Original Article

# Top-100 Most-Cited Sports-Related Concussion Articles Focus on Symptomatology, Epidemiology, and Demographics

Kade S. McQuivey, M.D., M. Lane Moore, B.S., Jordan R. Pollock, B.S., Jeffrey D. Hassebrock, M.D., Karan A. Patel, M.D., and Anikar Chhabra, M.D.

**Purpose:** To analyze the top-100 cited articles on sports-related concussions together with a bibliometric analysis to determine citations by year, level of evidence, study design, and several other factors related to the top referenced articles in sports concussions. **Methods:** The Clarivate Analytics Web of Knowledge database was used to gather data using Boolean queries to capture all possible iterations of sports-related concussion research. Articles were organized in descending order based on the number of citations and included or excluded based on relevance to concussion. Collected information included author name, publication year, country of origin, journal name, article type, study focus, and the level of evidence. **Results:** The top-100 articles were cited 31,197 times with an average of 312.0 citations per publication. More than one half were published in 2006 or later (52). Cohort studies and descriptive articles were the most prevalent study types (22 each). Studies with Level V evidence were the most common (33). The most common areas of study were symptomatology (short term, long term) with 17 articles, followed by epidemiology/demographics with 16 articles. The least common area of study was concussion prevention (2 articles), followed by management/treatment, diagnostics (labs, imaging) with 4 articles each. **Conclusions:** We identified the most influential studies in sports-related concussion based on number of citations and citation density. A majority of these articles were published in the United States after 2006 and are most commonly cohort studies (Level IV evidence) and descriptive articles (Level V evidence). Current research focuses most heavily on the symptomatology and epidemiology/demographics of sports concussion. **Clinical Relevance:** This study serves to identify the most influential articles in sports-related concussion and identify research topics with general deficiencies within the field of sports-related concussion research.

Concussion is defined by the American Medical Society for Sports Medicine, the International Olympic Committee, and the American Academy of Neurology, as a "biomechanically provoked alteration of brain function, usually transient, after the initiation of a complex pathophysiologic process."[1-3] This complex process can be caused by a either direct or indirect contact that ultimately leads to force transmission through the head/neck region. Although current diagnostic imaging modalities do not detect structural changes, the clinical, functional, and cognitive sequalae of such trauma can result in a variety of symptoms. These symptoms may include headache, vision changes, confusion, disorientation, delayed reaction time, amnesia, photophobia, decreased postural balance, dizziness, and mood changes.[4,5] The duration of these symptoms is similarly varied, with reported ranges from days to months depending upon severity of the injury.[5]

The earliest known descriptions of concussions began with the ancient Greeks. They described an injury that led to a temporary state of altered mentation.[6] Historically, concussions remained poorly described until the advent of American football in the late 1800s and early 1900s. During this era, it was observed that the best protection afforded a football player was, "but a bushy

*From the Department of Orthopedic Surgery, Mayo Clinic, Phoenix (K.S.M., J.H., K.P., A.C.); and Mayo Clinic Alix School of Medicine, Scottsdale (L.M., J.R.P.), Arizona, U.S.A.*

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*Address correspondence to Kade S. McQuivey, M.D., Department of Orthopedic Surgery, Mayo Clinic Arizona, 5777 East Mayo Blvd, Phoenix, AZ 85054. E-mail: McQuivey.Kade@mayo.edu*



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head of hair." [6] Given our poor understanding of concussion during this time, there was a rapid growth in concussion incidence, including several deaths secondary to closed head injuries.[7] The following excerpt from *The Trainers Bible*, published in 1948, provided the most comprehensive guidelines on concussions in sports at that time:

> *"If he shows normal muscular control, complete orientation, does not complain of dizziness or headache, the conclusion must be that the jarring of the brain was quite mild. If the physician approves, the boy may resume play. If there is no urgent need of him, take him out for a rest and further observation…A severe fall or blow may result in nothing worse than a momentary sensation of "seeing stars."*[8]

This brief history of concussion serves as a reminder that we have come a long way in our understanding of the pathophysiology, mechanisms, long-term sequalae, and innumerable other aspects of sport related concussion within the last few decades. Given the immense body of literature that exists in the field of sports-related concussion, it can be difficult for clinicians to evaluate the quality and impact of any single article. One well-established tool to identify common themes and to analyze how the science is trending within a field is through a bibliographic analysis. Bibliometric analysis differs from systematic reviews in that bibliometric analyses focus solely on the quantity of published articles and quantity of citations obtained by each publication whereas systematic reviews analyze information of specific research outcomes from each publication to be analyzed together with several other studies. Information obtained through bibliometric analysis can be used to calculate citation impact and other research power indicators. These analyses also assist researchers/clinicians in identifying areas that are well established and those in need of further investigation. They also serve to assist researchers/clinicians in identifying research areas that are well established and those in need of further investigation.[9,10] These analyses are also very useful, as they serve to identify high-impact articles within a certain field and to determine the relative impact an article has on a specific field.[11,12] Sports concussion represents a dynamic topic that is rapidly evolving, as such, it is important to analyze the most influential work in this dynamic field. This analysis will prove beneficial to care providers as we attempt to identify the most impactful, and up to date literature on sport-related concussion.

