A concussion is a relatively common sports-related injury that affects athletes of all ages. Although orthopaedic surgeons are not expected to replace sports medicine physicians and neurologists with regard to the management of concussions, orthopaedic surgeons, particularly those who are fellowship-trained in sports medicine, must have a current knowledge base of what a concussion is, how a concussion is diagnosed, and how a concussion should be managed. Orthopaedic surgeons should understand the pathophysiology, assessment, and management of concussion so that they have a basic comprehension of this injury, which is at the forefront of the academic literature and North American media. This understanding will prepare orthopaedic surgeons to work in concert with and assist sports medicine physicians, athletic trainers, and physical therapists in providing comprehensive care for athletes with a concussion.

Although concussion has been a topic of investigation for many years, media scrutiny of concussion has increased in the past decade as a result of several high-profile athletes who sustained a concussion, which has highlighted the potential long-term sequelae associated with repeated head trauma. This media attention has triggered a concomitant increase in medical and academic attention that is dedicated to understanding concussion. Although the scientific community has not yet discovered sufficient evidence that directly links recurrent head trauma to the development of severe medical conditions, such as chronic traumatic encephalopathy (CTE), substantial advances in how to better identify and manage concussions have been made. Emerging concussion awareness and subsequent policy changes have made concussion a national public health issue by demonstrating that concussion affects not only professional athletes but also youth- and collegiate-level athletes.

In the past decade, the increase in reported concussions across all ages and all sports has led to the development of several concussion management guidelines, including those published by the Concussion in Sport Group in the 2012 Zurich Consensus statement and those published by the American Academy of Neurology in 2013. Despite these standardized concussion management guidelines, the heterogeneity of concussion and the lack of objective measures to identify a concussion have led to variation and confusion with regard to proper diagnosis and management, which has furthered the need...
for increased education across care providers, coaches, and athletes. Orthopaedic surgeons, who commonly treat athletes for a variety of musculoskeletal injuries, must have a current knowledge base of what a concussion is, how a concussion is diagnosed, and how a concussion is managed to properly address the full spectrum of sports-related injuries that they may encounter, even if this only means properly recognizing concussion symptoms and knowing when to refer an athlete with a concussion to an appropriate physician.

Epidemiology

The Centers for Disease Control and Prevention estimates that 1.6 to 3.8 million persons in the United States sustain a sports-related mild traumatic brain injury each year. A substantial portion of these sports-related mild traumatic brain injuries occur in children and adolescents, and the incidence of sports-related mild traumatic brain injuries has continued to rise with increased youth sports participation and improved concussion awareness and management. From 2001 to 2009, the number of hospital visits for sports- and recreation-related concussions that occurred in patients younger than 19 years increased by 62%, from 153,375 to 248,418. A recent systematic review reported that the concussion incidence in high school and college sports ranged from 0.1 to 21.5 per 1,000 athletic exposures, varying by sport, sex, and level of play (Table 1).

Definitions

Concussion is a term that is used to describe clinical symptoms resulting from mild to moderate brain trauma that may not necessarily be related to a gross structural injury. The Concussion in Sport Group, which included the authors of the 2012 Zurich Consensus statement, formally defined concussion...
as “a complex pathophysiological process affecting the brain, induced by biomechanical forces.”

The Concussion in Sport Group further identified several key diagnostic elements that are common to concussions. A concussion may be caused by a direct blow to the head or by an indirect blow elsewhere on the body that transmits forces to the head and typically results in neuropathologic changes. These functional, rather than structural, neuropathologic changes are not detected via standard structural neuroimaging studies but may result in clinical and cognitive symptoms that typically resolve within a few days; however, in some patients, symptoms may take several weeks or more to resolve. Echoing the definition of concussion that was developed by the Concussion in Sport Group, the authors of the 2013 American Academy of Neurology guideline on the evaluation and management of concussion in sports defined concussion as “a clinical syndrome of biomechanically induced alteration of brain function, typically affecting memory and orientation, which may involve loss of consciousness.”

**Clinical Pathophysiology**

Concussive trauma, which is sustained to the head or body, transmits impulsive forces to the brain. These impulsive forces stretch and distort axonal networks and shear cell membranes, which results in indiscriminate ion efflux. This ion efflux leads to the widespread release of neurotransmitters, such as glutamate and other excitatory amino acids, which trigger widespread depolarization. In an attempt to restore a normal resting potential, sodium-potassium adenosine triphosphate pumps increase their activity, becoming hyperglycolytic, which drastically increases the brain’s demand for glucose and oxygen. Although the energy demand increases, the cellular response to injury restricts cerebral blood flow, which results in a metabolic mismatch or an uncoupling between energy supply and demand.

