International Orthopaedics (SICOT) (2017) 41:1405–1412
DOI 10.1007/s00264-017-3513-3

ORIGINAL PAPER

The fifty highest cited papers in anterior cruciate ligament injury

Ines Vielgut[1] · **Jan Dauwe**[1,2] · **Andreas Leithner**[1] · **Lukas A. Holzer**[1]

Received: 4 January 2017 / Accepted: 7 May 2017 / Published online: 27 May 2017

Abstract
Introduction The anterior cruciate ligament (ACL) is one of the most common injured knee ligaments and at the same time, one of the most frequent injuries seen in the sport orthopaedic practice. Due to the clinical relevance of ACL injuries, numerous papers focussing on this topic including biomechanical-, basic science-, clinical- or animal studies, were published. The purpose of this study was to determine the most frequently cited scientific articles which address this subject, establish a ranking of the 50 highest cited papers and analyse them according to their characteristics.
Methods The 50 highest cited articles related to Anterior Cruciate Ligament Injury were searched in Thomson ISI Web of Science® by the use of defined search terms. All types of scientific papers with reference to our topic were ranked according to the absolute number of citations and analyzed for the following characteristics: journal title, year of publication, number of citations, citation density, geographic origin, article type and level of evidence.
Results The 50 highest cited articles had up to 1624 citations. The top ten papers on this topic were cited 600 times at least. Most papers were published in the American Journal of Sports Medicine. The publication years spanned from 1941 to 2007, with the 1990s and 2000s accounting for half of the articles (n = 25). Seven countries contributed to the top 50 list, with the USA having by far the most contribution (n = 40). The majority of articles could be attributed to the category "Clinical Science & Outcome". Most of them represent a high level of evidence.
Discussion Scientific articles in the field of ACL injury are highly cited. The majority of these articles are clinical studies that have a high level of evidence. Although most of the articles were published between 1990 and 2007, the highest cited articles in absolute and relative numbers were published in the early 1980s. These articles contain well established scoring- or classification systems.
Conclusion The identification of important papers will help current clinicians and scientists to get an overview on past and current trends in that special field of ACL injury and provides a basis for both further discussion as well as future research.

Keywords Anterior cruciate ligament · Injury · Bibliographic analysis

Introduction

The anterior cruciate ligament (ACL) is one of the most common injured knee ligaments and at the same time, one of the most frequent injuries seen in orthopaedic practice.

There are various predisposing factors for ACL injury, including neuromuscular and biomechanical abnormalities, mutations within collagen producing genes, female sex hormones, abnormal joint laxity, and primary structural influences of the knee [1–4].

ACL rupture is a serious knee injury that affects mainly physically active young people [5]. It is usually the result of a non-contact injury whereby a combination of movements such as femoral adduction and internal rotation, knee flexion, or tibial rotation with the foot and ankle in valgus result in partial or complete anterior cruciate ligament tears [6]. The injury is characterized by joint instability, which is associated

✉ Lukas A. Holzer
lukas.holzer@medunigraz.at

[1] Department of Orthopaedics and Trauma, Medical University of Graz, Auenbruggerplatz 5, 8036 Graz, Austria

[2] Department of Orthopaedic Surgery, University Hospitals Leuven, Weligerveld 1, 3212 Lubbeek, Belgium

with an increased risk of early secondary osteoarthritis of the knee [7]. Treatment options range from non-operative strategies including physiotherapy, bracing and the modification of physical activity, to surgical reconstruction of the ligament. Especially for sports-active patients and athletes, as well as for patients with complex knee (−ligament) injuries, the operative treatment seems to be the procedure of choice [8, 9].

Given the clinical relevance of this injury, numerous scientific papers focusing on this topic, including biomechanical-, basic science-, clinical- or animal studies, were published.

The purpose of this study was to determine the most frequently cited scientific articles which address the subject of anterior cruciate ligament injuries and to establish a ranking of the 50 highest cited papers by the use of the Thomson ISI Web of Science® Database.

Analyses of most cited papers have been performed in various medical disciplines such as orthopaedic surgery or plastic surgery, various diseases such as burns or osteoporosis and a variety of orthopaedic subspecialties including arthroplasty, shoulder-, foot- or hand surgery [10–14]. However, no such study has been done focusing on "ACL injury".

