Update on Sports Concussion

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Abstract Over the past 20 years, sports concussion has become one of the most researched topics in sports medicine. Significant resources have been allocated to the study of this issue, with a dramatic increase in information concerning most aspects of this common sports injury. In light of this considerable increase in research, this review is offered to provide clinicians involved in the care of athletes a summary of key features of the evaluation and management of sports concussion with attention to recent contributions to the literature.

Keywords Concussion · Loss of consciousness · Amnesia · Cervical spine injury · Sideline concussion evaluation · Mental status exam · Balance testing · BESS · SCAT3 · Biomarkers of neurologic injury · Functional MRI · Positron emission tomography · Diffusion tensor imaging · Magnetic resonance spectroscopy · Neuropsychologic testing · Cognitive rest · Prolonged postconcussion syndrome · Vestibular therapy · Chronic traumatic encephalopathy

Introduction and definition

In the early 1990s, sports concussion was not given a significant amount of attention. Times have certainly changed. Over the past 20 years, the injury has become a subject of great importance; the focus of conferences, consensus meetings, congressional hearings, hundreds of scientific abstracts and papers, millions of research dollars, and legislation that has touched virtually every state in this country. Media stories are common, and a movie about the challenges of a professional athlete with complications from concussion is in production.

It would seem appropriate to acknowledge that the medical and lay communities' knowledge and appreciation of concussion has grown exponentially in just the past decade. However, sports concussion remains a complicated injury with many collateral issues. The great variability in clinical presentation and recovery stems from the simple reality of the complex nature of the brain. At times, the old adage seems to ring true—"the more we know, the more we don't know".

One simple yet important achievement has been the generation of a workable definition for the injury. McCrory et al account for the most salient features of the entity: (1) concussion is a clinical syndrome caused by biomechanical forces to the brain, either direct or indirect (such as a "whiplash" mechanism); (2) concussion typically manifests as the rapid onset of neurologic dysfunction, which typically resolves spontaneously; (3) the symptoms and signs can essentially be considered an alteration in function rather than brain structure; and (4) concussion results in a "graded set of clinical symptoms that may or may not involve loss of consciousness," with resolution typically following a sequential course [1•].

Despite the gains in knowledge through research, guidance for the clinician still relies significantly on consensus opinion, and the admonition to "treat each injury individually." The purpose of this review is to review key features of sports concussion for the practicing physician, with special attention to recent updates to the medical literature. Any such attempt must fully acknowledge the rapidly evolving nature of our collective knowledge and experience for what we all now appreciate as a most important sports medicine—and public health—topic.

Epidemiology

The epidemiology of sports concussion has been studied for many years in a variety of populations [2•, 3, 4]. Study results

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vary based on a variety of factors including definition of injury, recording mechanisms, and other methodological factors. Although recent investigations reinforce earlier findings of specific sports being associated with higher risk, some studies indicate higher overall rates of injury when compared with past investigations.

Rosenthal noted concussion rates increased for all 9 of the studied high school sports between 2005–2006 to 2011–2012, with 5 of the 9 rate increases being statistically significant. For all sports, the rate increased from 0.23 concussions per 1000 athlete-exposures (AEs) to 0.51. In another study of high school sports concussions from a single school district, Lincoln et al demonstrated an increase from 0.12 concussions per 1000 AEs in 1997–1998 to 0.49 in the 2007–2008 school year [3]. Possible explanations for these findings include an actual increase in the frequency of the injury vs increased reporting of injury because of heightened awareness of participants, parents, coaches, and medical staffs and improved reporting mechanisms.

There is recent data to support the concussion legislation that has been passed by nearly all state legislatures providing for, in part, mandatory education of participants, parents, and coaches, has likely had an effect on concussion reporting. The Lystedt law, so named for second impact syndrome patient Zachary Lystedt, was initially passed in the state of Washington in 2009. Bompadre et al examined the concussion incidence rates in Seattle public schools in the years before and after the law was enacted [5•]. The concussion rate was 1.09 % the year before the legislation was passed and 2.26 % for 2 consecutive years after the law took effect.

