter*, 2019, 24(4): e12589.
- Zhang W, Tang N, Li X, George DM, He G, Huang T. The top 100 most cited articles on total hip arthroplasty: a bibliometric analysis. *J Orthop Surg Res*, 2019, 14(1): 412.
- Zhang Y, Wumaier M, He D, Xiao B, Zhang J. The 100 top-cited articles on spinal deformity: a Bibliometric analysis. *Spine*, 2020, 45: 275–283.
- Holzer LA, Holzer G. The 50 highest cited papers in hip and Knee Arthroplasty. *J Arthroplasty*, 2014, 29: 453–457.
- Baldwin K, Namdari S, Donegan D, Kovatch K, Ahn J, Mehta S. 100 most cited articles in fracture surgery. *Am J Orthop (Belle Mead, NJ)*, 2013, 42: 547–552.
- Lefavre KA, Shadgan B, O'Brien PJ. 100 Most cited articles in Orthopaedic surgery. *Clin Orthop Relat Res*, 2011, 469: 1487–1497.
- Lum ZC, Pereira GC, Giordani M, Meehan JP. Top 100 most cited articles in orthopaedic surgery: an update. *J Orthop*, 2020, 19: 132–137.
- Wang W-g, D-b Y, N-f Z, Hong W, Z-r L. Clinical diagnosis and arthroscopic treatment of acetabular labral tears. *Orthop Surg*, 2011, 3: 28–34.
- Kuhns BD, Weber AE, Levy DM, Wuerz TH. The natural history of Femoroacetabular impingement. *Front Surg*, 2015, 2: 58.
- Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA. Femoroacetabular impingement a cause for osteoarthritis of the hip. *Clin Orthop Relat Res*, 2003, 417: 112–120.
- Philippon MJ, Stubbs AJ, Schenker ML, Maxwell RB, Ganz R, Leunig M. Arthroscopic management of femoroacetabular impingement - Osteoplasty technique and literature review. *Am J Sports med*, 2007, 35: 1571–1580.
- Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. *Clin Orthop Relat Res*, 2004, 418: 74–80.
- Beck M, Kalhor M, Leunig M, Ganz R. Hip morphology influences the pattern of damage to the acetabular cartilage - Femoroacetabular impingement as a cause of early osteoarthritis of the hip. *J Bone Joint Surg*, 2005, 87B: 1012–1018.
- Groh MM, Herrera J. A comprehensive review of hip labral tears. *Curr Rev Musculoskelet med*, 2009, 2: 105–117.
- Wenger DE, Kendell KR, Miner MR, Trousdale RT. Acetabular labral tears rarely occur in the absence of bony abnormalities. *Clin Orthop Relat Res*, 2004, 426: 145–150.

21. Hunt D, Clohisy J, Prather H. Acetabular labral tears of the hip in women. *Phys Med Rehabil Clin N Am*, 2007, 18: 497–520 ix-x.
22. Myers SR, Ejler H, Ganz R. Anterior femoroacetabular impingement after periacetabular osteotomy. *Clin Orthop Relat Res*, 1999, 363: 93–99.
23. Matsumoto K, Ganz R, Khanduja V. Infographic: the history of femoroacetabular impingement. *Bone Joint Res*, 2020, 9: 633.
24. Lee S, Shin J, Haro M, et al. Fifty most cited articles for femoroacetabular impingement and hip arthroscopy. *Front Surg*, 2015, 2: 41.
25. Cassar-Gheiti AJ, Downey RE, Byrne DP, Molony DC, Mulhull KJ. The 25 Most cited articles in arthroscopic Orthopaedic surgery. *Art Ther*, 2012, 28: 548–564.
26. Kolb B, Peterson C, Fadel H, et al. The 25 most cited articles on lateral lumbar interbody fusion: short review. *Neurosurg Rev*, 2021, 44(1): 309–315.
27. Adams AB, Simonson D. Publication, citations, and impact factors of leading investigators in critical care medicine. *Resp Care*, 2004, 49: 276–281.
28. Baltussen A, Kindler CH. Citation classics in critical care medicine. *Intens Care Med*, 2004, 30: 902–910.
29. Baltussen A, Kindler CH. Citation classics in anesthetic journals. *Anesth Analg*, 2004, 98: 443–451.
30. Fan JC, McGhee CNJ. Citation analysis of the most influential authors and ophthalmology journals in the field of cataract and corneal refractive surgery 2000-2004. *Clin Exp Ophthalmol*, 2008, 36: 54–61.
31. Holzer LA, Leithner A, Holzer G. The Most cited papers in osteoporosis and related research. *J Osteoporos*, 2015, 2015: 1–12.
32. Link AM. US and non-US submissions: an analysis of reviewer bias. *JAMA*, 1998, 280: 246–247.
33. Ito K, Minka-Ii MA, Leunig M, Werlen S, Ganz R. Femoroacetabular impingement and the cam-effect - a MRI-based quantitative anatomical study of the femoral head-neck offset. *J Bone Joint Surg*, 2001, 83B: 171–176.