Purpose

The purpose of this study was to determine the 50 highest cited articles in ACL injury research in order to provide clinicians, researchers, and trainees a list of "citation classics" on the topic of ACL injury, including an analysis of the papers' characteristics (year of publication, number of citations, citation density, geographic origin, article type, and level of evidence).

Methods

Search strategy

In July 2016, Thomson ISI Web of Science® was searched for the following search terms "Cruciate", "Cruciate Ligament", "ACL", "Gracilis", "Gracilis Tendon" "Semitendinosus", "Semitendinosus Tendon", "Patella Tendon", "Hamstring", "Knee Ligament", "Ligament" "Quadriceps Tendon", "Instability", "Joint Instability", "PCL", "Unhappy Triad", "Arthroscopy", "Reconstruction", "Drawer Test", "Drawer Sign", "Lachmann", "Pivot Shift".

After completion of the search, the search output was recorded. Scientific papers with no direct reference to the topic were excluded. All types of scientific papers with reference to the ACL were included in the study and ranked according to the number of highest citations. In cases with identical absolute numbers of citations, papers with higher citation density (see below) were ranked higher. A list of the 50 highest cited articles was established. The initial search with the above described search terms was done by a medical student (J.D.). Subsequently the articles were analyzed by an Orthopaedic surgeon (L.A.H.) who decided which studies were included in the definitive list of the 50 highest cited articles in ACL injury.

Data analysis

Each of the 50 highest cited articles was reviewed for the following information in order to create a list: article title, journal title, year of publication, and origin of the corresponding author. Each paper was assigned to a single country according to the corresponding author's address because of the corresponding author's primary responsibility for the study [15].

In order to determine the relative impact of a published paper, the citation density, the number of citations per year since publication, was calculated as mentioned above [16].

Furthermore, the level of evidence of each clinical article irrespective of the journal, where it was published, was set using the Journal of Bone and Joint Surgery, American Volume authors' guidelines that are published online [17].

All papers were sorted according to the scientific category including "Clinical Science & Outcome", "Basic Science", "Classification & Scoring System", "Review & Meta-analysis".

At last, all papers' content was screened and each article was assigned to one of the following categories: "Anatomy & Biomechanics", "Classification & Scoring System", "Imaging", "Injury Mechanism", "Prevention & Rehabilitation", "Surgical Technique & Outcome" and "Tissue Engineering".

Results

The 50 highest cited articles on ACL injury were cited from 315 to 1624 times. The top ten papers according to absolute numbers were cited at least 600 times. The 50 highest cited papers according to the absolute number of citations can be seen in Table 1.

The majority of articles could be attributed to the category Clinical Science & Outcome (n = 20). Within this category, level of evidence could be analyzed in 14 clinical papers, primarily distributed in level II (n = 10) and level III (n = 3) papers. One paper was categorized as level of evidence V (expert opinion). The distribution of the other categories can be seen in Fig. 1.

Most papers (n = 22) were published in the *American Journal of Sports Medicine*. Other journals include the *Journal of Bone and Joint Surgery; American and British Volume*, *Clinical Orthopaedics and Related Research, Biomaterials, Medicine and Science in Sports and Exercise, Orthopaedics, Radiology, Clinical Biomechanics, Clinical Journal of Sports Medicine, Arthroscopy, Journal of Athletic Training* and *Arthritis and Rheumatism*. The distribution of