The author's perspective is that the heightened awareness of the injury, combined with improved mechanisms for injury surveillance and reporting, account for the steady increase in rates of reported injury. For many years, concussion was underreported by athletes. Intentional underreporting by athletes occurred for fear of losing playing time. Unintentional underreporting occurred due to a lack of understanding of the signs and symptoms of the injury and the importance of timely reporting. The broad education efforts directed at all stakeholders appears to be minimizing both forms of underreporting.

Initial presentation and evaluation

Concussion remains a clinical diagnosis that may present to the clinician with a variety of possible signs and symptoms. The most obvious marker for injury, loss of consciousness, occurs in a relatively small percentage of sports concussion [1•].

The onset of symptoms and signs is usually rapid, though in some cases may be delayed for several minutes to hours. The clinician must consider that presentation may involve any of the following clinical domains: (1) symptoms (headache, dizziness, feeling like in a fog, feeling more emotional); (2) signs, such as

loss of consciousness; (3) cognitive impairment (eg, attention, concentration issues); (4) sleep disturbances—sleeping more or less than usual; and (5) behavioral change—such as increased irritability [1•, 6]. Presence of any of these issues in the setting of significant biomechanical stress to the head and neck should arouse suspicion for diagnosis of concussion. Concomitant neck injury needs to be considered in the context of any head injury. If clinically indicated (axial neck pain, neurologic signs, and symptoms in extremities), full cervical spine precautions are taken, including careful spine immobilization and transport to the nearest trauma facility.

If concussion is suspected by a medical provider, coach, or supervising parent, the athlete should be removed from the activity. The critical information about a possible injury may come from a teammate who often may be in the best position to know a teammate is “not right.” Ideally, the athlete is evaluated at the time of suspected injury by an experienced medical provider to confirm or rule out the diagnosis of concussion. If a medical provider is not available on site, the athlete is removed from activity for the day, and should be precluded from returning to an at-risk activity until further evaluation.

No single sideline or training room tool or test assures complete diagnostic accuracy. There is no “Lachman's test of the brain,” where high sensitivity and specificity is present with a simple maneuver or test. The recommended elements of evaluation include a detailed history of the current injury and past concussions and an assessment of signs and symptoms. In addition, the patient should undergo a limited cognitive evaluation focused on orientation, memory, attention, and concentration. Balance problems are common in the acute phases of injury and assessment is part of the initial and follow-up examinations [7]. Sideline evaluation tools, such as the updated SCAT3, are available and provide for an efficient and systematic assessment of the injured athlete [8, 9]. Diagnostic accuracy is enhanced when baseline data from these assessments is available for the clinician to compare pre- and postinjury performance.

Novel methods of improving the diagnostic accuracy of concussion evaluation are the subject of ongoing investigations. In recent years, sideline reaction time tests [10•], oculomotor tests [11•], and portable EEG assessment [12•] are among the tests that have been studied.

Reaction time is commonly affected after sports concussion. Researchers have investigated reaction time tests that are simple and convenient in hopes of providing another potentially important piece of clinical information to concussion evaluation. Tests have been studied in both college and high school athletes [10•]. More recent work in high school athletes has raised issues of validity and reliability in the high school athlete population [13•].

Biomarkers of neurologic injury continue to be studied as a more objective means of concussion diagnosis and possibly, a valuable method of monitoring recovery. Neuron-specific

enolase (NSE), S-100 calcium-binding protein B (S-100 B), and tau in plasma have all been studied as markers of neurologic injury. Both NSE and S-100 B have been found to be elevated in boxers who received head blows during training and competition [14, 15].

