CONCUSSION IN SPORT AUSTRALIA

POSITION STATEMENT

An initiative of the Australian Institute of Sport, Australian Medical Association, Australasian College of Sport and Exercise Physicians and Sports Medicine Australia

Dr Lisa Elkington, Dr Silvia Manzanero and Dr David Hughes
Australian Institute of Sport

Updated October 2018

"if in doubt, sit them out"

CONTENTS

EXECUTIVE SUMMARY

There has been growing concern in Australia and internationally about the incidence of sport-related concussion and potential health ramifications for athletes. Concussion affects athletes at all levels of sport, from the part-time recreational athlete to the full-time professional. If managed appropriately most symptoms and signs of concussion resolve spontaneously. Complications can occur, however, including prolonged duration of symptoms and increased susceptibility to further injury. There is also growing concern about potential long-term consequences of multiple concussions.

Over recent years there has been elevated public awareness of sport-related concussion and increased focus on the importance of diagnosing and managing the condition promptly, safely and appropriately.

Sport administrators, medical practitioners, coaches, parents and athletes are seeking information regarding the timely recognition and appropriate management of sport-related concussion. There is a need for clear, unequivocal and reliable information to be readily accessible to all members of the community.

Funded by the Australian Government, this Concussion in Sport Australia Position Statement brings together the most contemporary evidence-based information and presents it in a format that is appropriate for all stakeholders. The Position Statement is intended to ensure that participant safety and welfare is paramount when dealing with concussion in sport.

This updated version includes the latest advancements in evidence-based management of concussion in children, and the latest evidence presented by the Concussion in Sport Group at the 2016 Consensus Conference. It ensures that this Position Statement remains consistent with contemporary evidence.

The Australian Institute of Sport (AIS) is Australia's peak high performance sport agency. The Australian Medical Association (AMA) is the peak membership organisation, representing registered medical practitioners (doctors) and medical students. The Australasian College of Sport and Exercise Physicians (ACSEP) is the pre-eminent professional body representing sport and exercise physicians and sport and exercise medicine in Australasia. Sports Medicine Australia (SMA) provides leadership in the areas of sports exercise and medicine, sports injury, physical activity, sports exercise and science, and the healthy performance and participation of Australians in physical activity and sport. The AIS, AMA, ACSEP and SMA have a clear and unequivocal focus on ensuring the safety and welfare of Australians participating in sport. Through Concussion in Sport Australia, these organisations seek to ensure that all members of the public have rapid access to information: to increase their understanding of sport-related concussion; and to assist in the delivery of best practice medical care.

CONCUSSION IN SPORT AUSTRALIA POSITION STATEMENT

Introduction

Sport-related concussion is a growing health concern in Australia. It affects athletes at all levels of sport, from the part-time recreational athlete to the full-time professional. Concerns about the incidence, and possible health ramifications for athletes, have led to an increased focus on the importance of diagnosing and managing the condition safely and appropriately[1,2]. Parents, coaches, athletes, medical practitioners and others involved in sport are seeking information regarding the best management of sport-related concussion. Participant safety and welfare is paramount when dealing with all concussion incidents.

Funded by the Australian Government, this position statement aims to:

- provide improved safety and health outcomes for all people who suffer concussive injuries while participating in sport
- assist all sporting organisations and clubs to align their policy and procedures to the most up-to-date evidence
- protect the integrity of sport through the consistent application of best practice protocols and guidelines
- provide a platform to support the development of national policy for the management of concussion in Australia.

What is concussion?

Concussion is a traumatic brain injury, induced by biomechanical forces to the head, or anywhere on the body which transmits an impulsive force to the head[3,4]. It causes short-lived neurological impairment and the symptoms may evolve over the hours or days following the injury. Evidence from animal and functional imaging studies points towards a series of interrelated biochemical and physiological changes that impair neuronal function[6,7]. The symptoms should resolve without medical intervention[3]. Rest, followed by gradual return to activity, is the main treatment[5].

Recognising concussion

Recognising concussion can be difficult. The symptoms and signs are variable, non-specific and may be subtle. Onlookers should suspect concussion when an injury results in a knock to the head or body that transmits a force to the head. A hard knock is not required, concussion can occur from minor knocks.