The purpose of this study was to analyze the top-100 cited articles on sports-related concussions together with a bibliometric analysis to determine citations by year, level of evidence, study design, and several other factors related to the top-referenced articles in sports concussions. The authors hypothesized that publication year would have a significant influence on the number of citations that an article was able to generate and that the majority of articles would address the epidemiology and symptomatology of sports concussion.

## Methods

After we obtained institutional review board exempt status, our study methods were designed after similar studies conducting bibliometric analyses.[13-20] We used the Clarivate Analytics Web of Knowledge database to gather data and metrics on April 6, 2020. We performed the search using varying Boolean queries to capture all possible iterations of concussion research. The final Boolean search phrases were: TS = [(Concussion OR Mild Traumatic Brain Injury OR Traumatic Brain Injury OR TBI) AND (Sports OR Sports Medicine OR Athlete OR Collegiate OR Player OR NCAA OR High School OR Professional OR Rugby OR Rugby Union)]. No date, language, journal, or country of origin restrictions were placed on this search. The web of science database includes articles that are not in English. This resulted in 10,104 total articles.

The resulting search list was sorted in descending order based on the number of citations, and the title and abstract of each article were then reviewed by 2 independent reviewers to determine its relevance to concussions in sports. Inclusion criteria comprised studies with a central focus on concussion or traumatic brain injury in a sports setting were included for analysis. Occasionally, broad literature searches can result in several articles where, although mentioned in the abstract, concussion was not the central focus of the study. Exclusion criteria included papers that did not have sport concussion as their central focus or had mention of chronic traumatic encephalopathy. If a study was unclear or if there was a question as to whether it should be excluded, the full article was obtained and reviewed by 2 independent reviewers. If these authors were in disagreement, the senior author reviewed the article and ultimately decided upon inclusion or exclusion. The authors decided a priori to only include the top 100 concussion articles in the final analysis. A total of 171 articles were reviewed, with 71 articles being excluded for failure to meet aforementioned criteria. See Appendix Table 1, available at www.arthroscopyjournal.org, for a list of the top-100 cited sports-related concussion articles.[21-117]

The final 100 studies were manually reviewed to obtain the following information: author name, publication year, country of origin, journal name, article type (expert opinion, review article, descriptive study, case report, case series, case–control study, cohort

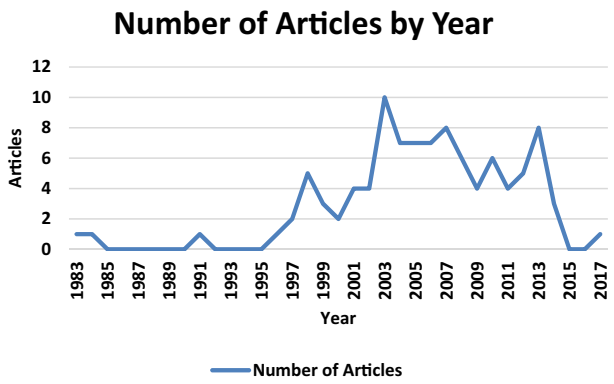


**Fig 1.** Number of articles published per year.

study, randomized controlled trial, nonrandomized controlled trial, or consensus/position statement), and the level of evidence for clinical articles based on the guidelines published by *The Journal of Bone and Joint Surgery*. The level of evidence was determined by consensus opinion between the two independent reviewers. If a study had a published self-designated level of evidence, it was re-evaluated according to the previously mentioned *The Journal of Bone and Joint Surgery* criteria to ensure accuracy and consistency of reported results. If there was still a question of classification, the senior author was consulted. If an article simply reviewed the literature, and no systematic approach was used, it was classified in the "expert opinion" category. However, if an article incorporated a systematic approach to reviewing the literature or if a meta-analysis was performed, the article was classified in the "review article" category.

In an attempt to identify well-studied areas and those in need of further investigation, each article included in this study was categorized into one of 11 of the following categories; Epidemiology/Demographics, Summary/Consensus/Position Statement, Symptomatology (long term, short term), Grading/Evaluation, Mechanisms/Biomechanics, Recovery, Pathophysiology, Associated Conditions, Diagnostics (imaging, labs), Management/Treatment, and finally Prevention. Categorization into 1 of the 11 categories occurred by 2 reviewers and a third reviewer settled discrepancies of article categorization.

Included articles were analyzed by citation density in addition to total number of citations. Citation density was calculated as the total number of citations divided by the number of years since publication. A subanalysis was performed for the articles published before and after 2006, as this represented a midpoint in the data. A Student *t* test was performed to compare the difference in citation density and total citations for studies published before and after 2006 with $P < .05$ indicating statistical significance. An $R^2$ value was also calculated for the growth in total citations since 1983. All data collection and analysis were completed using Microsoft Excel (Microsoft Corp, Redmond, WA).

