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The Most Cited Original Articles on Anterior Cruciate Ligament Injuries in the Past 20 Years

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ABSTRACT: Anterior cruciate ligament (ACL) injuries continue to be a major focus in sports medicine research. With so many changes to our understanding of ACL anatomy and with rapid advances in reconstruction techniques and rehabilitation protocols within the past 20 years, it is important to identify the landmark research that has laid the foundation for current ACL treatments. Using the *Web of Science* citation index, a search was carried out for the 30 most cited articles on ACL injury published in the last 20 years. The generated list was sorted from highest to lowest citation number. Clinical studies were subcategorized as therapeutic, prognostic, diagnostic, or economic/decision analysis and assigned a level of evidence. Basic science articles were designated anatomic, animal, biomechanical, or clinical. The number of citations per year (citation density) was calculated. The search yielded 6,345 articles. The total number of citations among the top 30 ranged from 188 to 611. Citation density ranged from 10.1 to 66.2. Nineteen articles were clinical, 8 were basic science, and 3 were video analyses. Clinical articles were most commonly therapeutic (18 of 19; 95%). Basic science articles were most commonly biomechanical (7 of 8; 88%). The most common level of evidence was Level II (10 of 19; 53%). More than half of the articles in the top 30 (16 of 30; 53%) were published in *The American Journal of Sports Medicine*. Many of these articles have played a large role in shaping current clinical practice regarding ACL injuries. We hope that by compiling this list we can draw attention to the continued need for studies of the highest level of evidence.

KEY WORDS: anterior cruciate ligament injury, ACL, influential articles, citation analysis

I. INTRODUCTION

Evidence-based medicine and peer review continue to shape the clinical practice of medicine through rigorous analysis of outcomes. For this reason, the need to identify articles with the greatest impact on a physician's field of practice has become especially important. It has been suggested that the number of times a paper is cited is an indicator of its overall impact. Studies in orthopedic surgery have addressed this notion by compiling the most frequently cited articles in several different fields.[1–9] These reports have been used to identify trends in literature published over time and patterns in resident and fellow education.

Such publications have ranged in scope from identifying the most cited articles in all of orthopedics to identifying those exclusively related to the shoulder.[1,4] Cassar Gheiti el al. published a list of the 25 most commonly cited articles related to arthroscopy; however, only 5 of them pertain specifically to the anterior cruciate ligament (ACL).[8] We feel this is an inadequate representation of a topic that has dominated the recent literature in sports medicine. Since its inception, ACL surgery has made tremendous advancements both in surgical techniques and in our basic understanding of the anatomy and biomechanics of the ligament itself.[10] Surgical techniques have progressed from early open ACL repair to arthroscopically assisted and all-arthroscopic ligament reconstructions. The importance of anatomic reconstruction continues to be a focal point of recent research as studies aim to find the best ways to recreate the body's natural anatomy.

In an attempt to identify those articles with the greatest impact on current clinical treatment and anatomic understanding, we endeavored to create a list of the most commonly cited articles pertaining to ACL injuries published over the last 20 years.

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II. MATERIALS AND METHODS

In October 2014, we used a *Web of Science* citation index search to identify the 30 most cited articles pertaining to ACL injury published in the last 20 years. The *Web of Science* has an index of over 60 of the best known journals in English in the field of orthopedic surgery. This type of citation search had been employed in previous studies.[1–9]

The search is conducted by entering a key word (or words) into the topic section. A list of pertinent articles containing that key word is then generated. For the purpose of the present study, we entered "'ACL reconstruction' OR 'anterior cruciate ligament reconstruction' OR 'ACL biomechanics' OR 'anterior cruciate ligament biomechanics' OR 'ACL rehabilitation' OR 'anterior cruciate ligament rehabilitation' OR 'ACL surgery' OR 'anterior cruciate ligament surgery' OR 'ACL prevention' OR 'anterior cruciate ligament prevention.'" Both "ACL" and "anterior cruciate ligament" were used as modifiers to ensure that no article was missed based on a particular wording. In the research area modifier section, we entered "orthopedics" and "surgery." The search time frame was set to January 1994 to the present day. These search criteria generated a list that was then arranged from highest number of citations to lowest.

