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Measuring the scientific impact of sports-related concussion research: A citation analysis study

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OBJECTIVES: Sports-related concussion (SRC) is an emerging public health concern that has received increased attention in the academic literature over the past two decades. Citation analysis is a bibliometric method that can quantify the impact of individual publications on a given healthcare field. The goal of this study was to identify the top 50 most highly cited journal articles and citation classics in the field of SRC.

METHODS: Citation analysis was carried out using the publicly-accessible search software Harzing's Publish or Perish and the keywords "sports-related concussion" and "sport concussion" to identify the top 50 cited works related to SRC. Papers focusing on non-SRC or mild traumatic brain injury (mTBI) were excluded. Lifetime and annual citation rates were calculated. Critical appraisal was carried out to categorize these publications on the basis of year and journal of publication, study population, design, and topic. Citation classics were defined as articles cited over 400 times.

Over the past 20 years, sports-related concussion (SRC) has become increasingly recognized as an important public health concern that affects millions of North Americans annually (1-5). One of the factors fueling this increased attention is the recent explosion in peer-reviewed research publications that have appeared in journals representing a wide spectrum of healthcare fields including neuropsychology, sports medicine, athletic therapy, rehabilitation medicine, neurology, and neurosurgery. In addition to these studies, a number of national and international groups have published consensus position statements that summarize the existing literature in this field and make recommendations on the diagnosis, management, and prevention of concussion in certain athletic populations (6-19). Despite the recent surge in academic productivity, the content of these consensus position statements has remained remarkably consistent over the years, with a significant proportion of recommendations and practice guidelines based largely upon modest empirical evidence and expert opinion with a number of persistent knowledge gaps identified throughout sources.

Measuring the scientific impact of individual academic and research publications within a given field or specialty is challenging. To aid in this assessment, a number of bibliometric measures have been developed to help quantify the impact of individual publications on a given healthcare field as well as the productivity of individual researchers (20-22). Among these techniques is citation analysis which can be used to calculate the overall number of times, or the number of times annually a given publication is cited in the literature (23,24). Publications that are cited more than 400 times in literature are defined as "citation classics" (22,25). Examination of the citation classics is an objective way of quantifying the breadth of a healthcare

RESULTS: The top 50 most highly cited papers related to SRC were identified. The most common populations addressed by these articles included mixed populations (i.e. high school and collegiate athletes etc., 23), collegiate athletes (9), high school athletes (8), and retired professional athletes (5). The most common study designs included prospective cohort (7), prospective uncontrolled cohort (6), retrospective cohort (6), and consensus position statements (7). The most common topics addressed were epidemiology/natural history (26), practice guidelines (12), diagnosis/assessment (6), and long-term effects (5). Of the top 50 most highly cited articles, 14 met the criterion for citation classic.

CONCLUSIONS: The majority of the top 50 most highly cited journal articles and citation classics related to SRC focus on the epidemiology and natural history of this condition and establish practice guidelines for certain athletic populations. Despite the increase in SRC research over the past decades, there remain persistent knowledge gaps and controversies regarding the diagnosis and management of SRC, especially among children and adolescents.

Key Words: *Bibliometrics, Citation analysis; Literature; Research; Sports-related concussion*

field and identifying those publications that have made the greatest impact on that field (20,26-28). Citation analyses have been carried out in diverse medical fields such as trauma (29), orthopedics (30), critical care (31), ophthalmology (32), neurosurgery (20,21), depression (27), anorexia (28), and epilepsy (26). Although a previous study identified the top fifty highly cited articles related to traumatic brain injury (TBI) (33), there have been no studies that have restricted searches to SRC.

Accordingly, we carried out a bibliometric study to identify the fifty most frequently cited articles related to SRC and categorized these studies according to journal, year of publication, study population, design, and topic. This study provides an estimate of the most influential studies in SRC to date and identifies areas where future research is needed.