## Results

The earliest year of publication for the 100 included studies was 1983 and the latest was 2017. Of these studies, 86 were published in 2000 or after, and more than one half were published in 2006 or later (52). The most articles published in a single year was 2003 (10), followed closely by 2007 and 2013 (8) (Fig 1). The total number of citations for the 100 included studies was 31,197, with an average of 312.0 citations per publication. The most-cited article was cited a total of 1,170 times at the time the search was performed.[1] The second- and third-most cited articles were cited a total of 1,061 and 953 times, respectively.[21,118] There was a large range between the most-cited and least-cited article (1,170 to 174). Across the 100 most-cited concussion studies, the year with the most cumulative citations occurred in 2017 with a total of 3,271 citations. The years 2019 and 2016 followed closely behind with 3,196 and 3,083 citations, respectively. The growth in citation rate for the 100 included concussion studies also has shown significant growth over the past 4 decades with an $R^2$ value of 0.91 (Fig 2).

The top 3 articles by citation density were attributed to McCrory et al. (161.5 citations/year),[1] McCrory et al. (146.2 citations/year),[26] and Hootman et al. (75.8 citations/year).[22] The oldest published study included in this study, published in 1983 by Gerberich et al.[75] ranked 58th in total citations (219) and was tied for last in citation density (5.8 citations/year). McCrory et al.[26] was the author of the most recently published article in 2017 and ranked seventh in total citations (646) and first in citation density (161.5 citations/year). The average citation density of studies published in 2006 or later was 30.0 citations/year and was 17.3 citations/year for articles published before 2006. This difference was statistically significant ($P < .01$). The average number of citations for studies published before

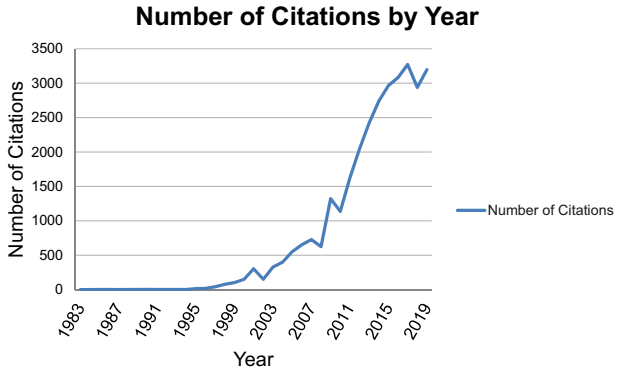


**Fig 2.** Number of citations per year of the top-100 cited sports-related concussion papers.

**Table 1.** Authors With More Than 1 Publication in the Top-100 Most-Cited Sports-Related Concussion Papers

| Author | Number of Articles Included | Total Number of Citations | Average Citations per Publication |
|---|---|---|---|
| Guskiewicz | 8 | 3,848 | 481.0 |
| McCrory | 8 | 3,608 | 451.0 |
| McCrea | 7 | 2,613 | 373.3 |
| Collins | 4 | 1,253 | 313.3 |
| Lovell | 4 | 1,229 | 307.3 |
| Iverson | 3 | 747 | 249.0 |
| Broglio | 3 | 676 | 225.3 |
| Harmon | 2 | 679 | 339.5 |
| Pellman | 2 | 573 | 286.5 |
| Kelly | 2 | 476 | 238.0 |
| Cantu | 2 | 469 | 234.5 |
| Vagnozzi | 2 | 450 | 225.0 |

2006 was 328.5 and 296.7 for studies published after 2006. This difference was not statistically significant ($P = .41$).

There was a total of 12 authors who were credited with 2 or more articles included in this study of the 100 most-cited concussion studies (Table 1). Guskiewicz and McCrory were credited with the most publications, with 8 each. They were followed closely behind by McCrea (7), Collins (4), and Lovell (4). All 100 included articles were published in English and originated in 29 different journals (Table 2). Of these journals, *Neurosurgery* was the most represented, with 14 articles, followed by the *Clinical Journal of Sports Medicine* (12) and the *Journal of Athletic Training* (11). The average impact factor for all represented journals was 7.213 (standard deviation 9.6). The top 100 concussion articles had first authors who originated from 7 different countries (Fig 3). None of the top 100-cited articles came from publications in a different language in our search. The United States was responsible for 78% of the articles, followed by Australia (9%) and Canada (6%). Cohort studies and descriptive articles were the most prevalent study types (22 each) followed by case series (17) and consensus/position statements (12) (Table 3). This is closely correlated to the level of evidence, with Level V being the most common (33) followed by Level IV (30) studies (Table 4).

The most common areas of study among the top-100 most-cited sports concussion papers were symptomatology (short term, long term) with 17 articles, followed by epidemiology/demographics with 16 articles, and finally summary/consensus/position statements with 15 articles published. The least common area of study was prevention (2 articles), management/