The 30 articles with the highest number of citations were separated and organized into another list that all authors reviewed for relevancy. All meta-analyses and review articles were excluded, as well as any article pertaining to intra-articular knee pathology not specific to the ACL. Meta-analyses were excluded so that the list would specifically contain only the 30 most cited original articles. All authors individually reviewed each article and designated it either basic science or clinical. Basic science articles were further subdivided as anatomic, animal, biomechanical, or in vitro. All clinical studies were assigned a level of evidence and a study type according to the guidelines published by *The Journal of Bone and Joint Surgery–American Volume*. Clinical studies were subdivided as therapeutic, prognostic, diagnostic, or economic/decision analysis. The study designation and the level of evidence given to each article by each author were compared by all authors until consensus was reached.

The following information was collected from each article: author(s), journal, year of publication, number of citations since publication, PubMed ID (PMID), and citation density (number of publications per year since publication).

III. RESULTS

The search criteria yielded a total of 6,345 articles, which were organized from the most to the fewest citations. A list of the top 30 according to the predefined inclusion and exclusion criteria was created (Table 1).[11–40] Among these, the number of total citations in the last 20 years ranged from 188 to 611. The citation density ranged from 10.1 to 66.2. Nineteen articles were clinical studies, 8 were basic science papers, and 3 were video analyses related to injury patterns, which were designated a separate group. Of the clinical studies, 18 of the 19 (95%) were therapeutic and the remaining 1 was diagnostic (1 of 19; 5%). There were no prognostic or economic/decision analyses articles. Seven of the 8 basic science papers (88%) were biomechanical in design, and 1 was anatomic (12%).

Nineteen articles on the list could be assigned a level of evidence. There were 4 Level I studies (21%), 10 Level II studies (53%), and 5 Level IV studies (26%). A total of 8 papers (8 of 30; 27%) were categorized as basic science and could not be assigned a level of evidence. There were 3 video analyses (3 of 30; 10%), which were also not assigned a level of evidence. There were no Level III or Level V studies.

Nine of the 30 articles (30%) dealt with comparing different graft options for ACL reconstruction; 5 (17%) were related to evaluation of intra-articular graft placement during reconstruction; 5 (17%) were related to gender differences in ACL injuries; 3 (10%) analyzed mechanisms of ACL injury; and 2 (7%) treated prevention of ACL injuries, in particular exercise or stretching programs specifically designed to aid prevention. Twenty-two of the 30 articles had been published in the first decade analyzed (1994–2003). Of the 8 articles published since 2004, 4 were Level II; none were Level I. Three of the 5 articles related to gender differences had been published after 2004 (Fig. 1).

TABLE 1: Thirty most cited anterior cruciate ligament articles since 1994

Rank	Title	Number of citations	Citation density	Study type	Level of evidence
1[18]	Daniel DM, Stone ML, Dobsen BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-Injured patient—a prospective outcome study. Am J Sports Med. 1994;22(5):632–644. PMID: 7810787	611	30.6	Therapeutic	II
2[22]	Hewett TE, Myer GD, Ford KR et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sports Med. 2005;33(4):492–501. PMID: 15722287	596	66.2	Therapeutic	II
3[29]	Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. J Orthop Sports Phys Ther. 1998;28(2):88–96. PMID: 9699158	584	36.5	Diagnostic	II
4[16]	Boden BP, Dean GS, Feagin JA Jr, Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. Orthopedics. 2000;23(6):573–578. PMID: 10875418	421	30.1	Video analysis	N/A
5[37]	Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. Am J Sports Med. 2002;30(5):660–666. PMID: 12238998	415	34.6	Basic science (biomechanical)	N/A
6[11]	Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. Am J Sports Med. 1994;22(2):211–217. PMID: 8198189	325	16.3	Therapeutic	II
7[25]	Mandelbaum BR, Silvers HJ, Watanabe DS et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes—2-year follow-up. Am J Sports Med. 2005;33(7):1003–1010. PMID: 15888716	317	35.2	Therapeutic	II

TABLE 1: (*continued*)