METHODS

We performed a search for the top 50 cited journal articles related to SRC using a publicly-accessible search software called *Harzing's Publish or Perish* (34). This software calculates citation metrics based on a literature search collected from Google Scholar. A search was carried out for all journal articles using the keywords "sports-related concussion" and "sport concussion" on May 6th, 2015. There were no restrictions regarding date or language of publication. Citations were then manually ordered from most to least cited according to the overall number of times a journal was cited in the literature (lifetime citation rate). To arrive at the top 50 cited journal articles related to SRC, two authors independently manually reviewed the results and removed articles that: a) were identified as book chapters, manuals, or non-peer-reviewed publications etc.; b) focused primarily on non sports-related

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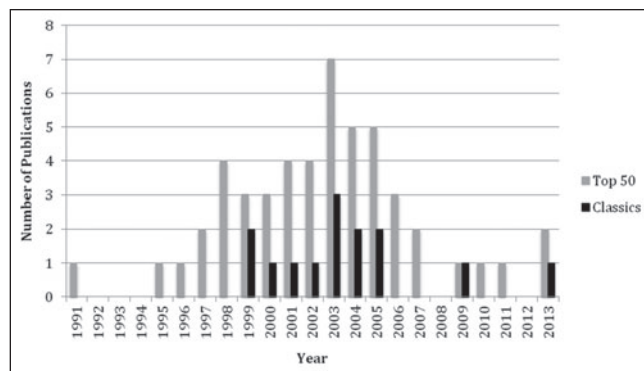


Figure 1) Distribution of top 50 citations and citation classics in sports-related concussion by year

concussion; and/or c) focused primarily on mild traumatic brain injury (mTBI). Any discrepancies were resolved through discussion and consensus. Primary research studies, reviews, and consensus position statements were included.

Critical appraisal was carried out independently by one author to categorize journal articles according to: year of publication, journal, study population (high school, collegiate, professional etc.), study design (randomized controlled trial, retrospective review, etc.), and topic (epidemiology, diagnosis, etc.). A second author reviewed the critical appraisal results for accuracy and any discrepancies were resolved through discussion. The top 50 cited works identified in this search were compared to a general PubMed search for all articles published over the same period of time using the keyword "sport concussion". Eugene Garfield, founder of the Institute of Scientific Information defined "citation classics" as articles that were cited over 400 or more times and articles were designated as citation classics if they met this criterion (22,25).

RESULTS

Using the outlined search methodology, we identified the top 50 cited journal articles related to SRC (Table 1). The mean number of overall citations was 377.84 (SD 190.80; range 205 to 1105). The mean annual citation rate among these journal articles was 40.57 (SD 45.60; range 22.78 to 184.17). The journals in which the top 50 cited articles were found are summarized in Table 2. The study populations among these works included children/adolescents (2), high school athletes (8), collegiate athletes (9), active professional athletes (2), retired professional athletes (5), mixed populations (i.e. high school and collegiate athletes etc., 23), and unspecified population (1). The types of studies identified in this search included prospective cohort (7), prospective uncontrolled cohort (6), retrospective cohort (6), consensus position statement (7), review (a non-systematic and non-reproducible review of a topic, 4), structured literature review (i.e. included a systematic review or structured review of the literature, 4), nested case-control (4), retrospective uncontrolled cohort (4), case-control (3), case report (3), prospective controlled cohort (2; see Table 3). The articles were classified according to topic as follows: epidemiology/natural history (26), practice guidelines (12), diagnosis/assessment (6), long-term effects (5), and pathophysiology (1; see Table 3).

Among the top 50 cited works, 14 met the criterion for a citation classic. Study populations among the citation classics included mixed populations (8/14), collegiate athletes (3/14), high school athletes (2/14), and retired professional athletes (1/14). The types of studies identified among the citation classics included consensus position statements (5/14), prospective uncontrolled cohort (3/14), retrospective cohort (3/14), nested case-control (2/14) studies, and review (1/14). The topics of the citation classics included epidemiology/natural history (7/14), practice guidelines (5/14), pathophysiology (1/14), and long-term effects (1/14). A PubMed search performed on the same

day as our citation analysis using the term "sport concussion" yielded 1930 articles. As such, the citation classics accounted for 14 of the 1930 (0.7%) journal articles published in the field and 14/50 (28%) of the top 50 most highly cited articles. The distribution of publication year for the top 50 articles and citation classics are illustrated in Figure 1.

DISCUSSION

The present study utilized citation analysis methodology to identify the top 50 cited journal articles related to SRC. The results of this study provide a unique opportunity to objectively evaluate the breadth of this field, assess where the field of SRC research is at, and identify what areas need to be addressed to move the field forward. Critical analysis of these papers allowed the authors to address the following important questions.