Table 1 The 50 highest cited papers in anterior cruciate ligament injury

Rank	Article	Absolute number of citations	Citation density	Scientific category	Level of evidence
1	Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res. 1985 Sep;(198):43–9	1624	52.4	Classification & scoring system	N/A
2	Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med. 1982 May-Jun;10(3):150–4	1347	39.6	Classification & scoring system	N/A
3	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 Aug;28(2):88–96	840	46.7	Classification & scoring system	N/A
4	Hewett TE, Myer GD, Ford KR, Heidt RS Jr., Colosimo AJ, McLean SG, van den Bogert AJ, Paterno MV, Succop P. 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 Apr;33(4):492–501	829	75.4	Injury mechanism	II
5	Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. Am J Sports Med. 1995 Nov-Dec;23(6):694–701	758	36.1	Injury mechanism	N/A
6	Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. J Bone Joint Surg Am. 1984 Mar;66(3):344–52	739	23.1	Anatomy & biomechanics	N/A
7	Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient. A prospective outcome study. Am J Sports Med. 1994 Sep-Oct;22(5):632–44	687	31.2	Surgical technique & outcome	II
8	Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. Am J Sports Med. 1999 Nov-Dec;27(6):699–706	672	39.5	Prevention & rehabilitation	II
9	Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF. Tendon-healing in a bone tunnel. A biomechanical and histological study in the dog. J Bone Joint Surg Am. 1993 Dec;75(12):1795–803	653	28.4	Anatomy & biomechanics	N/A
10	Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med. 2007 Oct;35(10):1756–69. Epub 2007 Aug 29	601	66.8	Surgical technique & outcome	N/A
11	Girgis FG, Marshall JL, Monajem A. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clin Orthop Relat Res. 1975 Jan-Feb;(106):216–31	597	14.6	Anatomy & biomechanics	N/A
12	Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. Am J Sports Med. 1990 May-Jun;18(3):292–9	591	22.7	Prevention & rehabilitation	N/A
13	Noyes FR, Mooar PA, Matthews DS, Butler DL. The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. J Bone Joint Surg Am. 1983 Feb;65(2):154–62	541	16.4	Surgical technique & outcome	III
14	Boden BP, Dean GS, Feagin JA Jr., Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. Orthopaedics. 2000 Jun;23(6):573–8	530	33.1	Injury mechanism	III
15	Altman GH, Horan RL, Lu HH, Moreau J, Martin I, Richmond JC, Kaplan DL. Silk matrix for tissue engineered anterior cruciate ligaments. Biomaterials. 2002 Oct;23(20):4131–41	525	47.7	Tissue engineering	N/A
16	Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. Arthritis Rheum. 2004 Oct;50(10):3145–52	516	43.0	Surgical technique & outcome	III
17	Woo SL, Hollis JM, Adams DJ, Lyon RM, Takai S. Tensile properties of the human femur-anterior cruciate ligament-tibia complex. The effects of specimen age and orientation. Am J Sports Med. 1991 May-Jun;19(3):217–25	497	19.9	Anatomy & biomechanics	N/A
18	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 Sep-Oct;30(5):660–6	490	35.0	Anatomy & biomechanics	N/A

Table 1 (continued)

Rank	Article	Absolute number of citations	Citation density	Scientific category	Level of evidence
19	Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. J Athl Train. 2007 Apr-Jun;42(2):311–9	487	54.1	Prevention & rehabilitation	N/A
20	Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med. 1996 Nov-Dec;24(6):765–73	467	27.5	Prevention & rehabilitation	II
21	Solomonow M, Baratta R, Zhou BH, Shoji H, Bose W, Beck C, D'Ambrosia R. The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. Am J Sports Med. 1987 May-Jun;15(3):207–13	458	15.8	Anatomy & biomechanics	N/A
22	Noyes FR, Grood ES. The strength of the anterior cruciate ligament in humans and Rhesus monkeys. J Bone Joint Surg Am. 1976 Dec;58(8):1074–82	442	11.1	Anatomy & biomechanics	N/A
23	Gollehon DL, Torzilli PA, Warren RF. The role of the posterolateral and cruciate ligaments in the stability of the human knee. A biomechanical study. J Bone Joint Surg Am. 1987 Feb;69(2):233–42	427	14.7	Anatomy & biomechanics	N/A
24	Kurosaka M, Yoshiya S, Andrish JT. A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. Am J Sports Med. 1987 May-Jun;15(3):225–9	406	14.0	Anatomy & biomechanics	N/A
25	Sachs RA, Daniel DM, Stone ML, Garfein RF. Patellofemoral problems after anterior cruciate ligament reconstruction. Am J Sports Med. 1989 Nov-Dec;17(6):760–5	400	14.8	Surgical technique & outcome	II
26	Mandelbaum BR, Silvers HJ, Watanabe DS, Knarr JF, Thomas SD, Griffin LY, Kirkendall DT, Garrett W Jr. 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 Jul;33(7):1003–10	393	357	Prevention & rehabilitation	II
27	Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. J Orthop Res. 1995 Nov;13(6):930–5	392	18.7	Anatomy & biomechanics	N/A
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 Jun;32(4):1002–12	389	32.4	Injury mechanism	N/A
29	Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part I. The medial compartment and cruciate ligaments. J Bone Joint Surg Am. 1976 Mar;58(2):159–72	383	9.6	Classification & scoring system	N/A
30	Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. Med Sci Sports Exerc. 2003 Oct;35(10):1745–50	381	29.3	Anatomy & biomechanics	N/A
31	Longo UG, Oliva F, Denaro V, Maffulli N. Oxygen species and overuse tendinopathy in athletes. Disabil Rehabil. 2008;30(20–22):1563–71	379	34.5	Injury mechanism	N/A
32	Noyes FR, DeLucas JL, Torvik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain-rate sensitivity and mechanisms of failure in primates. J Bone Joint Surg Am. 1974 Mar;56(2):236–53	376	9.0	Anatomy & biomechanics	N/A
33	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 Mar-Apr;22(2):211–7	359	16.3	Surgical technique & outcome	II
34	Grood ES, Stowers SF, Noyes FR. Limits of movement in the human knee. Effect of sectioning the posterior cruciate ligament and posterolateral structures. J Bone Joint Surg Am. 1988 Jan;70(1):88–97	355	12.7	Anatomy & biomechanics	N/A
35	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. 2002 Richard O'Connor Award paper. Arthroscopy. 2003 Mar;19(3):297–304	350	26.9	Surgical technique & outcome	N/A
36	Noyes FR, Bassett RW, Grood ES, Butler DL. Arthroscopy in acute traumatic hemarthrosis of the knee. Incidence of anterior cruciate tears and other injuries. J Bone Joint Surg Am. 1980 Jul;62(5):687–95, 757	350	9.7	Surgical technique & outcome	II

