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Management of Sport-Related Concussion in Young Athletes

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Abstract

Sport-related head injuries are a common clinical problem. Most head injuries in young athletes are mild traumatic brain injuries or concussions. The highest number of sport-related concussions has been reported in American football. In addition to the well described physical and psychosocial growth, there is ongoing neurocognitive development of the brain during childhood and through adolescence. This developmental process has direct implications in the assessment and management of head injuries in young athletes. Research on the management and long-term outcome following brain injuries in young athletes is limited. Traditionally, the assessment of concussion has been based on clinical history and physical and neurological examination. Increasingly, neuropsychological testing, especially computerised testing, is providing objective measures for the initial assessment and follow-up of young athletes following brain injuries. Numerous guidelines

have been published for grading and return to play criteria following concussion; however, none of these have been prospectively validated by research and none are specifically applicable to children and adolescents.

Sport-related head injuries have been reported in contact and collision sports resulting from direct blows to the head as well as in non-contact sports resulting from acceleration, deceleration, and rotational forces.[1-5] Impact to the head may result in injuries to the scalp or the skull and may or may not be associated with brain injury. Severe and catastrophic injuries to the head and neck are fortunately rare in youth sports.[3] In the US, 300 000 sport-related brain injuries occur every year in high-school sports and most (about 90%) of the brain injuries are mild traumatic brain injuries or concussions.[2,5-8] The highest number of sport-related head injuries has been reported in American football.[8] Head injuries also occur in other popular youth sports including soccer, rugby, wrestling, ice hockey, field hockey, snowboarding, martial arts and lacrosse. This article reviews the management of sport-related concussions in young athletes.

1. Some Aspects Specific to Children and Adolescents

Any discussion of brain injuries in children and adolescents must take into consideration the inherent differences between children and adolescents and adults, especially the normal developmental process and how it may interact and affect the nature of the injury and its outcome.[9-12] Our knowledge in this regard at present is limited, and it can be argued that most of the current management guidelines may not be applicable to children and young adolescents.[10]

1.1 Neurocognitive Development and Neuropsychological Testing

With the normal neurological maturation, there is a rapid and substantial development in the cognitive abilities during childhood and throughout adolescence.[9,10] In addition, with ongoing learning and experiences, there is tremendous acquisition of new knowledge and skills during childhood and adolescence coincident with rapidly progressing neurodevelopmental and neurocognitive maturation, especially between the ages of 8–15 years.[9,10] Return to baseline profile on neuropsychological testing is considered to be the most sensitive indicator of resolution of effects of concussion in adults. However, in children and adolescents, return to baseline may not necessarily indicate resolution of effects of concussions, since continued improvement in cognitive abilities with time would be expected, and this must be taken into consideration while interpreting results of neuropsychological assessment.[10] It also implies that baseline testing may have to be done more frequently in children and adolescents.

1.2 Biomechanics and Pathophysiology of Brain Injury

Because of the differences in physiological response to mechanical stress, anatomical configuration of the head and brain, and structural properties of the skull, it has been shown that a relatively much greater impact to the head is required to produce clinical symptoms of concussion in children compared with adults.[10,12-14] This implies that a clinically symptomatic child has sustained a severe brain injury. Certain aspects of pathophysiology following brain trauma are unique to children and adolescents as exemplified by development of malignant brain oedema in young children and the second impact syndrome described in young male adolescent athletes.[1,2,10,12,15]

1.3 Acute and Chronic Sequelae of Brain Injury

When an athlete with persistent post-concussion symptoms from an initial injury sustains a second blow to the head, he or she may develop second impact syndrome.[15] Second impact syndrome is characterised by rapid development of brain oedema

and herniation with a high mortality rate.[1,12,15] Case reports of second impact syndrome have been described in adolescent male athletes; however, careful recent reviews suggest that such a phenomenon is a rare occurrence.[1,10,15] Although the significance of second impact syndrome has not been fully elucidated because of the potential for life threatening consequences, an athlete with any symptoms from a concussion should not be allowed to return to contact sports.