A recent study of Swedish professional hockey players examined levels of plasma T-tau, Serum S-100 B, and NSE in participants who sustained concussion [16•]. T-tau levels were significantly higher from 1 hour to 6 days in postconcussion samples compared with preseason levels obtained in asymptomatic players from different teams. S-100 B levels were elevated postconcussion only in the samples obtained 1 hour post-injury, but not in the remaining samples. Post-injury NSE levels were not found to be elevated compared with controls. It has been noted that biomarker levels (NSE and S-100B) increase after hockey activity without concussion injury [16•]. To date, biomarker technology to diagnose and monitor sports concussion must be regarded as in the preliminary stages.

Advances in imaging have given rise to a number of new technologies that have been utilized in the assessment of concussion, including functional MRI [17], positron emission tomography, diffusion tensor imaging, and magnetic resonance spectroscopy [18••]. This innovative work is contributing to the understanding of the pathophysiology of concussion, though is used primarily in the research setting and not yet standard in the routine evaluation of concussion. Conventional imaging of sports concussion (CT, MRI) is used primarily to detect structural brain injury and skull fracture. In the acute setting, indications for imaging include deterioration or worsening of clinical status, mental status changes, focal neurologic deficits, and possibly prolonged loss of consciousness (>1 minute) [1•, 2•, 3, 4, 5•, 6].

Neuropsychological evaluation

Neuropsychological testing (NP) has emerged as a prominent modality in both the diagnosis and management of sports concussion [19••], and is, therefore, interposed between these 2 sections. NP evaluation in athletes has evolved in a variety of forms over the past 15 years [20–22]. Computerized NP testing is administered at many athletic levels to assist in the diagnosis of injury and neurological recovery. Though its value in the management of sports concussion has great support, clinicians (and patients) are consistently reminded that NP testing is not to be used as a stand-alone test for the determination of return to play. That is, it remains a “piece of the puzzle.”

Most clinicians utilize NP testing after an athlete becomes asymptomatic to assure that cognitive recovery is correlating with resolution of postconcussion symptoms, though there are roles for testing in earlier time periods along the injury/recovery spectrum, particularly with pediatric and adolescent athletes [23].

Interpretation of computerized NP testing may be performed by neuropsychologists or appropriately trained physicians.

The role of baseline neurocognitive testing continues to be a point of discussion. Most recent consensus statements stop short of recommending baseline testing as a mandatory part of concussion assessment [1••]. There are many logistical, administrative, financial, and medical issues that come into play when considering baseline testing for large populations of athletes. The author has encountered resistance to mass testing of scholastic athletes from school boards and athletic directors who object to testing by a specific group or hospital, for reasons that are more political in nature.

Treatment and return to play

Cognitive and physical rest has been the treatment cornerstones for the immediate postconcussion period in hopes of decreasing the duration and severity of symptom burden and to hasten recovery. These recommendations have been focused on minimizing the effects of the brain’s “metabolic mismatch” that occurs in the acute phases of injury, and was first emphasized in the Second International Conference on Concussion in Sport [24].

Clinical experience has supported these long held beliefs about rest as a primary treatment, though few studies in the literature have examined this approach. A recent prospective study examined the effect of cognitive activity on concussion recovery in scholastic athletes [25••]. Increased levels of cognitive activity were associated with prolonged recovery in this sample of 335 patients with a mean age of 15 years old, thus, supporting the recommendation for cognitive rest after concussion. Cognitive rest generally is agreed to constitute the limiting of activities that require focus, concentration and attention, such as reading, studying, texting, video game play, and computer use. The timing and extent of activity limitation are areas requiring further study.

Aside from the standard recommendation for rest, treatment is often focused on symptoms such as headache and sleep dysfunction. A variety of medications may be used, with anecdotal experience generally guiding the clinician due to the lack of large prospective studies. It is hoped that pharmacologic treatment strategies in the future will be successful at facilitating neurologic recovery in addition to control of symptoms.