Table 1 (continued)

Rank	Article	Absolute number of citations	Citation density	Scientific category	Level of evidence
37	Daniel DM, Stone ML, Sachs R, Malcom L. Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. Am J Sports Med. 1985 Nov-Dec;13(6):401–7	349	11.3	Anatomy & biomechanics	N/A
38	Lee CH, Shin HJ, Cho IH, Kang YM, Kim IA, Park KD, Shin JW. Nanofiber alignment and direction of mechanical strain affect the ECM production of human ACL fibroblast. Biomaterials. 2005 Apr;26(11):1261–70	348	31.6	Tissue engineering	N/A
39	Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clin Biomech (Bristol, Avon). 2001 Jun;16(5):438–45	345	23.0	Surgical technique & outcome	N/A
40	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 Sport Med. 2003 Mar;13(2):71–8	344	26.5	Surgical technique & outcome	II
41	Griffin LY, Albohm MJ, Arendt EA, Bahr R, Beynnon BD, Demaio M, Dick RW, Engebretsen L, Garrett WE Jr., Hannafin JA, Hewett TE, Huston LJ, Ireland ML, Johnson RJ, Lephart S, Mandelbaum BR, Mann BJ, Marks PH, Marshall SW, Myklebust G, Noyes FR, Powers C, Shields C Jr., Shultz SJ, Silvers H, Slauterbeck J, Taylor DC, Teitz CC, Wojtys EM, Yu B. Valley II meeting, January 2005. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt. Am J Sports Med. 2006 Sep;34(9):1512–32	334	33.4	Prevention & rehabilitation	V
42	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 Jun;32(4):975–83	333	27.8	Anatomy & biomechanics	N/A
43	Marder RA, Raskind JR, Carroll M. Prospective evaluation of arthroscopically assisted anterior cruciate ligament reconstruction. Patellar tendon versus semitendinosus and gracilis tendons. Am J Sports Med. 1991 Sep-Oct;19(5):478–84	331	13.2	Surgical technique & outcome	II
44	Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR Jr. Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. Am J Sports Med. 2003 Jan-Feb;31(1):2–11	329	25.3	Surgical technique & outcome	N/A
45	Amis AA, Dawkins GP. Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. J Bone Joint Surg Br. 1991 Mar;73(2):260–7	329	13.2	Anatomy & biomechanics	N/A
46	Brantigan OC, Voshell AF. The mechanics of the ligaments and menisci of the knee joint. J Bone Joint Surg Am. 1941 Jan. 23 (1):44–66	325	4.3	Anatomy & biomechanics	N/A
47	Frank CB, Jackson DW. The science of reconstruction of the anterior cruciate ligament. Bone Joint Surg Am. 1997 Oct;79(10):1556–76	322	16.9	Surgical technique & outcome	N/A
48	Mink JH, Levy T, Crues JV 3rd. Tears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. Radiology. 1988 Jun;167(3):769–74	321	11.5	Imaging study	N/A
49	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 Jan;22(1):85–9	318	26.5	Anatomy & biomechanics	N/A
50	Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer – A 13-year review. Am J Sports Med. 2005 Apr;33(4):524–30	315	28.6	Injury mechanism	N/A

the highest cited papers in the various journals can be seen in Fig. 2.