What populations are studied among the top 50 most highly cited journal articles?

Sports-related concussion is a form of TBI that can occur in athletes of any age, during a wide range of sports, and at varying levels of play. Even after retirement from competitive sports, there is increasing concern that concussion and repetitive subconcussive head injuries sustained during sports can lead to long-term consequences that may emerge years after these injuries are sustained. Although the top 50 most highly cited journal articles in SRC sampled a wide spectrum of sport participants, certain populations remained more highly represented than others. The vast majority of top 50 studies focused on isolated samples of collegiate (18%) or high school athletes (16%) or mixed populations (46%) that commonly included these two age groups. Of the seven consensus position statements identified among the top 50 articles, the majority focused on general recommendations that were applicable to mixed populations including athletes of all ages. Despite increased media and medicolegal attention focused on SRC in professional sports, only 14% of the top 50 articles focused on professional athletes including two studies that focused on active professional athletes and five that focused on retired professional athletes. Of the five articles that focused on retired athletes, two included post-mortem analysis of neuropathological specimens from former professional athletes. While high school-aged athletes were included in a notable proportion of top 50 studies, there were only two studies that focused on child athletes, one unstructured review and one consensus position statement.

What topics are addressed in the top 50 papers?

Among the top 50 most highly cited works in SRC, just over half (52%) were devoted to the epidemiology and natural history of this condition. Most of these studies used prospective or retrospective study designs to examine the duration of time in which athletes took to achieve symptomatic or neurocognitive recovery. Of these studies most focused on recovery time in isolated populations of collegiate or high school athletes with some comparing recovery time between these unique populations. These early pioneering works have helped form our foundational understanding of SRC as a condition characterized by temporary physical, cognitive, sleep, and emotional symptoms that typically resolve within 7-10 days in collegiate athletes and may take longer to resolve among high school athletes (35-41). Some of these studies examined clinical variables associated with injury severity and prolonged recovery such as age (36), concussion history (42-44), loss of consciousness (41), and post-traumatic amnesia (37,45). Approximately one quarter of the top 50 articles were composed of expert consensus position statements, including 4 published by the international, multi-disciplinary Concussion In Sport Group (CISG) following meetings held in Vienna (6), Prague (16), and Zurich (17,18), and one each published by the National Athletic Therapy Association (46), the American Academy of Pediatrics (11) and the American Medical Society for Sports Medicine (12). These consensus position statements have helped advance the study of SRC by