**Table 2.** Journals in Which Top-100 Most-Cited Sports-Related Concussion Articles Were Published With Associated Impact Factor

| Journal of Origin | Number of Articles | Impact Factor |
|---|---|---|
| *Neurosurgery* | 14 | 4.605 |
| *Clinical Journal of Sports Medicine* | 12 | 2.702 |
| *Journal of Athletic Training* | 11 | 2.253 |
| *American Journal of Sports Medicine* | 9 | 6.093 |
| *British Journal of Sports Medicine* | 7 | 11.645 |
| *JAMA - Journal of the American Medical Association* | 7 | 51.273 |
| *Neurology* | 4 | 8.689 |
| *Pediatrics* | 4 | 5.401 |
| *Brain Injury* | 3 | 1.665 |
| *Journal of Neurosurgery* | 3 | 4.130 |
| *Journal of the International Neuropsychological Society* | 3 | 3.098 |
| *The Journal of Head Trauma Rehabilitation* | 3 | 2.667 |
| *Clinics in Sports Medicine* | 2 | 2.178 |
| *Journal of Neurotrauma* | 2 | 3.754 |
| *Stapp Car Crash Journal* | 2 | 1.500 |
| *Acta Neuropatholgica* | 1 | 18.174 |
| *American Journal of Public Health* | 1 | 5.381 |
| *Annals of Biomedical Engineering* | 1 | 3.474 |
| *Applied Neuropsychology* | 1 | 1.548 |
| *Archives of Clinical Neuropsychology* | 1 | 2.226 |
| *Brain* | 1 | 11.814 |
| *Clinical Neuropsychologist* | 1 | 2.006 |
| *Journal of Biomechanical Engineering - Transactions of the ASME* | 1 | 2.025 |
| *Journal of Pediatrics* | 1 | 3.739 |
| *Medicine and Science in Sports and Exercise* | 1 | 4.478 |
| *MMWR - Morbidity and Mortality Weekly Report* | 1 | 14.874 |
| *Neuroimage* | 1 | 5.812 |
| *Neuron* | 1 | 14.403 |
| *Sports Medicine* | 1 | 7.583 |

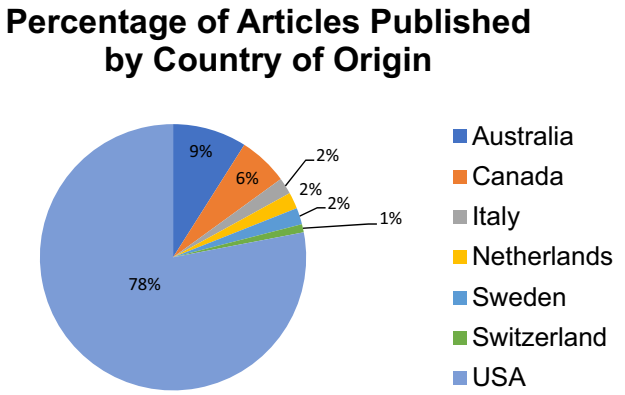


**Fig 3.** Percentage of articles published by country of origin.

treatment, diagnostics (labs, imaging), and associated conditions, each with 4 articles published (Fig 4).

## Discussion

The majority the top 100-cited articles (52%) were published after the year 2006. In comparison, similar bibliometric analyses in conducted within the field of sports medicine show a majority of top-cited articles being published between the 1970s and the 1990s.[13,19]

Within the last 20 years, there has been an explosion of concussion-related research that has significantly propelled our understanding on the subject. The renewed interest in sports-related concussion is further evidenced by the study designs of the most-cited articles. The top 100 most-cited articles were most commonly cohort studies and descriptive articles with Level IV and Level V evidence. Among the articles identified in this study there were no randomized controlled trials or articles with a Level I evidence. This is of little surprise, given the difficulty of performing a randomized controlled trial among this study population. As the state of sports-related concussion literature progresses, it is likely that study designs with higher level of evidence will displace case series, descriptive articles, and other study designs with lower level of evidence in the top 100 most-cited studies. As research continues to advance on a global scale, we anticipate higher-level research will replace some of the lower level of evidence research articles found in our study.

**Table 3.** Study Design pf Top-100 Cited Sports-Related Concussion Articles

| Study Type | Number of Articles |
|---|---|
| Randomized controlled trial | 0 |
| Nonrandomized controlled trial | 2 |
| Cohort study | 22 |
| Case–control Study | 8 |
| Case series | 17 |
| Case report | 1 |
| Review article | 5 |
| Descriptive article | 22 |
| Consensus/position statement | 12 |
| Expert opinion | 11 |

**Table 4.** Level of Evidence of Top-100 Cited Sports-Related Concussion Articles

| Articles Level of Evidence | Number of Articles |
|---|---|
| I | 0 |
| II | 19 |
| III | 18 |
| IV | 30 |
| V | 33 |

Sports-related concussion is also a rapidly evolving field of research. This is evidenced by the differences between citation density between older and newer articles. Older articles typically have an advantage in terms of the total number of citations generated as more time is provided for it to be cited, nonetheless the current citation density slows as an article gets older and the foundational knowledge becomes commonplace. This phenomenon is known as "obliteration by incorporation,"[119] This is what we observe in our analysis as the average citation density of studies published in 2006 or later was 30.0 citations/year compared with 17.3 citations/year for articles published before 2006. This finding is similar to many other dynamic fields where research continues to rapidly evolve.[13,15,19] In contrast, our analysis shows that among the top-100 cited sports concussion papers, the latest was published in 2017. It is reasonable to believe that articles published in the last 3 to 5 years, although impactful in the field, have not had adequate timing to be cited to the same extent as older articles of equal impact. Consequently, they were excluded from this analysis.