There may be obvious signs of concussion such as loss of consciousness, brief convulsions or difficulty balancing or walking. However, the signs of concussion can be more subtle. The Sport Concussion Assessment Tool (SCAT5) identifies 22 possible symptoms[8-10]:

- headache
- 'don't feel right'
- 'pressure in the head'
- difficulty concentrating
- neck pain
- difficulty remembering
- nausea or vomiting
- fatigue or low energy
- dizziness
- confusion
- blurred vision
- drowsiness
- balance problems
- sensitivity to light
- more emotional
- sensitivity to noise
- irritability
- feeling slowed down
- sadness
- feeling like 'in a fog'
- nervous or anxious
- trouble falling asleep (if applicable)

Recognising concussion is critical to correct management and prevention of further injury. The Concussion Recognition Tool (CRT5), developed by the Concussion in Sport Group to help those without medical training detect concussion, includes a list of these symptoms[11,12].

When an athlete is suspected of having a concussion, first aid principles still apply, and a systematic approach to assessment of airway, breathing, circulation, disability and exposure applies in all situations. Cervical spine injuries should be suspected if there is any loss of consciousness, neck pain or a mechanism that could lead to spinal injury. Manual in-line stabilisation should be undertaken and a hard collar applied until a cervical spine injury is ruled out.

A medical practitioner should review any athlete with suspected concussion. In a situation where there is no access to a medical practitioner, the athlete must not return to sport on the same day. If there is any doubt about whether an athlete is concussed, that athlete should not be allowed to return to sport that day. An athlete with suspected concussion should be reassessed to look for developing symptoms and cleared by a medical practitioner before returning to sport[12]. Due to the evolving nature of concussion, delayed symptom onset is not unusual[3]. Therefore, any athlete cleared to return to sport after medical assessment for suspected concussion should be monitored closely during the game/competition for developing symptoms or signs. If symptoms develop, the athlete should be removed from sport.

Sometimes there will be clear signs that an athlete has sustained a concussion. Athletes displaying any of the following clinical features should be immediately removed from sport:

- loss of consciousness
- no protective action taken by the athlete in a fall to ground, directly observed or on video
- impact seizure or tonic posturing
- confusion, disorientation
- memory impairment
- balance disturbance or motor incoordination (e.g. ataxia)
- athlete reports significant, new or progressive concussion symptoms
- dazed, blank/vacant stare or not their normal selves
- behaviour change atypical of the athlete.

Some features suggest more serious injury and athletes displaying any of these signs should be immediately referred to the nearest emergency department:

- neck pain
- increasing confusion, agitation or irritability
- repeated vomiting
- seizure or convulsion
- weakness or tingling/burning in the arms or legs
- deteriorating conscious state
- severe or increasing headache
- unusual behavioural change
- double vision.

Medical assessment of concussion

The diagnosis of concussion should be made by a practitioner. In diagnosing concussion, medical practitioners should conduct a clinical history and examination that includes a range of domains such as mechanism of injury, symptoms and signs, cognitive functioning and neurological assessment, including balance testing[8,13]. The SCAT5[9,10] is the internationally recommended concussion assessment tool and covers the above-mentioned domains. It should not be used in isolation, but as part of the overall clinical assessment. Computerised neurocognitive testing can be undertaken as part of the assessment, but again, it should not be used in isolation[14]. Baseline neurocognitive testing in the pre-season period can be useful for comparison with post-injury scores. Many programs, however, have reference ranges that can be applied in the absence of a baseline test.

There is currently no serum biomarkers or genetic testing that assists in the diagnosis of concussion[15]. Blood tests are not indicated for uncomplicated concussion. Medical imaging is not indicated in the diagnosis or management of uncomplicated concussion[15]; however, it may be indicated where there is suspicion of more serious head or brain injury[3].

Where resources allow, sporting organisations could use modern technology, such as pitch-side instant video, to enhance the ability to detect and manage concussion[14].

Predictors of clinical recovery

While the medical practitioner assessing the athlete with suspected concussion should make optimal use of available assessment tools, clinical judgement remains a cornerstone of concussion diagnosis and management. Predictors of clinical recovery may assist the clinician with management of the concussed athlete[3,16]. Such factors can be associated with a more protracted recovery time and they may include the following[16]:

- high severity of acute and subacute concussive symptoms
- a high number of concussive symptoms
- prolonged loss of consciousness (longer than one minute)
- post-concussive seizure
- previous history of concussion
- age of the athlete (a more conservative approach is indicated in children and adolescents)[17]
- female gender
- history of depression, anxiety, or migraine.