A stepwise approach to return to play has been outlined as a guide for clinicians charged with this important clinical decision [1••]. A table summarizing the steps is attached (Table 1). The guiding principles of this approach are (1) providing the athlete an initial rest and recovery phase where postconcussive signs and symptoms return to pre-injury baseline; (2) a graduated increase in physical activity with step progression dependent on completion without return of postconcussive signs and symptoms; and (3) should symptoms re-occur, the athlete

returns to the previous asymptomatic level and attempts progression when asymptomatic for a day.

The rate of stepwise progression is a subject of debate. The current international consensus statement recommends that each step take about 1 day before advancing, thus requiring approximately 1 week to be returned to competition in the usual scenario [1•]. The author is not aware of prospective studies that have evaluated varying lengths of return to play protocols. Anecdotally, older competitive athletes (college and professional) are sometimes managed with a more rapid return to play protocol, provided that the basic criteria are met: the athlete is asymptomatic at rest and full exertion, has a normal neurologic exam, and demonstrates neurocognitive performance at pre-injury levels.

Experienced clinicians well understand the pitfalls of relying only on symptom reporting as the sole criteria for monitoring of clinical progress and the return to play decision. A recent study utilized a text messaging robot to survey high school and collegiate athletes diagnosed with concussion to evaluate the potential variability of self-reporting of symptoms [26•]. Texts were sent to the concussed athletes 5 times daily and athletes completed the SCAT 2 symptom severity survey. Not unexpected, there was poor repeatability in the reported symptom scores by these young athletes.

Complications of concussion

While the majority of sports concussions resolve without apparent complications in a predictable time period, increasing attention is being directed to injuries that do not resolve as expected, and the possible long term or chronic effects of concussion, recurrent concussion, and/or chronic exposure to subconcussive head trauma.

Prolonged postconcussion syndrome is suspected when the symptom complex associated with concussion fails to resolve in the expected time period of 10 days to 2 weeks [27•, 28•, 29•]. Possible risk factors for prolonged recovery include a history of multiple concussions, female athletes, younger

athletes, and increased symptom burden at time of presentation. Treatment strategies are directed toward the various symptom complexes that persist, and may include work/school modification, activity modification including therapeutic exercise and subsymptom threshold aerobic training, vestibular therapy, sleep regulation, and treatment for mood disorders [27•]. Given the complicated nature of these cases, a multi-disciplinary approach is recommended to optimize outcomes.

Over the last several years, much attention has been focused on chronic traumatic encephalopathy as a seemingly uncommon but serious complication of severe or recurrent head injury. A detailed summary is beyond the scope of this review, but comprehensive reviews exist in the recent literature [30•]. Early reports of this syndrome were labeled as dementia pugilistica, or “punch drunk syndrome”, and were described in boxers [31, 32]. Since 2005, a few centers have published case studies of possible CTE in former athletes and military personnel that vary somewhat from the earlier cases from both clinical and neuropathologic perspectives [30•]. CTE is described by the current researchers as a complex neurologic syndrome characterized primarily by tau deposition on histologic study, and clinical characteristics primarily neuropsychological (mood disorders, paranoia, agitation, social withdrawal, poor judgment, and aggression) and cognitive (attention, concentration, memory, language, processing speed, and executive functioning) in nature [30•]. Gardner et al point out the limitations in linking the causality of head injury or concussion to the neuropathological and clinical syndrome of CTE, while acknowledging that “there is evidence of association between long-term participation in sport and long term cognitive, psychological, and neurobehavioral problems” [30•]. This research will proceed with great interest and impact in the coming years.

Prevention

In recent years, prevention of sports concussion has focused on a number of factors, including the protective equipment (helmet

Table 1 Stepwise return to play

Step	Activity	Purpose
1. Rest	Symptom limited cognitive rest Consider light stretching	Promote recovery
2. Light exercise	Stationary bike, walking	Increase heart rate
3. Advanced exercise	Bike, jog, elliptical Consider light weight lifting	Increase heart rate and BP, add movement
4. Noncontact; sport specific activity	Noncontact sport specific drills, increase in exercise and specific activity intensity	Higher levels of activity, cognitive load
5. Full contact and clearance	Return to full unrestricted practice including contact	Player confidence and skill assessment

Adapted with permission from McCrory P et al. Br J Sports Med. 2013;47:250–8 [1•]

and mouthguards), cervical muscle strengthening, teaching of proper techniques of play, and changes to rules that govern play.