It has been shown that in children and adolescents, resolution of cognitive deficits resulting from concussion occur at different rates in individual athletes depending upon the severity of injury and may lag behind resolution of clinical signs and symptoms.[10,16-20] Also, behavioural symptoms may develop and persist in children who have normal neuropsychological test results. Academic difficulties and problems with psychosocial adjustment as a consequence of effects of brain injury are significant for many children and adolescents.

1.4 Adolescent Development

Psychosocial development during adolescence has implications for the management of sports injuries in general and sport-related brain injuries in particular.[9,21,22] Early adolescence (12–14 years) is characterised by concrete thinking and preoccupation about physical effects of injuries. The adolescent at this stage of development fails to comprehend the significance of the long-term consequences of brain injuries and may be less forthcoming in seeking medical attention and adhering to treatment recommendations. During middle adolescent years (15–16 years) there is a move toward independence and emancipation from parents and home. At this stage, the adolescent is greatly influenced by peers and media. He or she is more likely to continue participating in sports despite recommendations against it, and take risks with a sense of invulnerability.[22] Sport participation to impress peers and gain social acceptance is more important during middle adolescent years. During middle adolescence some athletes may have a difficult time coping with not being able to continue sport participation because of an injury. Depression and loss of self-esteem may manifest as a result. Management decisions must take into account the enormous importance of sport in the life of adolescents at this stage of development.

Late adolescence (17–19 years) is characterised by abstract thinking and maturation in understanding of interpersonal and social relationships. The adolescent is now able to appreciate the significance of acute and long-term consequences of brain injuries. Sport participation is not the sole focus of life; other priorities such as academics and social relations emerge as more important. A more direct approach in the assessment and explanation of implications of injuries can be considered in late adolescent years.

Physical development during adolescence may affect the nature and severity of injuries. As the adolescent undergoes growth spurt there is increased weight and mass, which increase the force and momentum during collision, thus increasing the severity of injury including head trauma.

1.5 Research

There is a paucity of research on sport-related traumatic brain injuries in children and adolescents. There are no published specific assessment and management guidelines for sport-related brain injuries that take into account the cognitive, psychosocial and physical development of the child and adolescent.[10,11] Baseline data for neuropsychological tests in the assessment of concussions are limited for the adolescent age group. In recent years, computerised neuropsychological testing has greatly increased the use of neuropsychological tests in athletes at all levels of participation. Neuropsychological test data are increasing our understanding of the effects of concussion and in conjunction with clinical assessment help guide management decisions. At present, data are limited to adequately elucidate long-term effects of concussion in adolescents based on neuropsychological testing.

1.6 Genetics

Some investigators have reported an increased susceptibility to adverse outcome following brain injury linked to the specific gene apolipoprotein E, which is a susceptibility gene for late-onset familial and sporadic Alzheimer's disease.[23-27] Not unlike other areas of controversy, in the context of brain injuries in children and adolescents, one may in the future ask such questions as: should all children be screened for genetic susceptibility for adverse outcome from brain injury? Should those with such increased susceptibility be advised against participation in contact sports?[28] Advances in genetic knowledge may thus raise important ethical dilemmas in sports medicine.[29]

2. Definition of Concussion

There is no universally accepted definition of concussion.[2,7,30] The Committee of Head Injury Nomenclature of the Congress of Neurological Surgeons defined concussion as: a clinical syndrome characterised by immediate and transient impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to mechanical forces.[31]

More recently, the American Academy of Neurology in its practice parameter on concussion management defined concussion as a trauma-induced alteration in mental status that may or may not involve loss of consciousness.[32] Confusion and amnesia are considered the hallmarks of concussion. It further stated that the confusional episode and amnesia may occur immediately after the blow to the head or several minutes later.