TABLE 1
Top 50 most highly cited journal articles in sports-related concussion

Rank	First author	Title	Year	Journal	Lifetime citations	Annual citation rate (citations/year)
1	P McCrory	Consensus statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport held in Zurich, November 2008	2009	South African Journal of Sports Medicine	1105	184.17
2	KM Guskiewicz	Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study	2003	Journal of the American Medical Association	835	69.58
3	M McCrea	Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study	2003	Journal of the American Medical Association	710	59.17
4	P McCrory	Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004	2005	British Journal of Sports Medicine	706	70.60
5	M Aubry	Summary and agreement statement of the first International Conference on Concussion in Sport, Vienna 2001	2002	British Journal of Sports Medicine	704	54.15
6	CC Giza	The neurometabolic cascade of concussion	2001	Journal of Athletic Training	670	47.86
7	MW Collins	Relationship between concussion and neuropsychological performance in college football players	1999	Journal of the American Medical Association	664	41.50
8	P McCrory	Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012	2013	British Journal of Sports Medicine	557	278.50
9	KM Guskiewicz	Epidemiology of concussion in collegiate and high school football players	2000	American Journal of Sports Medicine	524	34.93
10	KM Guskiewicz	Association between recurrent concussion and late-life cognitive impairment in retired professional football players	2005	Neurosurgery	504	50.40
11	M McCrea	Unreported concussion in high school football players: implications for prevention	2004	Clinical Journal of Sports Medicine	496	45.09
12	JW Powell	Traumatic brain injury in high school athletes	1999	Journal of the American Medical Association	475	29.69
13	M Field	Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes	2003	Journal of Pediatrics	462	38.50
14	KM Guskiewicz	National Athletic Trainers' Association position statement: management of sport-related concussion	2004	Journal of Athletic Training	439	39.91
15	MW Collins	Cumulative effects of concussion in high school athletes	2002	Neurosurgery	387	29.77
16	KM Guskiewicz	Postural stability and neuropsychological deficits after concussion in collegiate athletes	2001	Journal of Athletic Training	382	27.29
17	SN Macciocchi	Neuropsychological functioning and recovery after mild head injury in collegiate athletes	1996	Neurosurgery	372	19.58
18	LM Gessel	Concussions among United States high school and collegiate athletes	2007	Journal of Athletic Training	371	46.38
19	MR Lovell	Recovery from mild concussion in high school athletes	2003	Neurosurgery	353	29.42
20	JP Kelly	Concussion in sports: guidelines for the prevention of catastrophic outcome	1991	Journal of the American Medical Association	337	14.04
21	EJ Pellman	Concussion in professional football: reconstruction of game impacts and injuries	2003	Neurosurgery	332	27.67
22	MR Lovell	Neuropsychological assessment of the college football player	1998	Journal of Head Trauma Rehabilitation	329	19.35
23	KM Guskiewicz	Recurrent concussion and risk of depression in retired professional football players	2007	Medicine and Science in Sports and Exercise	326	40.75
24	JP Kelly	Diagnosis and management of concussion in sports	1997	Neurology	318	17.67
25	BI Omalu	Chronic traumatic encephalopathy in a National Football League player	2005	Neurosurgery	312	31.20
26	RJ Echemendia	Neuropsychological test performance prior to and following sports-related mild traumatic brain injury	2001	Clinical Journal of Sports Medicine	298	21.29
27	ME Halstead	Sport-related concussion in children and adolescents	2010	Pediatrics	288	57.60
28	RC Cantu	Posttraumatic retrograde and anterograde amnesia: pathophysiology and implications in grading and safe return to play	2001	Journal of Athletic Training	287	20.50
29	JJ Bazarian	Mild traumatic brain injury in the United States, 1998-2000	2005	Brain Injury	280	28.00

Continued on next page

TABLE 1 – CONTINUED
Top 50 most highly cited journal articles in sports-related concussion

Rank	First author	Title	Year	Journal	Lifetime citations	Annual citation rate (citations/year)
30	MR Lovell	Grade 1 or “ding” concussions in high school athletes	2004	American Journal of Sports Medicine	279	25.36
31	GL Iverson	Cumulative effects of concussion in amateur athletes	2004	Brain Injury	278	25.27
32	KG Harmon	American Medical Society for Sports Medicine position statement: concussion in sport	2013	British Journal of Sports Medicine	262	131.00
33	HG Belanger	The neuropsychological impact of sports-related concussion: a meta-analysis	2005	Journal of the International Neuropsychological Society	260	26.00
34	M McCrea	Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete	1998	Journal of Head Trauma and Rehabilitation	257	15.12
35	MW Collins	On-field predictors of neuropsychological and symptom deficit following sports-related concussion	2003	Clinical Journal of Sports Medicine	254	21.17
36	P Schatz	Sensitivity and specificity of the ImpACT Test Battery for concussion in athletes	2006	Archives of Clinical Neuropsychology	253	28.11
37	JC Maroon	Cerebral concussion in athletes: evaluation and neuropsychological testing	2000	Neurosurgery	253	16.87
38	BE Gavett	Chronic traumatic encephalopathy: a potential late effect of sport-related concussive and subconcussive head trauma	2011	Clinics in Sports Medicine	250	62.50
39	DJ Thurman	The epidemiology of sports-related traumatic brain injuries in the United States: recent developments	1998	Journal of Head Trauma Rehabilitation	249	14.54
40	PR McCrory	Second impact syndrome	1998	Neurology	248	14.59
41	GL Iverson	Interpreting change on ImpACT following sport concussion	2003	The Clinical Neuropsychologist	246	20.50
42	M McCrea	Standardized assessment of concussion in football players	1997	Neurology	244	13.56
43	BL Riemann	Effects of mild head injury on postural stability as measured through clinical balance testing	2000	Journal of Athletic Training	235	15.67
44	M McCrea	Immediate neurocognitive effects of concussion	2002	Neurosurgery	226	17.38
45	J Bleiberg	Duration of cognitive impairment after sports concussion	2004	Neurosurgery	220	20.00
46	JS Delaney	Concussions among university football and soccer players	2002	Clinical Journal of Sports Medicine	220	16.92
47	DL Maddocks	The assessment of orientation following concussion in athletes	1995	Clinical journals of Sports Medicine	213	10.65
48	MR Lovell	Does Loss of Consciousness Predict Neuropsychological Decrements After Concussion?	1999	Clinical Journal of Sports Medicine	209	13.06
49	BI Omalu	Chronic traumatic encephalopathy in a national football league player: part II	2006	Neurosurgery	208	23.11
50	MW Kirkwood	Pediatric sport-related concussion: a review of the clinical management of an oft-neglected population	2006	Pediatrics	205	22.78