For sports such as football, it is acknowledged that improvements in helmet technology will not prevent all concussions, but it is hoped that alterations in design can decrease the risk of the injury. Video analysis of game concussions in American football improved our understanding of mechanisms of injury [33]. Researchers noted a significant number of concussive impacts occurred from impacts to the facemask and jaw/temple area. This information was helpful to helmet manufacturers who altered designs to address these biomechanical factors.

Can newer helmet football design have an effect on concussion risk? A retrospective analysis by Rowson et al utilized helmet telemetry data combined with clinical diagnosis of concussion in 8 college football teams over 5 years and noted a significant difference in concussion risk in players using 2 different models of football helmet [34]. As helmet design and player preference for certain helmet models often change, definitive proof can be challenging.

Helmets are important in the prevention of more severe head and face injury in a variety of sports and activities (equestrian, motor sports, cycling, skiing) and are recommended, though modification of concussion risk is less clear [35]. No definitive clinical studies demonstrate that mouthguards affect concussion risk, but remain important in preventing mouth and dental injury [1••].

Neck strength has received attention as a concussion risk factor variable that may be modified through exercise with the goal of altering injury risk, especially for younger athletes and female participants. Researchers have noted smaller neck circumference, smaller mean neck to head circumference ratio and weaker neck strength were associated with increased risk for concussion [36]. They conclude that higher risk individuals could be targeted for exercise prevention programs to potentially lower concussion risk.

Another recent study examined head impact data using the Head Impact Telemetry System (HITS) and anthropometric data on cervical muscle size and strength in high school and college football players to study the relationship between neck strength and head impacts [37]. The authors found conflicting data: players with larger and stronger cervical muscles did not demonstrate lowered head impact severity, although players with increased cervical stiffness showed lower odds of sustaining higher magnitude head impacts.

Rule changes, and enforcement of game rules, will hopefully continue to lower concussion risk. American football rule changes have emphasized protection of vulnerable players, including the quarterbacks and receivers. More severe penalties for inappropriate tackling techniques are being enforced at all levels of play with the goal of changing player behavior that can lead to injury. A concerted effort at teaching proper tackling and blocking techniques (Heads Up Football) are being emphasized at all levels of play.

Assessment of the effectiveness of these preventive strategies will require careful study over time. However, the improved methods of injury reporting and increased likelihood of symptom report and diagnosis (see [Epidemiology](#) section) may confound our ability to assess the true effectiveness of prevention efforts.

Summary

Sports concussion is complex injury that remains a diagnostic and treatment challenge to sports medicine providers. Undeniable gains have been made in understanding basic injury epidemiology, along with improvements in evaluation and treatment methods. Education efforts of all stakeholders have gained tremendous momentum due to legislative and other initiatives. Continuing efforts to change the culture of underreporting of symptoms will require ongoing efforts over many years. Refinement of available tools to assist in accurate and timely diagnosis is a priority. Cognitive and physical rest is the cornerstone of initial treatment, and further research offers the hope of interventions that may speed the recovery process. Those patients that suffer prolonged recovery appear to be a minority but the effects on their personal, social, and athletic lives may be profound. More effective means of treating complicated cases are likely to require a concerted and coordinated effort on the part of physicians, neuropsychologists, and physical therapists. The issues of chronic and/or cumulative effects of concussion and head trauma will garner much attention and resources and will likely be best understood with prospective studies over time. All in all, we have come a long way—and have a long way to go.

Compliance with Ethics Guidelines

Conflict of Interest Andrew Tucker reports personal fees from Brainscope, outside the submitted work.

Human and Animal Rights and Informed Consent No human or animal studies performed by the authors: This article does not contain any studies with human or animal subjects performed by any of the authors.

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