In 2000, at the First International Conference on Concussion held in Vienna, the Concussion in Sport Group (CSG) considered a more inclusive and elaborate definition of concussion:[33]

"Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathological, and biomechanical injury constructs that may be used in defining the nature of a concussive head injury include:

1. Concussion may be caused by a direct blow to the head, face, neck, or elsewhere on the body with an 'impulsive' force transmitted to the head.
2. Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolved spontaneously.
3. Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.
5. Concussion is typically associated with grossly normal structural neuroimaging studies."

Certain common concepts are evident from different definitions of concussion. None of the current definitions consider loss of consciousness as an essential defining characteristic of concussion; however, loss of consciousness may or may not be present as one of the features of concussion; symptoms are global and transient in nature, and the subtle nature of the symptoms and pathology makes diagnosis challenging.

3. Classification

Numerous guidelines have been published that grade severity of concussion based on clinical symptoms and signs; most of these grading systems take into consideration the presence or absence and/or duration of loss of consciousness, confusion, amnesia and a combination of other signs and symptoms.[34-44] Studies suggest that the severity and outcome following a moderate to severe brain injury may correlate with the duration of unconsciousness or post-traumatic amnesia, such a relationship has not been clearly shown in mild traumatic brain injuries.[44-48] Also, there is great variability between athletes in the time course of clinical and cognitive recovery, making it difficult to predict how long an individual athlete will take before it is considered safe for them to return to contact sport. More widely known grading systems are listed in table I.[1,34-38] There is a lack of sufficient scientific evidence to

Table I. Major concussion grading systems

Grade	Grading system				
	Congress of Neurological Surgeons	Cantu	Colorado Medical Society	American Academy of Neurology	McGill
1	No LOC; slight confusion; no or very transient memory loss; very rapid recovery	No LOC; PTA <30 min	No LOC; confusion without amnesia	No LOC; transient confusion; concussion symptoms or mental status abnormality resolve in <15 min	(1) No LOC, no PTA (1a) No PCS, only sec of confusion (1b) PCS and/or confusion that resolved within 15 min (1c) PCS and/or confusion that do not resolve within 15 min
2	LOC <5 min; momentary confusion; mild retrograde amnesia; complete recovery within 5 min	LOC <5 min; PTA >30 min and <24h	No LOC; confusion with amnesia	No LOC; transient confusion; concussion symptoms or mental status abnormality last >15 min	PTA <30 min and/or LOC <5 min
3	LOC >5 min; confusion >5 min; prolonged retrograde amnesia; slow recovery (>5 min)	LOC >5 min or PTA >24h	LOC	Any LOC, either brief or prolonged	PTA >30 min and/or LOC >5 min

LOC = loss of consciousness; **PCS** = post-concussion symptoms; **PTA** = post-traumatic amnesia.

support any one of the current concussion grading systems in the management of children and adolescents and each young athlete should be evaluated on an individual basis.[10,11,31]

At the 2nd International Conference on Concussion in Sport held in Prague (2004), a new concussion classification system was proposed.[49] A simple concussion, by definition, resolves within 7–10 days, with no residual deficits or complications. Most concussions are simple concussion, and athletes can return to play once asymptomatic and have normal examination. A complex concussion is characterised by the presence of persistent post-concussion symptoms, signs and specific complications. These athletes need a stepwise approach to full rehabilitation and return to play.

4. Evaluation

The clinician may need to evaluate the athlete at the sideline immediately following brain injury or the athlete may present to the clinician in his or her office later with persistent post-concussion symptoms, deteriorating academic performance or behavioural symptoms.[50] It is therefore essential that a thorough history of the evolution of symptoms is obtained. Historical information from the coach, teacher and parents who have known the athlete is very important to ascertain mood, personality changes, academic functioning, or interpersonal difficulties.