Managing concussion

Head-injury advice should be given to all athletes with concussion and to their carers. Any athlete with suspected or confirmed concussion should remain in the company of a responsible adult and not be allowed to drive. They should be advised to avoid alcohol and check medications with their doctor. Specifically, they should avoid aspirin, non-steroidal anti-inflammatory drugs, sleeping tablets and sedating pain medications.

Once the diagnosis of concussion has been made, immediate management is physical and cognitive rest[5]. This may include time off school or work and relative rest from cognitive activity. Having rested for 24–48 hours after sustaining a concussion, the patient can commence a return to light intensity physical activity as long as such activity does not cause a significant and sustained deterioration in symptoms[18]. The majority of concussive symptoms should resolve in 10–14 days[3]. The activity phase should then proceed as outlined below with a minimum of 24 hours spent at each level. The activity should only be upgraded if there has been no recurrence of symptoms during that time. If there is a recurrence of symptoms, there should be a 'step down' to the previous level for at least 24 hours (after symptoms have resolved)[3]. The steps in the activity phase are:

- light aerobic activity (at an intensity that can easily be maintained while having a conversation) until symptom-free
- basic sport-specific drills which are non-contact and with no head impact
- more complex sport-specific drills without contact (may add resistance training)
- full contact practice following medical review
- normal competitive sporting activity.

Sporting organisations need to continually review their policies for best practice concussion diagnosis and management. High-risk sports such as professional collision sports need to ensure that medical personnel are appropriately trained in the detection and management of concussion.

See diagram 1 on page 11.

Children and adolescents

A consistent and growing body of evidence supports a slower rate of recovery in children and adolescents aged 18 and under[16,17,19-21]. Given this, a more conservative approach to concussion is recommended, and return to learn should take priority over return to sport. School programs may need to include more regular breaks, rests and increased time to complete tasks. The child's return to sport program should be extended so that the child does not return to contact/collision activities less than 14 days from the resolution of all symptoms.

See diagram 2 on page 12.

Long-term consequences

There is concern about potential long-term consequences of concussion or an accumulation of subconcussive head impacts resulting from ongoing participation in contact, collision and combat sports[22-24]. There is some association between a history of multiple concussions and cognitive deficits later on in life[25]. However, there is currently no reliable evidence clearly linking sport-related concussion with chronic traumatic encephalopathy (CTE), a condition with unclear clinical diagnostic criteria[22]. The evidence purporting to show a link between sport-related concussion and CTE consists of case reports, case series, and retrospective and post-mortem analyses. Due to the nature of the studies, and the reliance on retired athletes volunteering for an autopsy diagnosis, there is significant selection bias in many of the reports[23]. The studies to date have not adequately controlled for the potential contribution of confounding variables such as alcohol abuse, drug abuse, genetic predisposition and psychiatric illness[22].

Given that concussion is very common and the number of cases of CTE reported is extremely small, the link between sport-related concussion and CTE remains tenuous. That being said, the potential link between concussion and CTE is of concern and there is a need for well-designed prospective epidemiological studies that take into account the potential confounding variables.

Education

General knowledge about concussion, although improved over recent years with the use of guidelines and education materials, is not yet optimal[26-28]. Education programs must target the various groups involved in sport-related concussion in order to effectively improve awareness and understanding in the community[26,29].

Athletes – need to have a good understanding of concussion to appreciate the importance of reporting symptoms and complying with rest and return to sport advice[30].

Parents and coaches – must be able to recognise symptoms and signs of concussion to detect concussions at the community-sport level where there is no medical supervision present[28,31].

Sporting and medical organisations – need to continue to develop specific recommendations around concussion to educate their own participants. However, complexity of the return to sport protocol has been highlighted as a potential barrier for community sport[32].

Key points for athletes, coaches, parents, teachers and allied health practitioners