Seven countries contributed to the top 50 list, with the USA having the most contributions (n = 40), followed by Sweden with three, the UK and Norway with two each, and Canada, Italy and South Korea with one each.

The number of highest cited papers according to the decade of publication can be found in Fig. 3. The majority of papers were published since 1990 (n = 32), the remaining publications are related to the 1970s and 1980s. Within the list of the 50 most cited articles with regard to our topic, none was published during the last six years.

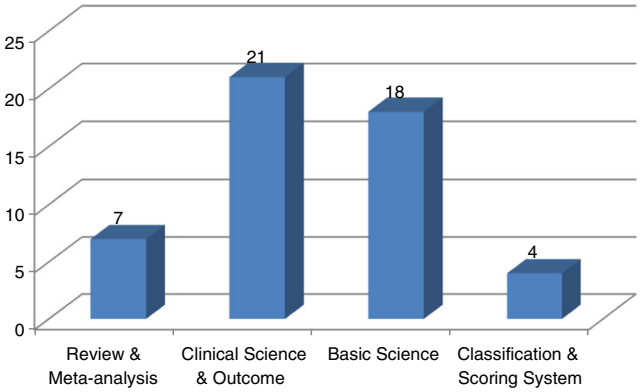

Fig. 1 Distribution of highest cited papers according to categories

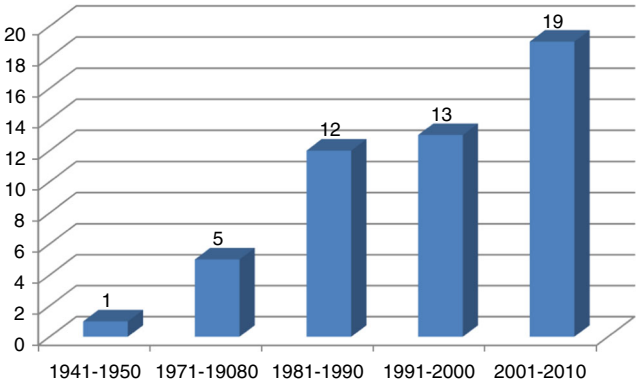

Fig. 3 Number of highest cited papers according to decade of publication

The distribution of the various scientific topics covered in the list of the 50 highest cited articles can be seen in Fig. 4. Papers in in the basic scientific fields of "Anatomy & Biomechanics" were most frequent.

Discussion

The purpose of this study was to determine the 50 highest cited articles in ACL injury research in order to provide clinicians, researchers, and trainees a list of "citation classics" on the topic of ACL injury, including an analysis of the papers' characteristics, content, and clinical significance.

The ACL is one of the most common injured ligaments of the knee. Therefore, ACL injuries have a high impact on the individual, but also on healthcare systems worldwide. Given the strong scientific interest raised by this topic, both in the older as well as in current literature, we tried to identify the most significant articles on the subject of ACL injury. Therefore, we did a literature search based on Thomson ISI Web of Science®, in order to create a list of highest cited papers on that topic, regardless of the age and category of these articles.

Although a high number of total citations may not be the only parameter to determine the influence or clinical importance of an article, it can be considered as a parameter for the scientific relevance on a specialized subject [18–20, 23]. Furthermore, such an analysis allows identifying the research activity in various fields.

Articles on ACL injury were cited up to 1624 times, with the top ten articles on this topic being cited at least 600 times. These numbers are lower than the highest cited papers in the industry driven field of arthroplasty [15]. However, the number of citations seems to be quite high when compared to the most cited articles in the subspecialty "Orthopaedic Cartilage Surgery", for example, which may be a comparable "hot topic" in the recent orthopaedic literature. The highest cited paper on this topic has reached 989 citations [19]. This is even more clear, when compared to highest cited papers in hand and shoulder surgery or paediatric orthopaedics [10–14].