This metabolic mismatch between increased cerebral metabolic needs and reduced blood flow and glucose delivery makes the brain vulnerable in the acute period after a concussion and has been used to justify recommendations for physical and cognitive rest after an injury in patients who sustain a concussion. Under such a state of physiologic stress, neurons are more susceptible to secondary injury, which may result in substantial negative sequelae.

Animal models have demonstrated this concept of acute metabolic vulnerability. In a study of adult rats that sustained repeated concussive injuries, Prins et al reported worse neurocognitive function and traumatic axonal injury in rats that sustained concussive injuries that were separated by only 3 or 5 days compared with rats that sustained concussive injuries that were separated by 7 days. Furthermore, second impact syndrome, which is a catastrophic complication (rapid brain swelling that may cause death) resulting from a closely-timed repeat injury that occurs before healing, has furthered the need for circumspect management of concussion immediately postinjury.

Media attention on professional athletes who sustain a concussion has focused on CTE, which is a neurodegenerative disease that is associated with head trauma. CTE is a postmortem histologic diagnosis that is characterized by the deposition of tau protein in neuronal tissue. Although previously believed to affect only boxers, CTE has been identified in former American football players, hockey players, wrestlers, and military veterans. Despite the reported increase of CTE in high-profile athletes, the risk for CTE, apart from a history of repeated head trauma, remains unknown, and the claim that CTE risk may increase with the duration of years of professional American football played has not been substantiated.

Complicating matters, comorbid neurodegenerative diseases may obscure a true diagnosis of CTE, and CTE has been diagnosed in autopsies of the brains of patients who had no history of CTE symptoms. Given the lack of scientific evidence, studies are premature to conclude that playing contact sports will lead to CTE; however, further research on CTE is necessary, and orthopaedic surgeons must recognize the role that CTE and high-profile media reports have on the public’s understanding of sports-related concussion.

Concussion management is complicated by not only a consideration of the long-term negative sequelae of repeated head injury but also the challenge of determining the point at which a full metabolic recovery has occurred. Although approximately 80% to 90% of concussions in humans tend to resolve symptomatically within 7 to 10 days, uncertainty remains with regard to whether full symptom resolution indicates a full metabolic recovery. Currently, no biomarker or imaging study exists that indicates a complete metabolic recovery after a concussion, and several studies have reported continued deficits in balance, reaction time, and neurocognitive function in patients who sustained a concussion and in whom symptoms have resolved.

Moreover, some brain metabolites, such as N-acetylaspartate in the frontal white matter, that were studied with the use of magnetic resonance spectroscopy have been identified.
reported to require as many as 30 days postinjury before they return to normal levels.20 The long-term negative sequelae of repeated head injury in combination with the subjective nature of a full metabolic recovery underlie the uncertainty associated with the management of postconcussion recovery and underscore the necessity of ensuring that a patient’s brain has had the chance to re-establish neuro-metabolic equilibrium before being placed at risk for subsequent injury.

**Evaluation and Management**

**Sideline Evaluation**

Any athlete in whom a concussion is suspected should be removed from play and assessed by a licensed medical provider. If performing a sideline evaluation, clinicians must adhere to standard emergency management principles (ie, airway, breathing, circulation) and exclude an injury to the cervical spine. Sideline evaluation indications for the transfer of an athlete to an emergency department include, but are not limited to, a Glasgow Coma Scale score <15; deteriorating mental status; progressive, worsening, or new neurologic signs, such as repetitive emesis, extremity numbness, or seizure; and potential spinal injury.2 After substantial injuries have been excluded, clinicians should evaluate the athlete for a concussion. Both the mechanism of injury and concussion-related symptoms should be considered; however, neither should be used as the sole determinant of whether an athlete has sustained a concussion because concussions can occur in the absence of clear trauma, and symptoms may be delayed in onset or appear temporarily and then reappear hours to days later.21

Although athletes should be monitored for signs or symptoms of concussion, including headache, dizziness, disorientation, confusion, and memory loss, the acute evaluation of an athlete with a suspected concussion depends on sideline assessment tools, which represent less comprehensive forms of neurocognitive tests that are used to assess a range of domains, including cognitive impairment and balance deficits. The Sport Concussion Assessment Tool, third edition (SCAT3), which is the most well-known and widely used sideline assessment tool, consists of eight sections, including Glasgow Coma Scale score, Maddocks Score, symptom evaluation, cognitive assessment with the Standardized Assessment of Concussion, neck examination, balance examination with Modified Balance Error Scoring System (BESS) testing, coordination examination, and Standardized Assessment of Concussion Delayed Recall. A modified version of the SCAT3 exists for children aged 6-12 years to account for age and the overall developmental stage of children within that age range.