Rank	Title	Number of citations	Citation density	Study type	Level of evidence
8[28]	Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. Am J Sports Med. 2004;32(4):1002–1012. PMID: 15150050	306	30.6	Video analysis	N/A
9[24]	Loh JC, Fukuda Y, Tsuda E, Steadman RJ, Fu FH, Woo SL. Knee stability and graft function following anterior cruciate ligament reconstruction: Comparison between 11 o'clock and 10 o'clock femoral tunnel placement. Arthroscopy. 2003;19(3):297–304. PMID: 12627155	291	26.5	Basic science (biomechanical)	N/A
10[27]	Myklebust G, Engebretsen L, Braekken IH, Skjølberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: A prospective intervention study over three seasons. Clin J Sports Med. 2003;13(2):71–78. PMID: 12629423	291	26.5	Therapeutic	II
11[35]	Tashman S, Collon D, Anderson K, Kolowich P, Anderst W. Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. Am J Sports Med. 2004;32(4):975–983. PMID: 15150046	267	26.7	Therapeutic	II
12[19]	Gabriel MT, Wong EK, Woo SL, Yagi M, Debski RE. Distribution of in situ forces in the anterior cruciate ligament in response to rotatory loads. J Orthop Res. 2004;22(1):85–89. PMID: 14656664	259	25.9	Basic science (biomechanical)	N/A
13[17]	Corry IS, Webb JM, Clingeleffer AJ, Pinczewski LA. Arthroscopic reconstruction of the anterior cruciate ligament—a comparison of patellar tendon autograft and four-strand hamstring tendon autograft. Am J Sports Med. 1999;27(4):444–454. PMID: 10424213	255	17.0	Therapeutic	II

TABLE 1: (*continued*)

Rank	Title	Number of citations	Citation density	Study type	Level of evidence
14[31]	Sakane M, Fox RJ, Woo SL, Livesay GA, Li G, Fu FH. In situ forces in the anterior cruciate ligament and its bundles in response to anterior tibial loads. J Orthop Res. 1997;15(2)285–293. PMID: 9167633	252	14.8	Basic science (biomechanical)	N/A
15[38]	Yasuda K, Kondo E, Ichiyama H, et al. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. Arthroscopy. 2004;20(10):1015–1025. PMID: 15592229	242	24.2	Therapeutic	IV
16[32]	Shelbourne KD, Gray T. Anterior cruciate ligament reconstruction with autogenous patellar tendon graft followed by accelerated rehabilitation—a two- to nine-year follow-up. Am J Sports Med. 1997;25(6):786–795. PMID: 9397266	235	13.8	Therapeutic	IV
17[36]	Woo SL, Kanamori A, Zeminski J, Yagi M, Papageorgiou C, Fu FH. The effectiveness of reconstruction of the anterior cruciate ligament with hamstrings and patellar tendon—a cadaveric study comparing anterior tibial and rotational loads. J Bone Joint Surg Am. 2002;84–A(6):907–914. PMID: 12063323	233	19.4	Basic science (biomechanical)	N/A
18[39]	Yasuda K, Kondo E, Ichiyama H, Tanabe Y, Tohyama H. Clinical evaluation of anatomic double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: comparisons among 3 different procedures. Arthroscopy. 2006;22(3):240–251. PMID: 16517306	227	28.4	Therapeutic	II
19[34]	Steiner ME, Hecker AT, Brown CH Jr, Hayes WC. Anterior cruciate ligament graft fixation—comparison of hamstring and patellar tendon grafts. Am J Sports Med. 1994;22(2):240–246. PMID: 8198194	220	11.0	Basic science (biomechanical)	N/A

TABLE 1: (*continued*)