4.1 Clinical Features

Direct blow is only one of the mechanisms that cause brain injury; non-contact acceleration, deceleration, and rotational brain injuries are equally important, hence the absence of a history of direct blow to the head does not rule out the possibility of brain injury.[1,2,5,7,12,51,52] The athlete may give a history of direct impact to the head resulting from a collision with another athlete, fall to the ground, or getting hit by a puck, a bat or other type of object. Also, the athlete may not realise the significance of the symptoms and may not report them. Often other athletes or the coach or the trainer at the sideline may first identify the confused or disoriented player. Because the injury in concussion is diffuse, multiple global functions are affected, resulting in generalised symptoms. Symptoms and signs associated with acute cerebral concussion as described by the CSG are listed in table II.[33] In addition to acute symptoms, the athlete may develop symptoms over several weeks following the brain injury, including light-headedness, difficulty concentrating, loss of memory, easy fatigability, irritability, sleep disturbances, intolerance to bright light and loud noises and mood disturbances.[2,7,32,51] Parents, coach,

Table II. Symptoms and signs of acute cerebral concussion from the Concussion in Sport Group's first international conference on concussion

Cognitive features
Unaware of period, opposition, store of game
Confusion
Amnesia
Loss of consciousness
Unaware of time, date, place
Typical symptoms
Headache
Dizziness
Nausea
Unsteadiness/loss of balance
Feeling 'dinged' or stunned or 'dazed'
Feeling of 'having my bell rung'
Seeing stars or flashing lights
Ringing in the ears
Double vision
Physical signs
Loss of consciousness/impaired conscious state
Poor coordination or balance
Concussive convulsion/impact seizure
Gait unsteadiness/loss of balance
Slow to answer questions or follow directions
Easily distracted, poor concentration
Displaying unusual or inappropriate emotions, such as laughing or crying
Nausea/vomiting
Vacant stare/glassy eyed
Slurred speech
Personality changes
Inappropriate playing behaviour (e.g. running in the wrong direction)
Appreciably decreased playing ability

teacher and friends close to the athlete often note the most sensitive findings; those who know the athlete often find that he or she "just isn't quite acting himself or herself".[50] Generally, there are no focal findings or localising signs on neurological examination.

4.2 Sideline Mental Status Evaluation

There has been an increasing interest in the development and application of brief sideline mental status and cognitive assessment tools that can be easily administered and interpreted to screen athletes on the sidelines following brain injury, for example, the Standardized Assessment of Concussion (SAC), used in American football players.[53-55] SAC measures orientation, immediate memory, concentration and delayed recall, and includes neurological screening (recollection of injury, strength, sensation and coordination). It gives a numerical score (maximum 30) that is compared with the athlete's baseline score. Concussed players typically have scores below their baseline. Use of SAC does not require knowledge of psychometric testing and can be completed in about 5 minutes at the sideline. SAC has also been used to follow recovery of players with concussion. There has been increased use and application of computerised assessment in the evaluation and management of concussions, including immediate sideline assessment. An electronic version of SAC called eSAC (Sideline Assistant, HeadMinder™ [1] Inc., New York, USA) can be used for sideline assessment. eSAC is administered using handheld devices.[56] Symptoms are recorded and appropriate return to play parameters are provided on the handheld device. The information on eSAC is later synchronised and integrated on the Internet-based computerised neuropsychological assessment tool Concussion Resolution Index (HeadMinder™ Inc., New York, USA).

Another handheld device that can be used for sideline assessment and follow up is Sideline ImPACT© (ImPACT© Applications, Inc., Hilton Head Island, South Carolina, USA), which also provides for standardised assessment of concussion and can be synchronised with the ImPACT© 3.0 computerised neuropsychological assessment tool.[57] A pocket PC version of Sideline ImPACT© will also be available in the near future.