The King-Devick test, which is a portable, 2-minute test that involves reading single digits that are displayed on cards, has been increasingly used as a sideline assessment tool. The King-Devick test assesses rapid eye movement and can be used in combination with the SCAT3 to detect subtle saccadic visual dysfunction that is associated with concussion.22 Recent studies have reported that the King-Devick test, if used in combination with the Modified BESS test and the Standardized Assessment of Concussion, accurately identified 100% of concussions.23,24 Computerized neurocognitive testing, such as Immediate Post-Concussion Assessment and Cognitive Testing and Axon Sports/Cogstate Sport, also has been increasingly used as a sideline assessment tool.

Computerized neurocognitive tests are frequently administered before the sporting season begins to establish an athlete’s baseline values, which can then be referenced for comparison if an injury occurs. Van Kampen et al.25 reported that computerized neurocognitive testing improved the accuracy and sensitivity of concussion diagnosis in the immediate postinjury window if used in conjunction with self-reported symptoms, which further reinforces the potential utility of computerized neurocognitive testing as a sideline assessment tool.

Although sideline assessment tools can be used to assess a variety of domains, the sensitivity and reliability of these tools for the diagnosis of a concussion, especially without pre-injury baselines for comparison, remain unknown.26 Given the dangers of a secondary injury, the sideline evaluation of an athlete with a suspected concussion should err on the side of caution, and return-to-play on the day of a concussive injury should never occur.2 Ultimately, a licensed medical provider who is trained in the management of concussions should make the final determination with regard to an athlete’s fitness to play.

**Clinical Evaluation**

Although clinical imaging modalities, such as CT and MRI, are useful to rule out more severe traumatic brain injury, they currently are insufficient to diagnose a concussion.27 Although other imaging modalities, including functional MRI, diffusion tensor imaging, and positron emission tomography, have shown promise in detecting changes after mild traumatic brain injury, they are not yet routinely used in the clinical setting, primarily because of prohibitive cost and implementation barriers.28 Therefore, the diagnosis of a concussion relies heavily on...
clinical judgment that is based on an athlete’s injury history and physical examination. Clinicians must obtain details on the mechanism of injury, the onset and timing of symptoms, and the specific activities associated with the worsening of symptoms. Although objective baseline data on preinjury function typically are unavailable, clinicians should obtain an athlete’s history of prior concussions and comorbid conditions, including attention-deficit/hyperactivity disorder, anxiety, depression, and migraines, all of which have been associated with a more complicated and prolonged recovery after a concussion.29

After an athlete’s medical history has been obtained, the clinician should perform a comprehensive physical examination, which is essential to properly diagnose and manage a concussion. After a thorough head, cervical spine, and neurologic examination has been performed, the physical examination should specifically target the vestibular and vision systems because they are the most common systems affected by a concussion, and balance and vision deficits may be otherwise undetected.30,31 Because substantial overlap exists in the underlying pathophysiology and effects of concussion on the vestibular and vision systems, the two systems often are assessed in tandem. The Vestibular/Ocular Motor Screening assessment, which was developed and validated by the University of Pittsburgh, assesses vestibular and ocular impairments via a suite of exercises, including smooth pursuit, horizontal and vertical saccades, near point of convergence, horizontal vestibular ocular reflex, and visual motion sensitivity.32 The Vestibular/Ocular Motor Screening assessment demonstrated internal consistency and sensitivity in the identification of patients with a concussion, and warrants further attention as a practical, clinically useful tool for the diagnosis of a concussion.

Static and dynamic balance testing can be used to clinically assess for balance or coordination deficits. The Modified BESS test, which is inexpensive, easily administered, and incorporated in the SCAT3, is commonly used to evaluate static balance; however, its potential limitations for clinical use recently have been scrutinized.33,34 A dynamic tandem gait test, which asks a patient to walk forward and backward with his or her eyes open and closed, may offer clinicians a more reliable alternative to the Modified BESS test.35

Computerized neurocognitive testing, which also is used in the clinical setting, provides clinicians with a useful snapshot of a patient’s neurocognitive function, which can be used as a supplementary tool for the diagnosis of a concussion and to monitor a patient’s postconcussion recovery.36 Athletes are increasingly required to take a preseason computerized neurocognitive test that will serve as a baseline for comparison if they sustain a head injury.37 Even with baseline data for comparison, computerized neurocognitive testing is not sufficient to replace a patient’s clinical history or physical examination because computerized neurocognitive test results may be greatly affected by confounding factors.