The majority of articles could be attributed to the category Clinical Science & Outcome. Most of the articles in this group, on which a level of evidence could be assigned to, were based on level II and level III studies. Despite of one article, which was referred to as a level V article (expert opinion), no clinical studies with lower levels of evidence could reach a sufficient number of citations to join the list of the 50 highest cited papers. This will unlikely change or will even provide papers with a higher level of evidence in future publications

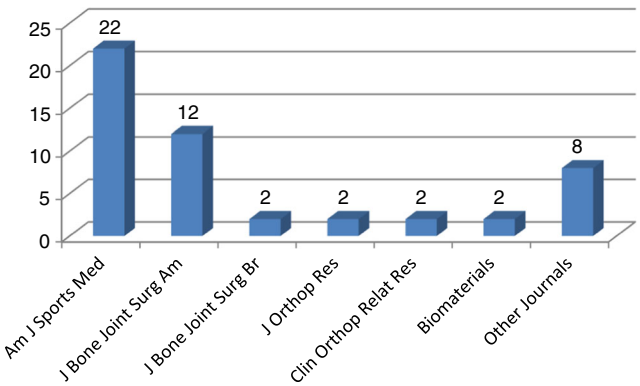

Fig. 2 Distribution of the highest cited papers according to the published journal

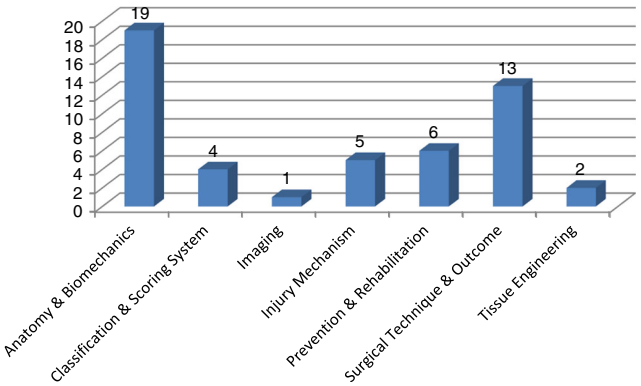

Fig. 4 Distribution of various topics covered in the list of the 50 highest cited articles

due to the trend toward prospective-randomized trials and the focus on evidence-based medicine. [24].

These point to the fact that there are numerous high quality papers in the field of ACL injury research, especially when compared to other fields such as arthroplasty, where most papers were level of evidence IV [15].

The second frequent article type fell within the category of Basic Science. These articles are predominantly based on anatomic- and/or biomechanical cadaver studies. This shows that there is ongoing research incorporating novel techniques and technologies. Therefore, further "citation classics" are to be expected in this field. Interestingly, the three highest cited papers fall within the category "Classification & Scoring System". These articles are simultaneously the ones with the highest citation density. These include the frequently applied and worldwide known Tegner-Lysholm Knee Scoring Scale and the Knee Injury and Osteoarthritis Outcome Score, initially developed for the evaluation of knee ligament injuries [21–23]. These manuscripts are the real "classics", as they continue to be highly cited in research and are used in clinical practice frequently. A comparable high number of citations of classification or scoring systems have also been seen in other disciplines or subspecialities [25–28].

Particularly remarkable, when considering the article categories and contents, is the poor representation of papers focussing on surgical ACL repair techniques. The evolution of surgical treatment has undergone a paradigm shift over the decades, starting with the technique of open, primary repair of the ACL with all its biases as described in the corresponding literature. The subsequent developments, such as MRI and arthroscopy resulted in minimally-invasive techniques for ACL reconstruction- or augmentation. Solely, semitendinosus versus patellar tendon as an autograft used for ACL reconstruction were discussed in three of the listed papers. Anatomic and biomechanical studies, focussing mainly on anatomical, functional, and experimental analysis of the tissue-texture of both the ACL as well as ACL grafts, followed by clinical follow-up studies following ACL reconstruction and/or conservative treatment are the most contributing articles within the list of the "top 50" [29].