We also found the most common focuses of the included studies touched mainly on symptomatology (short term, long term) and epidemiology/demographics, with one third of articles falling in either of these 2 categories. Surprisingly, the fewest cited articles touched on management/treatment and prevention of sports-related concussion. Clinicians and researchers can use this data to shine light on areas of sports-related concussion that require further investigation. This study serves to identify future areas of research that could contribute to improve quality of care, improve patient safety, and reduce cost of care in patients who experience sports-related concussion.

### Limitations

There are several limitations inherent to this particular study design. The number of citations an article receives is an important metric, but it is not a perfect method for measuring an article's impact. Unlike older articles, articles published in the last several years, although impactful, have not had adequate timing to be

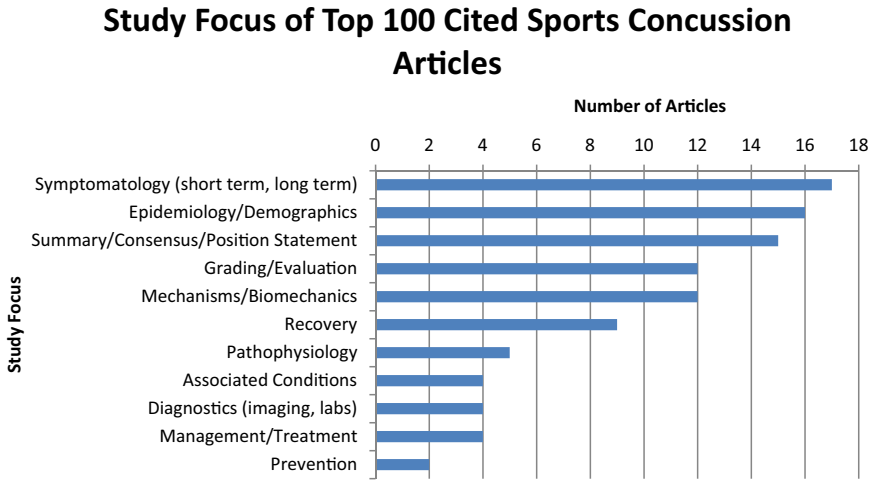


**Fig 4.** "Study Focus" of the top-100 cited sports-related concussion articles.

cited to the same extent as older articles of equal impact. Articles with fewer citations may have significant impact in sports concussion research but may have been overlooked. We attempted to minimize this effect by including citation density which as defined in the methods is total number of citations divided by the number of years since publication. The selection criteria used to include or exclude concussion articles as well as categorizing these articles based on "study focus" could represent a potential source for subjectivity. The authors incorporated several different reviewers in an attempt to be as objective as possible. There are several factors other than the impact of an individual article that influence citations.[19] For example, we did not take into account self-citations; therefore, high-volume authors who self-cite many times may be at a slight advantage. Finally, the Web of Knowledge Database was used in this analysis. This database is comprehensive, but it is possible that influential articles were excluded by the search criteria or the categorization of articles by citation number.

## Conclusions

We identified the most influential studies in sports related concussion based on number of citations and citation density. A majority of these articles were published in the United States after 2006 and are most commonly cohort studies (Level IV evidence) and descriptive articles (Level V evidence).. Current research focuses most heavily on the symptomatology and epidemiology/demographics of sports concussion.