Another more widely used assessment tool is the Maddocks questions, specifically designed to assess memory and orientation immediately after concussion.[58,59]

1 The use of trade names is for product identification purposes only and does not imply endorsement.

4.3 Sport Concussion Assessment Tool (SCAT)

The Sport Concussion Assessment Tool (SCAT) is a standardised tool developed by combining the different existing concussion assessment tools.[49] Medical evaluation based on SCAT consists of the following:

1. Signs (presence or absence of loss of consciousness or unresponsiveness; seizures or convulsive activities; balance problem/unsteadiness).
2. Memory assessment is based on modified Maddocks questions.
3. Post-Concussion Symptom Scale to assess the severity of the concussion.
4. Cognitive assessment (five-word recall; months in reverse order; digits backwards).
5. Neurological screening (speech; eye motion and pupils; pronator drift; gait assessment).

The main purpose of SCAT is to provide a standardised method for clinical assessment of concussion.

4.4 Neuropsychological Testing

The role of neuropsychological testing in the assessment and management of concussions is now well established, and neuropsychological testing in conjunction with clinical assessment, forms the cornerstone of concussion assessment and management. The application of neuropsychological testing in assessment and management of sport-related concussion has been reviewed in a number of recent studies and reviews.[60-85] Examples of some of the conventional (paper and pencil) test batteries are:

- Digit Span Test
- Halstead-Reitan Neuropsychological Test Battery
- Hopkins Verbal Learning Test
- Penn State Cancellation Test
- Stroop Test
- Symbol Digit Modalities Test
- Trail Making Test
- Vigil Continuous Performance Test
- Weschler Intelligence Tests – Revised
- Wisconsin Card Scoring Test.

All tests assess the following various neuropsychological functional domains: memory; speed of information processing; planning; executive functioning; visuospatial abilities; visuomotor abilities; and attention. Memory and speed of information processing appear to be the most susceptible impairments, and may not return to baseline for several days to months following a concussion.[64] Repeat testing may be affected to some extent by learning process; however, not all domains are affected equally. For example, reaction time, executive function, and spatial processing are relatively less affected then other domains.[64,67]

There is an emerging body of baseline and post-injury data on various measures of neuropsychological function in adult as well as adolescent athletes. The available data in adolescents show greater test retest variability compared with adults. Also, it is often difficult to discriminate poor performance on tests due to underlying neurological deficits or neurodevelopmental disorders. The ongoing cognitive development and knowledge acquisition throughout the childhood and adolescent years further confound the interpretation of test results. In terms of long-term follow-up in children and adolescents, a return of function to baseline following brain injury may or may not necessarily indicate full recovery. In the interpretation of results of neuropsychological testing in children and adolescents, one needs to take into account the effects of continued cognitive maturation, learning and acquisition of knowledge that normally occur during childhood and adolescent years.

Some of the factors influencing neuropsychological tests include age, education, cultural background, medications, learning disability, sleep deprivation, test anxiety and previous head injuries.[60,61,74] Children and adolescents have been shown to take longer time to recover from neurocognitive impairment following a concussion. Studies comparing neuropsychological testing have been limited by subject attrition, selection bias, and limited control of confounding factors.[50] Conventional neuropsychological testing requires neuropsychologists to administer and interpret the tests, typically

takes several hours to administer and interpret, is not widely available at non-professional high-school or community level, and is expensive. Conventional tests are not specifically designed for sport-associated concussion assessment.

More recently there has been an increasing interest in and development of computer-based tests specifically designed for sport-associated concussion management, examples of these are listed below:[56,57,75-85]

- CogSport[83]
- ConcussionSentinel[86]
- Concussion Resolution Index[56]
- Immediate Post Concussion Assessment and Cognitive Testing (ImPACT© 2.0).[57]

Properly constructed (with specific attention to psychometric properties) computerised neuropsychological tests overcome many of the limitations of conventional testing and offer many advantages (table III).[56,57,75,76,81,83] Access to a computer and the initial set up to administer computerised tests may be viewed as limitations of such tests.