establishing standardized definitions and best practice guidelines for this condition as well as summarizing the existing research in this field and providing directions for future study. While there is inherent value in evaluating the current state of the field over time, we are concerned about the relatively high number of position statements published within the last few years (7-9,11-15,18,19), some that provide very little new information compared to other available position statements in the field. Although articles that establish scales, classification systems, and practice guidelines have been found to aggregate towards the top 50 articles in other fields (20,21,26-28), there is certainly a risk of a field becoming oversaturated by articles driven largely by expert consensus - especially a field without any standards governing who can carry out care of this patient population. In addition to these topics, articles related to diagnosis and assessment (12%), long-term effects (10%), and pathophysiology (2%) of SRC made up the remainder of the articles in the top 50. Articles related to diagnosis and assessment focused on the psychometrics and reliability of components of the SCAT tool, including the Standardized Assessment of Concussion (SAC) (47), Maddocks Questions (48), the Balance Error Scoring System (BESS) (49), or the Immediate Post-Concussion Assessment and Cognitive Tool (ImpACT) computerized neurocognitive tool (50,51). Articles that addressed the long-term effects of SRC focused largely on the rates of depression and neurodegenerative diseases in retired professional football players (10,52) or summarized

the neuropathological findings of post-mortem specimens derived from this clinical population (53,54). Since these seminal studies, there has been a considerable increase in the number of published articles related to the epidemiology, clinical features, neuroimaging, and neuropathology of chronic traumatic encephalopathy (CTE) and neurodegenerative processes in retired athletes (55-60). The final area addressed by articles in the top 50 included one article that summarized the pathophysiological mechanisms underlying TBI and SRC. Although not a systematic review, this reference represents an excellent summary of the basic science literature related to this injury (61). Because our search was restricted to articles dealing explicitly with SRC, this likely contributed to an under-representation of basic science articles that often involve animal models of non-specific TBI. There were no studies examining the treatment of concussion identified among the top 50.

What papers comprise the citation classics in this field?

Defining the citation classics related to the field can be an objective method of assessing the quality of research within a field and identifying which studies have had the greatest influence on that field (20,26-28,62,63). At the same time, defining a specific work a citation classic does not always reflect the overall impact that a particular publication has had on shaping the contemporary understanding of a health condition or its contribution to advancements in patient care, public health

TABLE 2
Journals that published the top 50 most highly cited articles in sports-related concussion

Journal	Number of articles published
Neurosurgery	9
Clinical Journal of Sports Medicine	6
Journal of Athletic Training	6
Journal of the American Medical Association	5
British Journal of Sports Medicine	4
Journal of Neurology	3
Journal of Head Trauma and Rehabilitation	3
Journal of Pediatrics	3
American Journal of Sports Medicine	2
Brain Injury	2
Archives of Clinical Neuropsychology	1
Clinics in Sports Medicine	1
Journal of the International Neuropsychological Society	1
Medicine and Science in Sports and Exercise	1
South African Journal of Sports Medicine	1
The Clinical Neuropsychologist	1
Journal of Neurosurgery	1

policy, or practice guidelines. Other authors have pointed out that the citation classics should also be regarded as “required reading” for related healthcare professionals, since they are often responsible for building the foundation of knowledge within a given field (27). In the present study, 14 articles met the criterion for citation classic, constituting 28% of articles in the top 50 and 0.7% of total articles on sport concussion published up to the date of the study. Similar to the top 50 articles, the vast majority focused on mixed or isolated populations of collegiate and high school athletes. Among the 14 citation classics, 57% were primary research studies (including three prospective uncontrolled and retrospective cohort studies and two nested case-control studies) while 36% were consensus position statements and one was an unstructured review. Topics among the citation classics included epidemiology and natural history (50%), practice guidelines (36%), and one article each on long-term effects and pathophysiology of SRC. Comparison of the citation classics in SRC with studies that have completed similar analyses in other fields offers some interesting insights.