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51. Iverson GL, Lovell MR, Collins MW. Interpreting Change on ImPACT following sport concussion. *Clin Neuropsychologist* 2003;17:460-467.
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64. Broshek DK, Kaushik T, Freeman JR, Erlanger D, Webbe F, Barth JT. Sex differences in outcome following sports-related concussion. *J Neurosurg* 2005;102:856-863.
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71. Duma SM, Manoogian SJ, Bussone WR, et al. Analysis of real-time head accelerations in collegiate football players. *Clin J Sport Med* 2005;15:3-8.
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73. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus Statement on Concussion in Sport: The 4th International Conference on Concussion in Sport, Zurich, November 2012. *J Athletic Training* 2013;48:554-575.
74. Vagnozzi R, Signoretti S, Cristofori L, et al. Assessment of metabolic brain damage and recovery following mild traumatic brain injury: A multicentre, proton magnetic resonance spectroscopic study in concussed patients. *Brain* 2010;133:3232-3242.
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threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med* 2010;20:21-27.
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94. Broglio SP, Macciocchi SN, Ferrara MS. Sensitivity of the Concussion Assessment Battery. *Neurosurgery* 2007;60:1050-1058.
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96. Covassin T, Elbin RJ, Harris W, et al. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med* 2012;40:1303-1312.
97. McCrory P, Meeuwisse W, Aubry M, et al. Consensus Statement on Concussion in Sport—the 4th International Conference on Concussion in Sport Held in Zurich, November 2012. *Clin J Sport Med* 2013;23:89-117.
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99. Bakhos LL, Lockhart GR, Myers R, Linakis JG. Emergency department visits for concussion in young child athletes. *Pediatrics* 2010;126:550-556.
100. Rowson S, Duma SM, Beckwith JG, et al. Rotational head kinematics in football impacts: An injury risk function for concussion. *Ann Biomed Eng* 2012;40:1-13.
101. Bailes JE, Petraglia AL, Omalu BI, Nauman E, Talavage T. Role of subconcussion in repetitive mild traumatic brain injury. *J Neurosurg* 2013;119:1235-1245.
102. Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF. Concussion in professional football: Reconstruction of game impacts and injuries. *Neurosurgery* 2003;53:799-814.
103. Maugans TA, Farley C, Altaye M, et al. Pediatric sports-related concussion produces cerebral blood flow alterations. *Pediatrics* 2012;129:28-37.
104. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L. Immediate neurocognitive effects of concussion. *Neurosurgery* 2002;50:1032-1042.
105. Agel J, Evans TA, Dick R, Putukian M, Marshall SW. Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *J Athl Train* 2007;42:270-277.
106. Takhounts EG, Ridella SA, Hasija V, et al. Investigation of traumatic brain injuries using the next generation of simulated injury monitor (SIMon) finite element head model. *Stapp Car Crash J* 2008;52:1-31.
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111. Broglio SP, Puetz TW. The effect of sport concussion on neurocognitive function, self-report symptoms and postural control. *Sports Med* 2008;38:53-67.
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113. Collins MW, Field M, Lovell MR, et al. Relationship between postconcussion headache and neuropsychological test performance in high school athletes. *Am J Sports Med* 2003;31:168-173.
114. McClincy MP, Lovell MR, Pardini J, Collins MW, Spore MK. Recovery from sports concussion in high school and collegiate athletes. *Brain Injury* 2006;20:33-39.
115. Harmon KG, Drezner J, Gammons M, et al. American Medical Society for Sports Medicine position statement: Concussion in sport. *Clin J Sport Med* 2013;23:1-18.
116. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: An investigation of positional and event-type differences. *Neurosurgery* 2007;61:1229-1235.
117. Williamson IJS, Goodman D. Converging evidence for the under-reporting of concussions in youth ice hockey. *Br J Sports Med* 2006;40:128-132.
118. Guskiewicz KM. Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA Concussion Study. *JAMA* 2003;290:2549-2555.
119. Garfield E. 100 citation classics from the Journal of the American Medical Association. *JAMA* 1987;257:52-59.

**Appendix Table 1.** Top-100 Cited Sports-Related Concussion Articles

| Rank | Article | No. of Citations (Citation Density*) |
|---|---|---|
| 1 | McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: The 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med* 2013;47:250-258. | 1,170 (146.3) |
| 2 | Hootman JM, Dick R, Agel J. Epidemiology of Collegiate Injuries for 15 Sports: Summary and Recommendations for Injury Prevention Initiatives. *J Athl Train* 2007;42:311-319. | 1,061 (75.8) |
| 3 | Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA Concussion Study. *JAMA* 2003;290:2549-2555. | 953 (52.9) |
| 4 | McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: The NCAA Concussion Study. *JAMA* 2003;290:2556-2563. | 891 (49.5) |
| 5 | Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery* 2005;57:719-726. | 671 (41.9) |
| 6 | McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: Implications for prevention. *Clin J Sport Med* 2004;14:13-17. | 654 (38.5) |
| 7 | McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med* 2017;51:838-847. | 646 (161.5) |
| 8 | Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train* 2007;42:495-503. | 554 (39.6) |
| 9 | Collins MW, Grindel SH, Lovell MR, et al. Relationship between concussion and neuropsychological performance in college football players. *JAMA* 1999;282:964-970. | 549 (25.0) |
| 10 | McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med* 2005;39:196-204. | 534 (33.4) |
| 11 | Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr* 2003;142:546-553. | 517 (28.7) |
| 12 | Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: Concussion in sport. *Br J Sports Med* 2013;47:15-26. | 504 (63.0) |
| 13 | Guskiewicz KM, Weaver NL, Padua DA, et al. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med* 2000;28:643−650. | 503 (24.0) |
| 14 | Aubry M, Cantu R, Dvorak J, et al. Summary and Agreement Statement of the 1st International Symposium on Concussion in Sport, Vienna 2001. *Clin J Sport Med* 2002;12:6−11. | 502 (26.4) |
| 15 | Guskiewicz K, Marshall S, Bailes J, et al. Recurrent concussion and risk of depression in retired professional football players. *Med Sci Sports Exerc* 2007;39:903-909. | 492 (35.1) |
| 16 | Zhang L, Yang KH, King AI. A proposed injury threshold for mild traumatic brain injury. *J Biomech Eng* 2004;126:226-236. | 487 (28.7) |
| 17 | Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: Evaluation and management of concussion in sports. *Neurology* 2013;80:2250. | 480 (60.0) |
| 18 | Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med* 2012;40:747-755. | 462 (51.3) |
| 19 | Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athl Train* 2001;36:263-273. | 431 (21.6) |
| 20 | Halstead ME, Walter KD, Moffatt K, Council on Sports Medicine and Fitness. Sport-related concussion in children and adolescents. *Pediatrics* 2010;126:597-615. | 385 (35.0) |
| 21 | Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA* 1999;282:958-963. | 385 (17.5) |
| 22 | Pellman EJ, Viano DC, Tucker AM, Casson IR. Concussion in professional football: Location and direction of helmet impacts—Part 2. *Neurosurgery* 2003;53:1328-1341. | 382 (21.2) |
| 23 | McCrory P, Meeuwisse W, Johnston K, et al. Consensus Statement on Concussion in Sport: The 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *Br J Sports Med* 2009;43:i76-i84 (suppl 1). | 373 (31.1) |
| 24 | Lovell MR, Collins MW, Iverson GL, et al. Recovery from mild concussion in high school athletes. *J Neurosurg* 2003;98:296-301. | 352 (19.6) |
| 25 | Lovell MR, Iverson GL, Collins MW, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the Post-Concussion Scale. *ApplNeuropsychol* 2006;13:166-174. | 350 (23.3) |
| 26 | Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association Position Statement: Management of sport-related concussion. *J Athl Train* 2004;39:280-297. | 347 (20.4) |