Table III. Advantages of computerised neuropsychological testing

Practical aspects
Ease of administration
Short administration time
Easy and widespread accessibility via computers and Internet
Ideal for mass administration
Physicians can interpret and use results in conjunction with clinical evaluation
Can be used for on-site immediate assessment
Provides motivation and sense of control to the athlete
Cost effectiveness
Automated data collection, storage, analysis and interpretation
Ease of data retrieval
Psychometric aspects
Availability of many alternate forms of test batteries
Practice effects very small
Stimulus randomisation possible within test, between tests and between subjects
High test-retest reliability
Precise measurement of multiple domains of performance
Better measurement of performance variability
High sensitivity to subtle cognitive deficits
Ability to precisely control stimuli and stimuli characteristics, improving the reliability
Specifically designed to assess sport-related concussions

Computerised neuropsychological testing is used in many developed countries at high-school, collegiate and professional levels. Various protocols have been developed. Typically, all athletes are given a baseline assessment to create a baseline neuropsychological profile. The athlete is then evaluated immediately after a concussion and periodically thereafter to assess improvement or deterioration compared with the baseline profile. Neuropsychological test results must not be used in isolation in the management of concussion. A physician's clinical evaluation based on a careful history and physical and neurological examination is the most essential aspect of concussion management.

4.5 Postural Stability

Motor function and coordination deficits have been reported following sport-related concussion.[87] Studies suggest a characteristic pattern of abnormalities in postural stability and balance following concussion.[87,88] Such abnormalities have been noted to last for several days following brain injury. Measurement of postural stability has been suggested as an adjunct assessment tool for concussion.[87-90] Postural stability is measured by force plate technology and clinical balance tests. More research will likely increase the application of postural stability measurements in the overall plan of assessment of concussions.

4.6 Neuroimaging

Since the changes associated with concussion are diffuse and microscopic, structural abnormalities are rarely detected on static brain imaging modalities like computerised tomography (CT) or magnetic resonance imaging (MRI).[2,32,33] Imaging studies such as positron emission tomography (PET), functional MRI, and single photon emission tomography (SPECT) provide important metabolic and regional cerebral blood flow information; however, data on their application in the assessment of concussion are limited.[91-93] At present, routine use of neuroimaging is not recommended in the assessment of otherwise uncomplicated concussions.[32,33,94-96] Neu-

Table IV. Return to play criteria following first concussion

Guideline	Grade and criteria		
	1	2	3
Cantu	RTP if asymptomatic for 1wk; terminate season if CT/MRI abnormal	RTP if asymptomatic for 2wk; terminate season if CT/MRI abnormal	May not RTP for at least 1mo. After 1mo RTP if asymptomatic for 1wk
Colorado Medical Society	RTP if asymptomatic for 20 min	RTP if asymptomatic for 1wk	Transport to a hospital emergency department. May RTP 1mo after injury if asymptomatic for 2wk consecutive
American Academy of Neurology	RTP if asymptomatic for 15 min	RTP if asymptomatic for 1wk	Transport to a hospital emergency department. With brief LOC (sec) may RTP when asymptomatic for 1wk; with prolonged LOC (min) may RTP when asymptomatic for 2wk

asymptomatic = asymptomatic both at rest and on provocative exertion; **CT** = computerised tomography; **LOC** = loss of consciousness; **MRI** = magnetic resonance imaging; **RTP** = return to play.

roimaging is indicated when symptoms persist or worsen or if there are focal neurological deficits.

5. Management

5.1 Acute Cerebral Concussion

Because the signs and symptoms of concussion may evolve over several minutes following the injury, the athlete must be observed carefully and not left alone.[2,33,95,96] Based on personal experience and prevailing local practice, the clinician may use his or her individual clinical judgment or may follow one of several standard guidelines for grading the severity of the concussion and further management. However, it should be noted that their applicability in concussion management in children and adolescents, is not supported by scientific evidence at present (table IV).[1,2,10,31,32,34-43]

With the recognition that no valid guidelines for management of sport-related concussion exist, the CSG and the Canadian Academy of Sports Medicine (CASM) have outlined the following approach, now more widely used, for immediate response following recognition of any symptoms or signs of a concussion:[33,96]

- The player should not be allowed to return to play in the current game or practice.
- The player should not be left alone, and regular monitoring for deterioration is essential.
- The player should be medically evaluated after the injury.
- Return to play must follow a medically supervised stepwise process.