Rank	Title	Number of citations	Citation density	Study type	Level of evidence
20[14]	Beynnon BD, Fleming BC, Johnson RJ, Nichols CE, Renström PA, Pope MH. Anterior cruciate ligament strain behavior during rehabilitation exercises in-vivo. Am J Sports Med. 1995;23(1):24–34. PMID: 7726347	215	11.3	Therapeutic	IV
21[30]	Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. Am J Sports Med. 1999;27(3):312–319. PMID: 10352766	208	13.9	Therapeutic	II
22[20]	Hamner DL, Brown CH Jr, Steiner ME, Hecker AT, Hayes WC. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: biomechanical evaluation of the use of multiple strands and tensioning techniques. J Bone Joint Surg Am. 1999;81(4):549–557. PMID: 10225801	208	13.9	Basic science (biomechanical)	N/A
23[13]	Bach BR Jr, Tradonsky S, Bojchuk J, Levy ME, Bush-Joseph CA, Khan NH. Arthroscopically assisted anterior cruciate ligament reconstruction using patellar tendon autograft—five- to nine-year follow-up evaluation. Am J Sports Med. 1998;26(1):20–29. PMID: 9474397	199	12.4	Therapeutic	IV
24[15]	Beynnon BD, Johnson RJ, Fleming BC, et al. Anterior cruciate ligament replacement: comparison of bone-patellar tendon-bone grafts with two-strand hamstring grafts—a prospective, randomized study. J Bone Joint Surg Am. 2002;84–A(9):1503–1513. PMID: 12208905	197	16.4	Therapeutic	I
25[40]	Yasuda K, Tsujino J, Ohkoshi Y, Tanabe Y, Kaneda K. Graft site morbidity with autogenous semitendinosus and gracilis tendons. Am J Sports Med. 1995;23(6):706–714. PMID: 8600739	192	10.1	Therapeutic	I

TABLE 1: (*continued*)

Rank	Title	Number of citations	Citation density	Study type	Level of evidence
26[33]	Snyder-Mackler L, Delitto A, Bailey SL, Stralka SW. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomized clinical trial of electrical stimulation. J Bone Joint Surg Am. 1995;77(8):1166-1173. PMID: 7642660	192	10.1	Therapeutic	I
27[23]	Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball—video analysis of 39 cases. Am J Sports Med. 2007;35(3):359–367. PMID: 17092928	191	27.3	Video analysis	N/A
28[26]	Muneta T, Sekiya I, Yagishita K, Ogiuchi T, Yamamoto H, Shinomiya K. Two-bundle reconstruction of the anterior cruciate ligament using semitendinosus tendon with endobuttons: operative technique and preliminary results. Arthroscopy. 1999;15(6):618–624. PMID: 10495178	191	12.7	Therapeutic	IV
29[12]	Aune AK, Holm I, Risberg MA, Jensen HK, Steen H. Four-strand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction—a randomized study with two-year follow-up. Am J Sports Med. 2001;29(6):722–728. PMID: 11734484.	188	14.5	Therapeutic	I
30[21]	Harner CD, Baek GH, Vogrin TM, Carlin GJ, Kashiwaguchi S, Woo SL. Quantitative analysis of human cruciate ligament insertions. Arthroscopy. 1999;15(7):741–749. PMID: 10524822	188	12.5	Basic science (anatomic)	N/A

More than half of the articles (16 of 30; 53%) had been published in *The American Journal of Sports Medicine*, whereas 5 had been published in *Arthroscopy* and 4 had been published in *The Journal of Bone and Joint Surgery–American Volume*, Within the same 20-year search period, *The American Journal of Sports Medicine*, *Arthroscopy*, and *The Journal of Bone and Joint Surgery–American Volume* had published a total of 1,125, 1,151, and 202 articles pertaining to the study search criteria, respectively.