First, the number of overall citation classics identified in this field is much lower compared with fields related to other neurological diseases. Indeed, comparable searches have identified much higher numbers of citation classics among fields such as major depression (243) (27), Parkinson's disease (107) (63), clinical neurosurgery (106) (20), and epilepsy (89) (26). Of the top 50 most highly cited articles in TBI, all are cited over 400 times in the literature (33). While there are undoubtedly numerous explanations for the relatively low number of citation classics in SRC compared with other fields, these results are most likely the product of the relatively recent recognition of SRC as an important public health concern compared with other neurological disorders. This is supported by the finding that all of the citation classics in SRC were published between the years 1999-2013, whereas citation classics in major depression span the years of 1946-2010.

A second interesting finding concerns the types of articles that comprise the citation classics in SRC compared to other fields. As stated, consensus position statements accounted for 36% of the citation classics in SRC, which is quite high compared with the proportion of citation classics devoted to similar articles in fields such TBI (8%) (33) and clinical neurosurgery (7%) (20). Although this finding may be explained by the large number of articles that refer to these publications for standardized definitions and practice guidelines, it may also be reflective of the lower number of high-impact primary research articles in this field compared with others. The later explanation is supported by the finding

TABLE 3
Categorization of the top 50 most highly cited journal articles in sports-related concussion according to study population, design, and topic

Study population	Number of publications (n=50)
Mixed populations	23
Collegiate athletes	9
High school	8
Professional athletes, retired	5
Professional athletes, active	2
Children and adolescents	2
Not specified	1
Study design	
Prospective cohort	7
Prospective uncontrolled cohort	6
Retrospective cohort	6
Consensus position statement	7
Review	4
Structured literature review	4
Retrospective uncontrolled cohort	4
Nested case-control	4
Case-control	3
Case report	3
Prospective controlled cohort	2
Study topic	
Epidemiology/natural history	26
Practice guidelines	12
Diagnosis/assessment	6
Long-term effects	5
Pathophysiology	1

that, at present, a significant proportion of recommendations contained in published consensus position statements are supported by modest empirical evidence and expert opinion.

Where are the gaps in sports-related concussion research?

As the present study illustrates, there has been a significant increase in SRC research publications over the past 20 years. During the same period, a multitude of published consensus position statements from diverse national and international organizations have been developed to summarize the existing literature, develop practice guidelines, and establish the roles of certain healthcare professionals in the evaluation and management of SRC patients. This study not only provides a snapshot of the most influential journal articles that contribute to our current understanding of SRC but also sheds light on where future efforts must be directed to help address the persistent unmet needs, controversies, and knowledge gaps within this emerging field. Among the areas of SRC research that remain under-represented among the top 50 highest cited works and citation classics are studies related to the diagnosis and treatment of SRC, especially among children.

The diagnosis of acute SRC remains a significant challenge for physicians due to the subtle heterogeneity in clinical presentations, poor recognition and under-reporting of concussion symptoms among athletes, and a persistent lack of objective tools that provide real-time insight into the pathophysiology of this condition. To address these challenges, a number of assessments tools have been developed that offer standardized methods of evaluating subjective and objective aspects of this condition. The Sport Concussion Assessment Tools (i.e the SCAT2, SCAT3, and Child SCAT) (16-18) are perhaps the most well-recognized and commonly used concussion assessment tools that were originally designed for sideline assessment but have also been incorporated into use in the office setting by some healthcare