Maddocks questions provide a simple way for sideline assessment of concussion. The following questions focus on evaluation of memory and orientation.[58,59]

- Which ground are we at?
- Which team are we playing today?
- Who is your opponent at present?
- Which quarter is it?
- How far into the quarter is it?
- Which side scored the last goal?
- Which team did we play last week?
- Did we win last week?

Any incorrect answer to the above questions is a sign of concussion. Other tools for sideline assessment are the SAC, eSAC and Sideline ImPACT.

Any athlete with apparently severe head and neck trauma must be immediately transported to the hospital emergency department.[1-3,32,33,95] Other indications of transferring the athlete to hospital emergency department include: deterioration in consciousness, focal neurological abnormality, confusion or impairment of consciousness for >30 minutes, loss of consciousness for >5 minutes, severe or persistent headaches, persistent vomiting, seizures, multiple concussions in the same game or practice session, and an athlete with underlying bleeding disorder.[1,33,51,83,95] Any child with a brain injury should be removed from further participation and sent for evaluation.

Before the athlete can return to play, he or she must be completely asymptomatic both at rest and on exertion and must have a normal physical and neurological examination. The CSG and CASM recommend the following stepwise approach to rehabilitation prior to return to play:[33,96]

1. No activity, complete rest. Once asymptomatic proceed to (2).
2. Light aerobic exercise such as walking or stationary cycling.
3. Sport-specific training.
4. Non-contact training drills.
5. Full contact training after medical clearance.
6. Game play.

The athlete continues to proceed through the successive steps outlined above if he or she remains asymptomatic. If any symptoms or signs are noted, the athlete drops back to the previous asymptomatic level, and attempts to proceed further after 24 hours.

Although these guidelines have been used in adult athletes, their application in children and adolescents is not entirely clear. Neuropsychological impairment in children and adolescents typically lags behind recovery of symptoms. It is recognised that each individual athlete recovers at a different rate, and any criteria for return to play with an arbitrary period of time out are therefore invalid.

At the 2nd International Conference on Concussion in Sport (2004), a consensus was reached that the CSG/CASM recommendations should be applicable to children (defined as between ages 5 and 18 years).[49] It was further recommended that children limit physical exertion of daily living as well as scholastic activities while symptomatic. A period of physical as well as 'cognitive rest' is recommended until full recovery.

5.2 Multiple Concussions

The athlete with multiple or recurrent concussions presents special challenges in return-to-play decisions and current knowledge on sport-related concussion is insufficient to provide any conclusive guideline.[2,10,11,15,34,97,98] Conventional clinical guidelines have provided some criteria for return to play for athletes with multiple concussions as shown in table V.[32,34-38] Scientific validity of these criteria has been questionable and an athlete who fully recovers (including neuropsychological testing) after multiple concussions presents a difficult management dilemma for the clinician in terms of return to contact sports decisions. At present, the question of how many concussions are too many remains unresolved. On the other hand, any athlete with persistent symptoms or signs since concussion should not

Table V. Return-to-play (RTP) criteria: multiple concussions in the same season

Guideline	RTP criteria			
	concussion no.	grade 1	grade 2	grade 3
Cantu	Second	RTP in 2wk if asymptomatic for 1wk	May not RTP for at least 1mo. May then RTP if asymptomatic for 1wk. Consider terminating season	Terminate season. May RTP next season if asymptomatic
	Third	Terminate season. May RTP next season if asymptomatic	Terminate season. May RTP next season if asymptomatic	Consider no further contact sports
Colorado Medical Society	Second	RTP if asymptomatic for 1wk	Athlete may RTP if asymptomatic for 1mo. Consider terminating season	Terminate season. May RTP next season if asymptomatic
	Third	Terminate season. May RTP next season if asymptomatic	Terminate season. May RTP next season if asymptomatic	Terminate season; strongly discourage contact/collision sports
American Academy of Neurology	Second	RTP if asymptomatic for 1wk	Athlete may RTP if asymptomatic for 2wk. Terminate season if CT/MRI abnormal	May RTP if asymptomatic for ≥1mo. Terminate season if CT/MRI abnormal
	Third	No recommendation	No recommendation	No recommendation