In total, seven countries contributed to the top 50 list, with the USA having by far the most contributions ($n = 40$). A fact that may reflect the high level of orthopaedic research in the United States. This is also confirmed by the publishing journals. A large proportion of the articles were published in the American Journal of Sports Medicine, followed by the Journal of Bone and Joint Surgery, American Volume. Similar results have been seen in other fields were the USA led most rankings [11–13, 27].

The oldest article in this category, focussing on the mechanics of the ligaments and menisci of the knee joint, was published in 1941 and is still cited 4.3 times per year in average [20].

A last interesting point is that the majority of the articles have been published between 1990 and 2005. Within the last ten years, no article on this topic has reached a comparably high number of citations. This might be due to cross-sectional design of the present study.

Bibliometric studies like ours reflect a "snapshot" of the most frequently cited articles in their specific field. Furthermore, the listing of articles according to the number of absolute citations remains a selection [30]. Important and influential articles on the topic might have been excluded. The citation numbers may be improperly increased by several practices including self-citations, subpublications, and timing of publication [31]. These limitations point out the necessity for other metrics to identify prestigious articles [30]. Although more objective journal metrics, for example the "SJR indicator" or the "Eigenfactor-score" with all their benefits, including the evaluation of the importance of citations from various sources, the eliminated influence of self-citations, and the greater number of journals and languages included in the database, it was not possible to establish a ranking of the most influential and important articles on a specific topic by using these scores since they were developed to measure the total importance of a scientific journal but not single articles [31]. A recent development is web platforms, which provide alternative metric scores for articles, for example article views, downloads or mentions in social media and news media [30–32]. Given the rapid development and growing importance of these platforms, altmetrics, as here provided, may have a huge impact on the assessment of the importance of articles and journals in the near future. Therefore, we decided to search for the most cited articles on our topic as has been done in various other fields. Since we have performed the search in the Thomson ISI Web of Science®, another specific limitation of our search strategy arises from the fact that articles published in non-indexed journals as well as articles cited in textbooks, lectures or digital media could not be taken into account [32].

Despite these limitations, we think that citation analysis remains one of the best currently available tools to assess the impact of scientific articles on their field [30].

We believe that studies like ours represent a valuable summary of scientific milestones on the topic of ACL injury. The diversity of the listed articles regarding the article types and study design for clinical papers as well as the heterogeneity of the content, ranging from biomechanical studies on native ligament and graft analyses to tissue engineering and reconstruction techniques, prevention measures, and outcome analyses following surgical, non-surgical or combined treatment strategies may reflect the comprehensive, active research conducted on this subject both current as well as in the past few decades. Furthermore, the results may reflect the quality of prior scientific research [30].

In summary, this article provides a selection of the most read and cited articles on the specific topic of ACL injury. This

"reading list" may be helpful and interesting for both "unexperienced" readers as well as for senior readers or clinicians in order to provide a basis for both further discussion as well as future research.