professionals. Despite the widespread promotion of these tools by multiple consensus position statements among the top 50, there remains limited research to direct the evidence-based practice of SCAT testing in certain populations, especially children and adolescents. While psychometric studies have been performed on components of the SCAT tools in high school and collegiate athletes (47-49,64-67), important questions that remain understudied in the pediatric age group include the role of baseline testing, what constitutes a clinically-meaningful change in post-injury test scores, and to what extent these tools are reliable measures of neurological compromise. Some experts have pointed out that the sideline assessment of patients with suspected SRC should not focus on diagnosis but on the simple determination of whether an athlete should or should not be returned immediately to the field of play. If experts agree that every child with a suspected SRC should be removed from play and undergo evaluation by a physician, then it begs the question whether there remains any role for these sideline assessment tools in the pediatric group, especially when these tests can be normal in the setting of SRC (18)? Given these limitations it would seem that clinical training in TBI and judgment of the examiner would be of paramount importance in the sideline evaluation of patients with suspected SRC. Nevertheless there are no studies that address inter-rater reliability among the wide spectrum of "healthcare professionals" who currently utilize these tools to diagnose concussion. Research addressing these questions is not only under-represented among the top 50 highly cited articles in the field but also among the more recently published literature. To date, there are relatively few primary research articles that specifically address the use of SCAT2 and SCAT3 testing in any athletic population (65,66,68-74) compared with the over 100 articles devoted to CTE (53-60,75-80) a condition that has been diagnosed in an relatively small number of athletes. More recently, accumulating evidence has begun to suggest that mTBI and SRC are associated with objective abnormalities of the oculomotor and vestibular systems that can be detected with emerging standardized clinical assessment tools. Promising research suggests that incorporation of objective tools such as the King Devick Test into existing sideline assessment tools may enhance the detection of SRC (81-83), but most of these studies have been published in the last few years and are thus were not identified among the top 50.

Despite being heralded as one of the "cornerstones of concussion evaluation" by one early international consensus position statement (6), research aimed at establishing evidence-based recommendations for the use of neuropsychological and computerized neurocognitive tools in SRC are similarly lacking. Outstanding questions remain regarding which patients should undergo neurocognitive testing, when testing should be undertaken, and what approach (computerized, pencil-and-paper, or hybrid) is optimal for certain populations. Articles identified among the top 50 that focused on neuropsychological testing were largely aimed at assessing the psychometrics of abbreviated neurocognitive tools among high school and collegiate athletes (50,51,84). Although neuropsychologists undoubtedly play an important role in the multi-disciplinary management of concussion patients and are the only professionals with optimal training in neuropsychological test administration, interpretation, and psychometrics, concern remains that the vast majority of computerized neurocognitive testing in young athletes continues to be carried out by non-neuropsychologists to whom these tools are marketed (85-87). Neuropsychology experts point out that future research is needed to evaluate the role of baseline neurocognitive testing among children and adolescents, the reliability and clinical utility of post-injury computerized neurocognitive tools in preadolescent athletes, and the advantages and limitations of hybrid neuropsychological testing approaches in pediatric patients with acute SRC and post-concussion syndrome (85,87,88). Even while computerized neurocognitive tools remain a common component of standardized concussion protocols in numerous professional sports leagues, there is limited published data regarding the clinical value and limitations of these tools to help guide

clinicians caring for these athletes (89-91). These unresolved issues highlight the need to establish unbiased, evidence-based recommendations regarding the optimal role of neuropsychological and computerized neurocognitive assessment tools in evaluation and management of SRC patients.

Beyond the SCAT and computerized neurocognitive tools, there remain few available diagnostic tools that can assist physicians in the diagnosis and management of SRC. Expert opinion supports the notion that SRC is not associated with structural brain injury on routine computerized tomography (CT) and magnetic resonance imaging (MRI) studies (6,12,16-18). Although the past five years have witnessed an increase in advanced neuroimaging studies in SRC utilizing techniques such as diffusion tensor imaging, functional MRI, and MRI-based cerebral blood flow measurement, none of these tools have advanced beyond investigational use to impact patient care (92). As previously described here, there remains an urgent, unmet need for novel neuroimaging diagnostic tools that provide qualitative and quantitative assessment of TBI pathophysiology and can contribute to the diagnosis, classification, and confirmed recovery in individual SRC patients(93). More recently, advancements in positron emission tomography (PET) and customized radio-labeled ligands have permitted researchers to study the distribution of abnormal proteins within the brains of retired professional athletes with mild cognitive impairment and suspected CTE (94-96). These preliminary findings will undoubtedly be strengthened by future studies correlating neuroimaging findings with post-mortem neuropathological examinations.