One of the primary difficulties in the clinical diagnosis and management of concussion stems from a lack of preinjury data. Although a variety of assessment tools, such as those previously discussed, are available to aid in the diagnosis of a concussion, clinicians should exercise caution in the interpretation of test results because each patient has a different preinjury baseline for comparison. Therefore, clinicians can expect great individual variation in test results, and the comparison of test results with standardized normative values for different age groups may not be a reliable indicator of concussion. Given the difficulty of managing concussions without preinjury data, recent efforts have been made to incorporate multimodal assessment protocols in preseason baseline testing to help facilitate preinjury and postinjury comparisons for multiple areas of cognitive and physical function.22,38

The suite of assessment tools available to aid clinicians in the diagnosis of a concussion may help minimize clinician dependence on subjective symptom reports, which are subject to underreporting of symptoms by athletes who want to return to play or to overreporting of nonspecific symptoms as a result of factors other than concussion.39 Although the severity and extent of an athlete’s symptoms after a concussion may aid a clinician in managing and monitoring postconcussion recovery, symptom reports are most useful if other factors, such as an athlete’s comorbid conditions, injury history, and physical examination as part of a comprehensive evaluation after a concussion, are considered.

Clinical Care Plan

Because a concussion is a heterogeneous injury, clinicians often develop an individualized clinical care plan to address a patient’s specific symptoms and deficits, which are identified via a patient’s clinical history and physical examination. Although clinical care plans may vary for each patient, certain clinical care plan elements are commonly and consistently used for all patients who sustain a concussion.

In the immediate, acute post-concussion period, clinicians recommend physical and cognitive rest. In this vulnerable period after a concussion, rest allows a patient to avoid activities that may place his or her
brain at risk for subsequent injury or that may exacerbate the metabolic mismatch previously discussed, both of which may prolong symptoms and delay recovery after a concussion. Although physical and cognitive rest have been the benchmark of concussion management and are still advised in the first few days post-concussion, recent studies have challenged the utility of prolonged rest, reporting that it may lead to secondary symptoms of fatigue, depression, and physiologic deconditioning.40-42

Recent guidelines on concussion management have advocated a graded return to activity after a patient is asymptomatic. The concussion management guidelines published by the Concussion in Sport Group in the 2012 Zurich Consensus statement specify that an athlete should be symptom-free for a 24-hour period before he or she advances from one level of the stepwise return-to-play protocol to the next; therefore, at least 1 week may be required for an athlete to progress through all six levels of the protocol and return to play.2 If any postconcussion symptoms occur as an athlete progresses through the stepwise return-to-play protocol, he or she is advised to return to the previous asymptomatic level of the protocol, at which he or she should remain for an additional 24-hour period before attempting to progress to the next level of the protocol.2 Because the return-to-play progression depends on an athlete’s symptoms, which may be affected by factors other than concussion or masked by an athlete who wants to return to play, this stepwise return-to-play protocol should be led by an experienced healthcare professional who can properly gauge an athlete’s performance and readiness to progress through each stage of the protocol and return to play. Recent studies have reported that athletes who sustain a concussion have an increased risk for musculoskeletal injuries after they return to full sport participation if they are not properly reconditioned or if subtle symptoms, balance deficits, or cognitive deficits that predispose them to subsequent injury remain.43,44 This reinforces the need for sufficiently challenging tasks in return-to-play protocols that can aid in a patient’s rehabilitation and assessment of recovery after a concussion.

Although the clinical care plan for athletes who sustain a concussion primarily focuses on return-to-play, a return-to-learn plan also is critically important, especially for student athletes.45 To avoid triggering or exacerbating postconcussion symptoms via an abrupt return to full cognitive activity, return-to-learn protocols, which mirror return-to-play protocols, have been designed to gradually integrate student athletes back to a full day of school and adult athletes back to a full day of