34. Beck M, Leunig M, Parvizi J, Boutier V, Wyss D, Ganz R. Anterior femoroacetabular impingement part II. Midterm results of surgical treatment. *Clin Orthop Relat Res*, 2004, 418: 61–66.
35. Siebenrock KA, Schoeniger R, Ganz R. Anterior femoro-acetabular impingement due to acetabular retroversion - treatment with periacetabular osteotomy. *J Bone Joint Surg*, 2003, 85A: 278–286.
36. Espinosa N, Rothenfluh DA, Beck M, Ganz R, Leunig M. Treatment of femoroacetabular impingement: preliminary results of labral refixation. *J Bone Joint Surg*, 2006, 88A: 925–935.
37. Lavigne M, Parvizi J, Beck M, Siebenrock KA, Ganz R, Leunig M. Anterior femoroacetabular impingement part I. techniques of joint preserving surgery. *Clin Orthop Relat Res*, 2004, 418: 61–66.
38. Pfirrmann CWA, Mengiardi B, Dora C, Kalberer F, Zanetti M, Hodler J. Cam and pincer femoroacetabular impingement: characteristic MR arthrographic findings in 50 patients. *Radiology*, 2006, 240: 778–785.
39. Kelly BT, Weiland DE, Schenker ML, Philippon MJ. Arthroscopic labral repair in the hip: surgical technique and review of the literature. *Art Ther*, 2005, 21: 1496–1504.
40. Ganz R, Gill TJ, Gautier E, Ganz K, Krugel N, Berlemann U. Surgical dislocation of the adult hip - a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. *J Bone Joint Surg*, 2001, 83B: 1119–1124.
41. Ganz R, Leunig M, Leunig-Ganz K, Harris WH. The etiology of osteoarthritis of the hip - an integrated mechanical concept. *Clin Orthop Relat Res*, 2008, 466: 264–272.
42. Griffin DR, Dickenson EJ, O'Donnell J, et al. The Warwick agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. *Br J Sports med*, 2016, 50: 1169–1176.
43. Frank JM, Harris JD, Erickson BJ, et al. Prevalence of Femoroacetabular impingement imaging findings in asymptomatic volunteers: a systematic review. *Art Ther*, 2015, 31: 1199–1204.
44. Philippon MJ, Schenker ML. A new method for acetabular rim trimming and labral repair. *Clin Sports Med*, 2006, 25: 293.
45. Philippon MJ, Schenker ML, Briggs KK, Koppersmith DA, Maxwell RB, Stubbs AJ. Revision hip arthroscopy. *Am J Sport Med*, 2007, 35: 1918–1921.
46. Philippon MJ, Weiss DR, Koppersmith DA, Briggs KK, Hay CJ. Arthroscopic Labral repair and treatment of Femoroacetabular impingement in professional hockey players. *Am J Sport Med*, 2010, 38: 99–104.
47. Philippon MJ, Ho CP, Briggs KK, Stull J, LaPrade RF. Prevalence of increased alpha angles as a measure of cam-type Femoroacetabular impingement in youth ice hockey players. *Am J Sport Med*, 2013, 41: 1357–1362.
48. Philippon MJ, Nepple JJ, Campbell KJ, et al. The hip fluid seal-part I: the effect of an acetabular labral tear, repair, resection, and reconstruction on hip fluid pressurization. *Knee Surg Sport TR A*, 2014, 22: 722–729.
49. Domb BG, El Bitar YF, Stake CE, Trenga AP, Jackson TJ, Lindner D. Arthroscopic Labral reconstruction is superior to segmental resection for irreparable Labral tears in the hip a matched-pair controlled study with minimum 2-year follow-up. *Am J Sport Med*, 2014, 42: 122–130.
50. Domb BG, Stake CE, Botser IB, Jackson TJ. Surgical dislocation of the hip versus arthroscopic treatment of Femoroacetabular impingement: a prospective matched-pair study with average 2-year follow-up. *Art Ther*, 2013, 29: 1506–1513.
51. Ohlin A, Simunovic N, Duong A, Ayeni OR. FIRST Investigators. Low rate of adverse events in a randomized controlled trial addressing the surgical treatment of femoroacetabular impingement (FAI) syndrome. *Knee Surg Sports Traumatol Arthrosc*, 2021, 29(6): 2015–2020.
52. Kemp JL, Coburn SL, Jones DM, Crossley KM. The physiotherapy for Femoroacetabular impingement rehabilitation Study (physioFIRST): a pilot randomized controlled trial. *J Orthop Sport Phys*, 2018, 48: 307.
53. Murphy S, Tannast M, Kim YJ, Buly R, Millis MB. Debridement of the adult hip for femoroacetabular impingement. *Clin Orthop Relat Res*, 2004, 429: 178–181.