CT = computerised tomography; **MRI** = magnetic resonance imaging.

be allowed to return to contact sport until asymptomatic at rest as well as on exertion.

Cumulative and permanent brain injury resulting from repeated concussions has been described.[99-103] Some studies suggest that an athlete who has sustained one concussion is more likely to have another one and that effects of recurrent concussions are cumulative; more severe the concussion higher likelihood of cumulative effects.[1,98-103] The prevalence of cumulative brain injury in high-school athletes is not known. Cumulative effects are believed to be more pronounced if the interval between successive concussions is shorter and such effect is additive.[1] Resolution of neurocognitive abnormalities following either a single or multiple concussions may take from several days to several months to years or may be permanent, depending upon the severity of the injury.[7,18,20,64,97,98,101]

Most studies relating to increased likelihood of subsequent concussion in athletes who have sustained a previous one, and the cumulative effects of repeated concussions, are based on imprecise definitions and grading systems of concussions as well as methodological flaws. More accurate data over the next few years based on neuropsychological tests will help answer these questions more reliably.

6. Prevention

The most important prevention strategy is providing effective education to the athlete (and parents in the case of children and adolescents), as well as the coach and trainer regarding the importance of recognising concussion and seeking appropriate and timely medical attention.[2,10,104-106] Theoretically, neck muscle conditioning can allow the athlete to maintain the head in a fixed position during impact to the head, thereby dispersing the impact forces over a relatively greater area and reducing impact to the brain. Most head injuries are sudden and accidental and do not allow time for the athlete to consciously tense neck muscles before an impact. Enforcement of rules play an important role in the prevention of injuries and the effectiveness in preventing catastrophic head and neck injuries in American football following a ban on spear tackling has been well documented.[1,3,10,95,107] Properly fitted mouth guards have been shown to reduce the incidence of dental and orofacial injuries; however, their effectiveness in preventing or reducing the severity of concussion has not been clearly established.[108-110] Helmets designed specifically for certain sports (e.g. American football, baseball, ice hockey) have been shown to be effective in preventing or reducing severity of head injuries; however, soft helmets in other sports have not been shown to be effective.[111-115]

7. Conclusions

Although severe catastrophic head and neck injuries are rare in youth sports, concussions are common. There is a potential for long-term morbidity following concussions. Because of the continued development of the brain during childhood and adolescent years, injury to the brain can have long lasting impact on many neurocognitive domains. The management decisions have been traditionally guided based on personal experience of the clinician and prevailing local practice; however, newer assessment modalities such as computerised neuropsychological testing now provide objective measures for diagnosis and management of concussions in sports. Although neuropsychological testing greatly enhances the management of concussions in athletes, each case must be evaluated on an individual basis based on careful clinical (history and examination) assessment and clinical judgment. Increased public awareness of the significance of brain injuries and appropriate education efforts directed towards athletes, coaches and trainers must be integral part of prevention strategies. Because of significant differences between children and adolescents and adults in terms of neurological development, neuropsychological sequelae, time course of recovery, and academic and psychosocial consequences, the current sport-related concussion management guidelines may not be applicable to children and younger adolescents (aged approximately <15 years). There is a need for research in areas of acute and chronic effects of sport-related concussion on the developing brain, effects of multiple concus-

sions, the recovery process, application of neuropsychological assessment tools in children and adolescents, and the development of evidence-based guidelines for assessment and management of sport-related concussion in children and adolescents.

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