Acknowledgements Open access funding provided by Medical University of Graz.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Vaishya R, Hasija R (2013) Joint hypermobility and anterior cruciate ligament injury. J Orthop Surg (Hong Kong) 21(2):182–184
2. Shultz SJ, Schmitz RJ, Benjaminse A, Chaudhari AM, Collins M, Padua DA (2012) ACL research retreat VI: an update on ACL injury risk and prevention. J Athl Train 47(5):591–603
3. Evans S, Shaginaw J, Bartolozzi A (2014) Acl reconstruction - it's all about timing. Int J Sports Phys Ther 9(2):268–273
4. Vaishya R, Agarwal AK, Ingole S, Vijay V (2015) Current trends in anterior cruciate ligament reconstruction: a review. Cureus 7(11): e378. doi: 10.7759/cureus.378
5. Frobell RB, Roos EM, Roos HP, Ranstam J, Lohmander LS (2010) A randomized trial of treatment for acute anterior Crut tears. New Engl J Med 363(4):331–342
6. Brophy RH, Silvers HJ, Mandelbaum BR (2010) Anterior cruciate ligament injuries: etiology and prevention. Sports Med Arthrosc 18(1):2–11
7. Lohmander LS, Englund PM, Dahl LD, Roos EM (2007) The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med 35:1756–1769
8. Alazzawi S, Sukeik M, Ibrahim M, Haddad FS (2016) Management of anterior cruciate ligament injury: pathophysiology and treatment. Br J Hosp Med 77(4):222–225
9. Kaar SG, Stuart MJ, Levy BA (2011) Soft-tissue injuries about the knee. In: Flynn J (ed) Orthopaedic knowledge update, 10th edn. American Academy of Orthopaedic Surgeons, Rosemont
10. To P, Atkinson CT, Lee DH et al (2013) The most cited articles in hand surgery over the past 20-plus years: a modern-day reading list. J Hand Surg 38(5):983–987
11. Namdari S, Baldwin K, Kovatch K et al (2012) Fifty most cited articles in orthopaedic shoulder surgery. J Shoulder Elb Surg 21(12):1796–1802
12. Cassar Gheiti AJ, Downey RE, Byrne DP et al (2012) The 25 most cited articles in arthroscopic orthopaedic surgery. Arthroscopy 28(4):548–564
13. Lefaivre KA, Guy P, O'Brien PJ et al (2010) Leading 20 at 20: top cited articles and authors in the journal of Orthopaedic trauma 1987–2007. J Orthop Trauma 24(1):53–58
14. Mehlman CT, Wenger DR (2006) The top 25 at 25: citation classics in the journal of pediatric Orthopaedics. J Pediatr Orthop 26(5): 691–694
15. Holzer LA, Holzer G (2014) The 50 highest cited papers in hip and knee arthroplasty. J Arthroplast 29(3):453–457
16. Kurtz S, Ong K, Lau E, Mowat F, Halpern M (2007) Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 89(4):780–785
17. Instructions for authors. The Journal of Bone and Joint Surgery web site. Available from: URL: http://jbjs.org/public/instructionauthors.aspx
18. Lee KP, Schotland M, Bacchetti P, Bero LA (2002) Association of journal quality indicators with methodological quality of clinical research articles. JAMA 287(21):2805–2808
19. Arshi A, Siesener NJ, McAllister DR, Williams R 3rd, Sherman SL, Jones KJ (2016) The 50 most cited articles in orthopedic Cartilage surgery. Cartilage 3:238–247
20. Brantigan OC, Voshell AF (1941) The mechanics of the ligaments and menisci of the knee joint. J Bone Joint Surg Am 23(1):44–66
21. Tegner Y, Lysholm J. (1985) Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res (198):43–49
22. Lysholm J, Gillquist J (1992) Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10(3):150–154
23. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD (1998) Knee injury and osteoarthritis outcome Score (KOOS)–development of a self-administered outcome measure. J Orthop Sports Phys Ther 28(2):88–96
24. Baldwin K, Namdari S, Donegan D, Kovatch K, Ahn J, Mehta S (2013) 100 most cited articles in fracture surgery. Am J Orthop (Belle Mead NJ) 42(12):547–552
25. Baltussen A, Kindler CH (2004) Citation classics in anesthetic journals. Anesth Analg 98(2):443–451
26. Nason GJ, Tareen F, Mortell A (2013) The top 100 cited articles in urology: an update. Can Urol Assoc J 7(1–2):E16–E24. doi:10.5489/cuaj.12223
27. Lefaivre KA, Shadgan B, O'Brien PJ (2011) 100 most cited articles in orthopaedic surgery. Clin Orthop Relat Res 469(5):1487–1497
28. Kelly JC, Glynn RW, O'Briain DE, Felle P, McCabe JP (2010) The 100 classic papers of orthopaedic surgery: a bibliometric analysis. J Bone Joint Surg Br 92(10):1338–1343
29. Van der List JP, Di Felice GS (2016) Primary repair of the anterior cruciate ligament: a paradigm shift. NCBI doi: 10.1016/j.surge.2016.09.006
30. Ahmad SS, Evangelopoulos DS, Abbasian M, Roder C, Kohl S (2014) The hundred most-cited publications in orthopaedic knee research. J Bone Joint Surg Am 96(22):e190. doi:10.2106/JBJS.N.00029
31. Scarlat MM, Mavrogenis AF, Pećina M, Niculescu M (2015) Impact and alternative metrics for medical publishing: our experience with international Orthopaedics. Int Orthop 39(8):1459–1464
32. Jia Z, Ding F, Wu Y, He Q, Ruan D (2015) The 50 most-cited articles in orthopaedic surgery from mainland China. Clin Orthop Relat Res 473(7):2423–2430