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Functional Exercise</th>
<th>Objective</th>
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<tbody>
<tr>
<td>1. No activity</td>
<td>Symptom-limited physical and cognitive rest</td>
<td>Recovery</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Walking, swimming, or stationary cycling, keeping intensity &lt;70% of maximum permitted heart rate; no resistance training</td>
<td>Increase heart rate</td>
</tr>
<tr>
<td>3. Sport-specific exercise</td>
<td>Skating drills in ice hockey, running drills in soccer; no head-impact activities</td>
<td>Add movement</td>
</tr>
<tr>
<td>4. Noncontact training drills</td>
<td>Progression to more complex training drills (eg, passing drills in football and ice hockey); may begin progressive resistance training</td>
<td>Exercise, coordination, and cognitive load</td>
</tr>
<tr>
<td>5. Full-contact practice</td>
<td>After medical clearance, participation in normal training activities</td>
<td>Restore confidence and assessment of functional skills by coaching staff</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
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Ongoing Management

Although most concussions resolve within the first 2 weeks postinjury, a substantial subset of patients who sustain a concussion have symptoms that persist beyond the standard recovery period, and postconcussion syndrome may develop in some patients who sustain a concussion, with symptoms lasting for months after the concussion. In addition, patients in whom symptoms resolve may have prolonged deficits in balance, reaction time, and neurocognitive function. Given the lack of prognostic factors that can effectively identify postconcussion outcomes at the onset of care, clinicians are unable to grade the severity of a concussion or determine which patients will follow an atypical, delayed recovery after a concussion. Although no causal relationships have been identified, several factors, including a loss of consciousness during the injury, a history of concussion, younger age, female sex, a history of migraines, learning disorders, attention-deficit/hyperactivity disorder, anxiety, and depression, are associated with a delayed recovery after a concussion.

Patients who have symptoms and deficits beyond the standard postconcussion recovery period should be referred to a specialist who has extensive experience in the management of concussions. For patients with a delayed recovery after a concussion, a multimodal treatment plan that involves active rehabilitation may be necessary to target specific deficits. Several therapies, including aerobic, vestibular, vision, and cognitive behavioral therapy, have gained attention as promising approaches to help patients with a more complicated postconcussion recovery return to their preinjury baseline. Experienced medical specialists can help identify the specific deficits of a patient who sustained a concussion and make appropriate and targeted treatment recommendations.

Because a concussion is not only a cognitive injury but also a physiologic injury that affects both the heart and the autonomic nervous system, emerging evidence has shown that aerobic exercise may aid in postconcussion recovery by improving autonomic balance and cerebral blood flow regulation. Although exercise that is performed too soon or too intensively after a concussion has been associated with delayed recovery and is used to justify prolonged periods of rest, recent studies have reported that sub-symptom exacerbation threshold exercise, or exercise that does not lead to substantial additional or worsening of postconcussion symptoms, can be performed to safely address prolonged concussion-related symptoms that are associated with physiologic dysfunction. In addition, exercise has been reported to improve memory by increasing brain-derived neurotrophic factor and is believed to specifically aid in the relief of several symptoms that are associated with concussion, such as anxiety and depression.

Other treatment modalities should be considered in patients in whom physiologic disturbance is not the primary contributor to prolonged postconcussion deficits and symptoms. Cognitive behavioral therapy can help address psychologic changes after a concussion by identifying and altering maladaptive thinking or behavior that may exacerbate depression and anxiety symptoms. Vestibular and vision therapies have gained recent attention as modes of active rehabilitation that may help facilitate recovery in patients with balance or visual deficits that are detected via a physical examination after a concussion. Specialists who are trained in the management of concussions are increasingly using vestibular and ocular tests, such as the Vestibular/Ocular Motor Screening assessment, as part of the clinical evaluation of patients who sustain a concussion to detect and distinguish potential vestibular and vision problems. Vestibular therapy may be useful in patients with impairments on saccadic, gaze stability, or balance tests because it incorporates increasingly challenging tasks that are designed to re-train the vestibular and vision systems. Patients with vision abnormalities, such as convergence insufficiency, may require vision therapy beyond the simple vision exercises that are administered in vestibular therapy. In addition, given the amount of reading and near-visual work that is involved with school work, vision therapy is especially important in student-athletes who have prolonged postconcussion vision deficits.

Although each of these treatment modalities can be used in isolation to target specific postconcussion symptoms and deficits, they also can be used in combination for patients who require a multimodal approach to postconcussion recovery.

Summary

Although concussion management is not the primary responsibility of orthopaedic surgeons, the increased incidence of concussion and the multidisciplinary approach that is necessary to manage a concussion require orthopaedic surgeons to have a baseline understanding of this injury. Although concussion
research continues to rapidly evolve, orthopaedic surgeons must be aware of the clinical features, clinical tools, and consensus guidelines that currently guide the diagnosis and management of concussion, especially in athletes.

References

References in bold type are those published within the last 5 years.