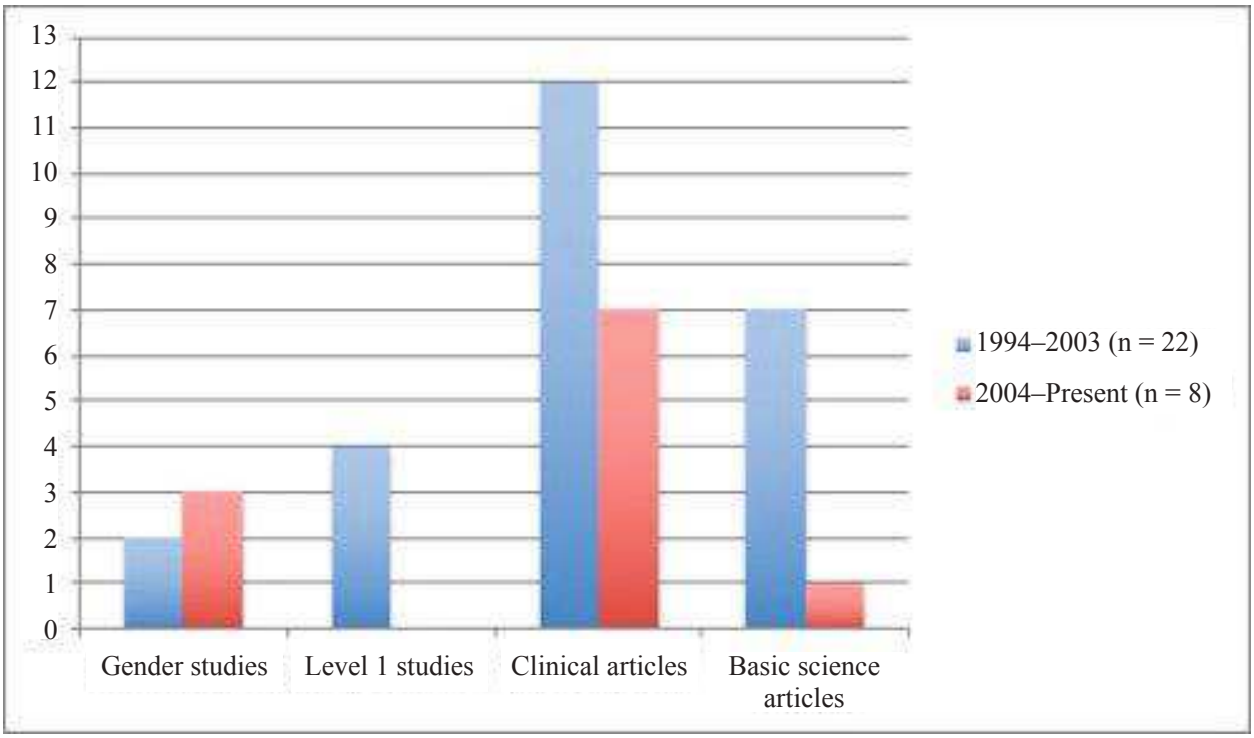

FIG. 1: Comparison of research topics by decade

IV. DISCUSSION

The purpose of this study was to categorize the 30 most commonly cited original articles related to anterior cruciate ligament injuries over the past 20 years. Although prior citation density studies included publications from the early 1900s until the present day, we chose to limit our study in part to highlight the paradigm shift that has occurred in ACL reconstruction since its inception, with ever-increasing attention placed on anatomic graft placement and re-creation of the individual bundle properties, and in part to provide a suitable list of studies that surgeons can reference for evidence-based decisions to use in their current practice.

The majority of study topics on our list relate to comparing graft choices in ACL surgery (9 of 30; 30%), while the second most frequent focus is graft placement and differences in ACL injuries between genders (5 of 30; 17%, respectively). This highlights a few trends in recent ACL literature—specifically regarding the role gender plays in ACL injury patterns—as 4 of the 5 had been published after 2003. Interestingly, the 2 studies related to prevention of ACL injuries dealt exclusively with injuries in female athletes.[25,27]

The majority of studies on our list were Level II clinical studies (10 of 30; 33%), differing from similarly published works for other subspecialties, in which Level IV studies were the most common.[1,4,6,7,9] There were 4 Level I studies on our list as well—all published within the first decade analyzed—accounting for 13% of all studies and 21% of clinical studies. This is a distribution of Level I studies comparable to that found in To et al. analyzing the 50 most cited articles in hand surgery within the last 20 years.[9] To et al. cite the recent focus on evidence-based medicine as the reason for a larger portion of Level I studies, contrasting with Lefaivre's compilation of the 100 most cited articles in orthopedics, which encompassed all time frames and in which less than 5% reported Level I studies.[4] We were surprised to find that none of the Level I studies published after 2003 had sufficient citations to make

this list. This could certainly be a result of insufficient time in publication to accumulate citations; in any case, it serves to reinforce the continued need for a high level of evidence in studies pertaining to ACL injury. The density of Level II prospective cohort studies on the present list emphasizes the variety of surgical techniques available for ACL reconstruction as well as the focus on evaluating the most ideal graft choice and surgical technique in recent ACL literature (bone-patellar tendon-bone autograft versus hamstrings, double-bundle versus single-bundle reconstruction, etc.).