54. Guanche CA, Bare AA. Arthroscopic treatment of femoroacetabular impingement. *Art Ther*, 2006, 22: 95–106.
55. Chen AW, Yuen LC, Ortiz-Declet V, Litrenta J, Maldonado DR, Domb BG. Selective debridement with Labral preservation using narrow indications in the hip: minimum 5-year outcomes with a matched-pair Labral repair control group. *Am J Sport Med*, 2018, 46: 297–304.
56. Byrd JWT, Jones KS. Prospective analysis of hip arthroscopy with 10-year Followup. *Clin Orthop Relat Res*, 2010, 468: 741–746.
57. Parvizi J, Bican O, Bender B, et al. Arthroscopy for Labral tears in patients with developmental dysplasia of the hip: a cautionary note. *J Arthroplasty*, 2009, 24: 110–113.
58. Kalore NV, Jiranek WA. Save the torn labrum in hips with borderline Acetabular coverage. *Clin Orthop Relat Res*, 2012, 470: 3406–3413.
59. Larson CM, Giveans MR, Stone RM. Arthroscopic debridement versus Refixation of the Acetabular labrum associated with Femoroacetabular impingement mean 3.5-year follow-up. *Am J Sport Med*, 2012, 40: 1015–1021.
60. Krych AJ, Thompson M, Knutson Z, Scoon J, Coleman SH. Arthroscopic Labral repair versus selective Labral debridement in female patients with Femoroacetabular impingement: a prospective randomized study. *Art Ther*, 2013, 29: 46–53.
61. Larson CM, Giveans MR. Arthroscopic debridement versus Refixation of the Acetabular labrum associated with Femoroacetabular impingement. *Art Ther*, 2009, 25: 369–376.
62. Bardakos NV, Vasconcelos JC, Villar RN. Early outcome of hip arthroscopy for femoroacetabular impingement the role of femoral osteoplasty in symptomatic improvement. *J Bone Joint Surg*, 2008, 90B: 1570–1575.
63. Beaulé PE, Le Duff MJ, Zaragoza E. Quality of life following femoral head-neck osteochondroplasty for femoroacetabular impingement. *J Bone Joint Surg*, 2007, 89A: 773–779.
64. Huffman GR, Safran MR. Arthroscopic treatment of labral tears. *Oper Techn Sport Med*, 2002, 10: 205–214.
65. Garbus DS, Masri BA, Haddad F, Duncan CP. Clinical and radiographic assessment of the young adult with symptomatic hip dysplasia. *Clin Orthop Relat Res*, 2004, 418: 18–22.
66. Audenaert EA, Peeters I, Vigneron L, Baelde N, Pattyn C. Hip morphological characteristics and range of internal rotation in Femoroacetabular impingement. *Am J Sport Med*, 2012, 40: 1329–1336.
67. Johnston TL, Schenker ML, Briggs KK, Philippon MJ. Relationship between offset angle alpha and hip chondral injury in femoroacetabular impingement. *Arthroscopy*, 2008, 24: 669–675.
68. Lewis CL, Sahrman SA. Acetabular labral tears. *Phys Ther*, 2006, 86: 110–121.
69. Santori N, Villar RN. Acetabular labral tears: result of arthroscopic partial limbectomy. *Art Ther*, 2000, 16: 11–15.
70. Czerny C, Hofmann S, Neuhold A, et al. Lesions of the acetabular labrum: accuracy of MR imaging and MR arthrography in detection and staging. *Radiology*, 1996, 200: 225–230.
71. Kubo T, Horii M, Yamaguchi J, et al. Acetabular labrum in hip dysplasia evaluated by radial magnetic resonance imaging. *J Rheumatol*, 2000, 27: 1955–1960.
72. Ueshima K, Takahashi KA, Fujioka M, et al. Relationship between acetabular labrum evaluation by using radial magnetic resonance imaging and progressive joint space narrowing in mild hip dysplasia. *Magn Reson Imaging*, 2006, 24: 645–650.
73. Byrd JWT, Jones KS. Diagnostic accuracy of clinical assessment, magnetic resonance imaging, magnetic resonance arthrography, and intra-articular injection in hip arthroscopy patients. *Am J Sport Med*, 2004, 32: 1668–1674.
74. Lodhia P, Slobogean GP, Noonan VK, Gilbert MK. Patient-reported outcome instruments for Femoroacetabular impingement and hip Labral pathology: a systematic review of the Clinimetric evidence. *Art Ther*, 2011, 27: 279–286.
75. Higginson IJ, Carr AJ. Measuring quality of life - using quality of life measures in the clinical setting. *Br Med J*, 2001, 322: 1297–1300.
76. Bot SDM, Terwee CB, van der Windt D, Bouter LM, Dekker J, de Vet HCW. Clinimetric evaluation of shoulder disability questionnaires: a systematic review of the literature. *Ann Rheum Dis*, 2004, 63: 335–341.
77. Gusenbauer M. Google scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. *Scientometrics*, 2019, 118: 177–214.