Among the top 50 cited articles identified in this study, very few address the treatment of SRC. According to consensus position statements published from 2002 to 2013, the cornerstone of concussion management is physical and cognitive rest followed by initiation of a graduated Return-to-Play protocol (6,16-18). Although none of the top 50 most highly cited articles provide empirical data to support these recommendations, conservative management remains the most acceptable and safe course of action and will lead to complete neurological recovery in the vast majority of SRC patients (97). More recently, several studies including a randomized controlled trial have aimed to address the impact of physical and cognitive rest on symptom duration (98-102). In addition to focusing on the return to sports-related activities, a limited number of recent studies have also begun to highlight the effects of school-related activities on concussion recovery and the need for individualized Return-to-Learn programs that provide academic accommodations tailored to the patient's individual needs and symptoms (103-106). Although the majority of concussion patients will achieve full neurological recovery within a week of injury, approximately 15-20% of collegiate and professional athletes will experience symptoms greater than 10 days (40,43,66,107) and 29-73% of pediatric patients will develop persistent concussion symptoms lasting greater than one month (108-114). Evidence-based guidelines for the management of these patients are also lacking (115). Among the top 50 most cited articles in SRC, there are no formal studies that have examined treatment options for patients with acute SRC or PCS. Recent reviews have advanced the concept that patients with PCS may comprise a heterogeneous population where symptom clusters, disorders, or trajectories may result from unique pathophysiological processes (116,117). To address these populations, emerging research has begun to establish the efficacy of sub-maximal aerobic exercise prescription for patients with physiologic post-concussion disorder (118-120) and one randomized controlled trial demonstrated enhanced recovery in SRC patients following cervicovestibular rehabilitation (121). There are few studies that have addressed treatment of patients with acute SRC or therapeutic options for SRC patients who develop post-traumatic headaches, post-injury psychiatric disorders, and those that develop early cognitive impairment in the setting of repetitive concussions. As advancements continue to be made in our understanding of the pathophysiology of SRC, PCS, and CTE, future studies examining targeted rehabilitation strategies for these clinical populations will undoubtedly become more available.

Study limitations

The present study is not without limitations. First, the most important limitation is that certain high-impact highly cited articles may not have been identified by our search methodology. Although we chose a search software program that has been used in previous citation analyses performed in other healthcare fields, it is possible that the use of other search software programs (i.e., ISI Web of Science) may have yielded different results. Second, by restricting the keywords used in this search to “sports-related concussion” and “sport concussion” we may have failed to identify certain highly cited articles. Specifically, articles that focused primarily on “mild TBI” may have indeed included SRC patients but may not be included in our results. Because our search was limited to concussions occurring in sport, this would also have likely contributed to a paucity of identified articles on the pathophysiology of SRC that often include animal models of TBI. Third, the results of this study represent a cross-sectional assessment of the top 50 cited articles on the day of the search. Given the number of articles related to SRC published on a monthly basis, the results of this study would be clearly subject to change over time. Fourth, while citation analysis has been used as measure to quantify the impact of a particular publication on its field, there are undoubtedly journal articles that are far less frequently cited but have made a substantial direct impact on the care of concussion patients and safety of those participating in sports. For instance, pioneering epidemiological work by Emery et al (122) was not identified among the top 50 most frequently cited articles but has played an instrumental role in the modification of body-checking rules in Canadian minor hockey leagues. As such, citation analysis must be viewed as only one of the many ways in which the impact of a given publication on the field of SRC can be measured. Lastly, previous studies in other fields have identified scientific and

non-scientific factors associated with citation rates including level of evidence, sample size, multi-institutional representation, and self-reported conflict of interest (30).

CONCLUSION

The present study used citation analysis to identify the 50 most frequently cited articles related to SRC in the scientific literature. The results of this study suggest that the most frequently cited works related to this field involve high school and collegiate athletes with very few focusing on younger athletes. Commonly cited articles focus largely on the epidemiology and natural history of SRC with less emphasis placed on the potential long-term consequences of SRC and advances in concussion diagnosis and management. Consensus position statements that address practice guidelines for SRC patients were also commonly identified among the top 50. Similar trends were also observed among the citation classics, which constitute 14 of the top 50 most highly cited articles. Despite the increased volume of consensus statements representing various healthcare fields, there remain no international professional guidelines directing what qualifications or clinical training is required to participate in the evidence-based, multi-disciplinary management of this unique TBI population. Even though there has been a significant increase in SRC publications over the past decade, there remains an urgent and persistent need for high-impact research aimed at the diagnosis and management of SRC, especially among the pediatric population.

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