Like To et al., we chose to exclude meta-analyses and review articles from our list.[9] This was in order to specifically highlight only original works of research with the highest impact in sports medicine. Although meta-analyses are an important element of evidence-based medicine and have a strong influence on the field of orthopedics, we felt a list solely comprising the most cited original works would be more useful for educational purposes.

While reviewing and assigning levels of evidence to the listed articles, the authors came upon a unique challenge and identified an area in need of clarification regarding evidence levels. Video analyses are prominent among the most commonly cited ACL papers, with 3 among the top 30. Krosshaug et al. designate their study a Level IV case series; however, we would argue that theirs and the other two video analyses do not fit the standard level-of-evidence classification.[6,16,23] This issue identifies both a growing trend with regard to study type and the need for consensus in the orthopedic community regarding video-based studies and the correct way to identify their utility with respect to other types of peer-reviewed research. Such a potential deficiency in levels of evidence remains despite a recently published update on *JBJS* evidence levels by Marx et al.[41] Although Marx et al. did not change any of the assigned levels in the present list, the subtle changes in categories did help to solidify decisions on evidence level for difficult studies. Unfortunately, the update still offered no help on how best to address video analyses.

Compiling our reference list provided a chance to critically assess the current body of highly cited ACL literature. Using it, we could identify possible deficiencies as well as potential areas deserving greater focus in the future. Despite the presence of 4 Level I studies within the last 20 years, the lack of highly cited such studies published after 2003 demonstrates that continued efforts must be made to produce research of the highest quality. We also found that 2 studies in the top 10 focused on prevention strategies for ACL injuries; both had been published after 2003. These publications have amassed 317 and 291 citations in just over ten years, respectively, illustrating that ACL injury prevention is an area of growing interest deserving further exploitation.[25,27] There were also no economic/decision analysis studies on our list. Considering the ever-changing landscape of current health care, studies of this nature may have tremendous practical value and should be pursued. It is noteworthy that our list specifically includes only articles with the highest number of citations, and it is certainly possible that publications in the aforementioned areas, although they can be found in the current literature, have so far failed to obtain enough citation density. This serves to reinforce the fact that physicians of all kinds have a responsibility to keep well abreast of current literature in their field.

As practicing surgeons and resident/fellow educators, we strongly believe that a proper understanding of the modern, scientific influences on ACL surgery is critical to guiding future practice and clinical decision making. Knowledge of a surgical procedure's technical evolution is important; however, keeping informed of the most recently published findings on and techniques involved in that procedure is vital to maintaining a reliable clinical practice and guiding future research. Thus, the generated list of the most recently published studies can serve as a useful educational reference for the orthopedic community, especially residents and fellows entering sports medicine. In order to make the list more useful, we included the PubMed ID (PMID) for each study on the list for easy access.

This study is not without weaknesses. Primarily, the search results were entirely dependent on the accuracy of the *Web of Science* citation index search, which does not include textbook chapters or presentations at annual meetings. By selecting the research area subsets "orthopedics" and "surgery," we may

have excluded nonsurgical journal titles. Moreover, number of citations does not necessarily correlate with overall quality or clinical impact. Indeed, the frequency with which an article is referenced can be influenced by self-citation as well as by what Lefaivre terms the "snowball effect," in which studies are cited because they were cited in referenced papers and not because of their quality or content.[4] These same limitations have been encountered by all similar citation-based studies.[1–6,8,9,16]

To summarize, we have created a list of the 30 most cited articles related to anterior cruciate ligament injury within the past 20 years. Our hope is that this list not only will help shape future research by identifying specific areas of interest but also will serve as an educational adjunct for orthopedic residents, fellows, and practicing surgeons.

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