(continued)

**Appendix Table 1.** Continued

| Rank | Article | No. of Citations (Citation Density*) |
|---|---|---|
| 27 | Belanger HG, Vanderploeg RD. The neuropsychological impact of sports-related concussion: A meta-analysis. *J Int Neuropsychol Soc* 2005;11:345-357. | 322 (20.1) |
| 28 | Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: A prospective 11-year study. *Am J Sports Med* 2011;39:958-963. | 320 (32.0) |
| 29 | Schatz P, Pardini JE, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Arch Clin Neuropsychol* 2006;21:91-99. | 306 (20.4) |
| 30 | Broglio SP, Cantu RC, Gioia GA, et al. National Athletic Trainers' Association Position Statement: Management of sport concussion. *J Athl Train* 2014;49:245-265. | 304 (43.4) |
| 31 | Collins MW, Lovell MR, Iverson GL, Cantu RC, Maroon JC, Field M. Cumulative effects of concussion in high school athletes. *Neurosurgery* 2002;51:1175-1181. | 301 (15.8) |
| 32 | Macciocchi SN, Barth JT, Alves W, Rimel RW, Jane JA. Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery* 1996;39:494-508. | 298 (11.9) |
| 33 | Blennow K, Hardy J, Zetterberg H. The neuropathology and neurobiology of traumatic brain injury. *Neuron* 2012;76:886-899. | 296 (32.9) |
| 34 | Iverson GL, Lovell MR, Collins MW. Interpreting Change on ImPACT following sport concussion. *Clin Neuropsychologist* 2003;17:460-467. | 294 (16.3) |
| 35 | McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on Concussion in Sport 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *Clin J Sport Med* 2009;19:185-200. | 289 (24.1) |
| 36 | Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med* 2011;30:1-17. | 287 (28.7) |
| 37 | Kleiven S. Predictors for traumatic brain injuries evaluated through accident reconstructions. *Stapp Car Crash J* 2007;51:81-114. | 280 (20.0) |
| 38 | Lovell MR, Collins MW. Neuropsychological assessment of the college football player. *J Head Trauma Rehabil* 1998;13:9-26. | 277 (12.0) |
| 39 | Cantu RC. Second-Impact Syndrome. *Clin Sports Med* 1998;17:37-44. | 274 (11.9) |
| 40 | Centers for Disease Control and Prevention. Nonfatal traumatic brain injuries related to sports and recreation activities among persons aged ≤19 years—United States, 2001-2009. *MMWR Morb Mortal Wkly Rep* 2011;60:1337-1342. | 263 (26.3) |
| 41 | Greenwald RM, Gwin JT, Chu JJ, Crisco JJ. Head impact severity measures for evaluating mild traumatic brain injury risk exposure. *Neurosurgery* 2008;62:789-798. | 258 (19.9) |
| 42 | McCrea M, Kelly J, Randolph C, et al. Standardized Assessment of Concussion (SAC): On-site mental status evaluation of the athlete. *J Head Trauma Rehabil* 1998;13:27-35. | 255 (11.1) |
| 43 | Talavage TM, Nauman EA, Breedlove EL, et al. Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion. *J Neurotrauma* 2010;31:327-338. | 255 (36.4) |
| 44 | Iverson GL, Gaetz M, Lovell MR, Collins MW. Cumulative effects of concussion in amateur athletes. *Brain Injury* 2004;18:433-443. | 252 (14.8) |
| 45 | Echemendia R, Putukian M, Mackin R, Julian L, Shoss N. Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clin J Sport Med* 2001;11:23-31. | 250 (12.5) |
| 46 | Lovell MR, Collins MW, Iverson GL, et al. Grade 1 or "ding" concussions in high school athletes. *Am J Sports Med* 2004;32:47-54. | 250 (14.7) |
| 47 | Broshek DK, Kaushik T, Freeman JR, Erlanger D, Webbe F, Barth JT. Sex differences in outcome following sports-related concussion. *J Neurosurg* 2005;102:856-863. | 248 (15.5) |
| 48 | Matser EJT, Kessels AG, Lezak MD, Jordan BD, Troost J. Neuropsychological impairment in amateur soccer players. *JAMA* 1999;282:971-973. | 248 (11.3) |
| 49 | Kelly JP, Nichols JS, Filley CM, Lillehei KO, Rubinstein D, Kleinschmidt-DeMasters BK. Concussion in sports: Guidelines for the prevention of catastrophic outcome. *JAMA* 1991;266:2867-2869. | 243 (8.1) |
| 50 | Guskiewicz KM, Mihalik JP, Shankar V, et al. Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery* 2007;61:1244-1253. | 240 (17.1) |
| 51 | Kelly JP, Rosenberg JH. Diagnosis and management of concussion in sports. *Neurology* 1997;48:575. | 233 (9.7) |
| 52 | Vagnozzi R, Signoretti S, Tavazzi B, et al. Temporal window of metabolic brain vulnerability to concussion: a pilot 1H-magnetic resonance spectroscopic study in concussed athletes—part III. *Neurosurgery* 2008;62:1286-1295. | 229 (17.6) |
| 53 | Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sport Med* 2003;13:222-229. | 227 (12.6) |

(continued)

**Appendix Table 1.** Continued

| Rank | Article | No. of Citations (Citation Density*) |
|---|---|---|
| 54 | Duma SM, Manoogian SJ, Bussone WR, et al. Analysis of real-time head accelerations in collegiate football players. *Clin J Sport Med* 2005;15:3-8. | 226 (14.1) |
| 55 | Chen J-K, Johnston KM, Frey S, Petrides M, Worsley K, Ptito A. Functional abnormalities in symptomatic concussed athletes: an fMRI study. *NeuroImage* 2004;22:68-82. | 223 (13.1) |
| 56 | McCrory P, Meeuwisse WH, Aubry M, et al. Consensus Statement on Concussion in Sport: The 4th International Conference on Concussion in Sport, Zurich, November 2012. *J Athletic Training* 2013;48:554-575. | 223 (27.9) |
| 57 | Vagnozzi R, Signoretti S, Cristofori L, et al. Assessment of metabolic brain damage and recovery following mild traumatic brain injury: A multicentre, proton magnetic resonance spectroscopic study in concussed patients. *Brain* 2010;133:3232-3242. | 221 (20.1) |
| 58 | Gerberich SG, Priest JD, Boen JR, Straub CP, Maxwell RE. Concussion incidences and severity in secondary school varsity football players. *Am J Public Health* 1983;73:1370-1375. | 219 (5.8) |
| 59 | Dick RW. Is there a gender difference in concussion incidence and outcomes? *Br J Sports Med* 2009;43:46-50. | 217 (18.1) |
| 60 | Majerske CW, Mihalik JP, Ren D, et al. Concussion in sports: Postconcussive activity levels, symptoms, and neurocognitive performance. *J Athletic Training* 2008;43:265-274. | 216 (16.6) |
| 61 | Rechel JA, Yard EE, Comstock RD. An epidemiologic comparison of high school sports injuries sustained in practice and competition. *J Athletic Training* 2008;43:197-204. | 214 (16.5) |
| 62 | Saunders RL, Harbaugh RE. The second impact in catastrophic contact-sports head trauma. *JAMA* 1984;252:538-539. | 213 (5.8) |
| 63 | McCREA M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. *J Int Neuropsychol Soc* 2005;11:58-69. | 212 (13.3) |
| 64 | Bleiberg J, Cernich AN, Cameron K, et al. Duration of cognitive impairment after sports concussion. *Neurosurgery*. 2004;54:1073-1080. | 211 (12.4) |
| 65 | Guskiewicz KM. Postural stability assessment following concussion: One piece of the puzzle. *Clin J Sport Med* 2001;11:182—189. | 211 (10.6) |
| 66 | McCrea M, Kelly JP, Kluge J, Ackley B, Randolph C. Standardized assessment of concussion in football players. *Neurology* 1997;48:586. | 211 (8.8) |
| 67 | Thurman DJ, Branche CM, Sniezek JE. The epidemiology of sports-related traumatic brain injuries in the United States: Recent developments. *J Head Trauma Rehabil* 1998;13:1—8. | 211 (9.2) |
| 68 | Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med* 2010;20:21-27. | 210 (19.1) |
| 69 | Crisco JJ, Fiore R, Beckwith JG, et al. Frequency and location of head impact exposures in individual collegiate football players. *J Athl Train* 2010;45:549-559. | 205 (18.6) |
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(continued)

**Appendix Table 1.** Continued

| Rank | Article | No. of Citations (Citation Density*) |
|---|---|---|
| 81 | Moser RS, Schatz P, Jordan BD. Prolonged effects of concussion in high school athletes. *Neurosurgery* 2005;57:300-306. | 193 (12.1) |
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| 86 | Maugans TA, Farley C, Altaye M, et al. Pediatric sports-related concussion produces cerebral blood flow alterations. *Pediatrics* 2012;129:28−37. | 187 (20.8) |
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| 97 | McClincy MP, Lovell MR, Pardini J, Collins MW, Spore MK. Recovery from sports concussion in high school and collegiate athletes. *Brain Injury* 2006;20:33-39. | 176 (11.7) |
| 98 | Harmon KG, Drezner J, Gammons M, et al. American Medical Society for Sports Medicine position statement: Concussion in sport. *Clin J Sport Med* 2013;23:1-18. | 175 (21.9) |
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