- Concussion is a type of brain injury that occurs from a knock to the head or body.
- Recognising concussion is critical to ensure appropriate management and prevention of further injury.
- The Concussion Recognition Tool 5 (CRT5) is recommended to help recognise the signs and symptoms of concussion. This can be downloaded at bjsm.bmj.com/content/bjsports/early/2017/04/26/bjsports-2017-097508CRT5.full.pdf
- First aid principles apply in the management of the athlete with suspected concussion. This includes observing first aid principles for protection of the cervical spine.
- Any athlete suspected of having concussion should be removed from sport and not allowed to return to sport that day. This athlete should be reviewed by a medical practitioner.
- Features that suggest more serious injury and should prompt immediate emergency department referral include neck pain, increased confusion, agitation or irritability, repeated vomiting, seizure, weakness or tingling/burning in the arms or legs, reduced level of consciousness, severe or increasing headache, or unusual behaviour.
- When assessing a patient with suspected concussion, a medical practitioner will ask about details of the event as well as past medical history and then assess the patient, including asking about symptoms, signs, testing memory function and concentration, balance and neurological function.
- There is no single test that can determine whether someone has sustained a concussion. Your doctor may not order blood tests or medical imaging unless they wish to exclude other more serious injuries.
- Once a diagnosis of concussion has been confirmed, the main treatment for concussion is rest. After 24–48 hours of rest, light intensity physical activity is allowed as long as such activity does not cause a significant and sustained deterioration in symptoms.
- The activity phase should proceed as outlined below with a minimum of 24 hours spent at each level. The activity should only be upgraded if there has been no recurrence of symptoms during that time. If this occurs there should be a 'step down' to the previous level for at least 24 hours (after symptoms have resolved):
  - > light aerobic activity (at an intensity that can easily be maintained while having a conversation), until symptom-free
  - > basic sport-specific drills which are non-contact and with no head impact
  - > more complex sport-specific drills without contact (may add resistance training)
  - > full contact practice following medical review
  - > normal competitive sporting activity.
- Children and adolescents take longer to recover from concussion. They should be advised to wait a minimum of 14 days from when symptoms cease before returning to full contact/collision activities (after medical clearance).
- The long-term consequences of concussion, and especially multiple concussions, are not yet clearly understood.
- **If in doubt, sit them out.**

See diagrams 3 and 4 for concussion management flow chart (on and off field) on pages 13–14.

Key points for medical practitioners

- Concussion can be very difficult to detect. The symptoms and signs can be varied, non-specific and subtle.
- Athletes with suspected concussion should be removed from sport and assessed by a medical practitioner.
- When assessing acute concussions, a standard primary survey and cervical spine precautions should be used.
- Concussion is an evolving condition. Athletes suspected of, or diagnosed with, concussion require close monitoring and repeated assessment.
- The diagnosis of concussion should be based on a clinical history and examination that includes a range of domains such as mechanism of injury, symptoms and signs, cognitive functioning and neurology, including balance assessment.
- The SCAT5 is the internationally recommended concussion assessment tool and covers the above-mentioned domains. It can be downloaded at bjsm.bmj.com/content/bjsports/early/2017/04/26/bjsports-2017-097506SCAT5.full.pdf. This should not be used in isolation, but as part of the overall clinical assessment.
- Computerised neurocognitive testing can be undertaken as part of the assessment, but should not be used in isolation.
- Children and adolescents take longer to recover from concussion. A more conservative approach should be taken with those aged 18 or younger. The graduated return to sport protocol should be extended such that the child does not receive medical clearance to return to contact/collision activities in less than 14 days from resolution of symptoms.
- Blood tests are not indicated for uncomplicated concussion. Medical imaging is not indicated unless there is suspicion of more serious head or brain injury.
- Standard head-injury advice should be given to all athletes suffering concussion and to their carers.
- Once the diagnosis of concussion has been made, immediate management is physical and cognitive rest. This includes time off school or work and deliberate rest from cognitive activity for 24–48 hours. After this period, the patient can return to light intensity physical activity as long as such activity does not cause a significant and sustained deterioration in symptoms. Concussive symptoms usually resolve in 10–14 days. Once the symptoms have resolved the patient can proceed with a graduated return to sport protocol.
- Some sports have their own guidelines or recommendations around the management of concussion in sport which should also be considered.
- **If in doubt, sit them out.**

There is currently no strong evidence clearly linking sport-related concussion with chronic traumatic encephalopathy (CTE). The evidence purporting to show a link between sport-related concussion and CTE consists of case reports, case series and retrospective analyses. The reliance on retired athletes nominating to posthumously undergo autopsy for this research generates significant bias in the samples examined. Confounding factors such as alcohol abuse, drug abuse, genetic predisposition and psychiatric illness have not been controlled for adequately. Well-designed prospective studies are needed to better understand the possible relationship.

See diagrams 5 and 6 for Concussion Management Flow Chart (on and off field) on pages 12–13.

Diagram 1: Return to Sport Protocol for adults over 18 years of age

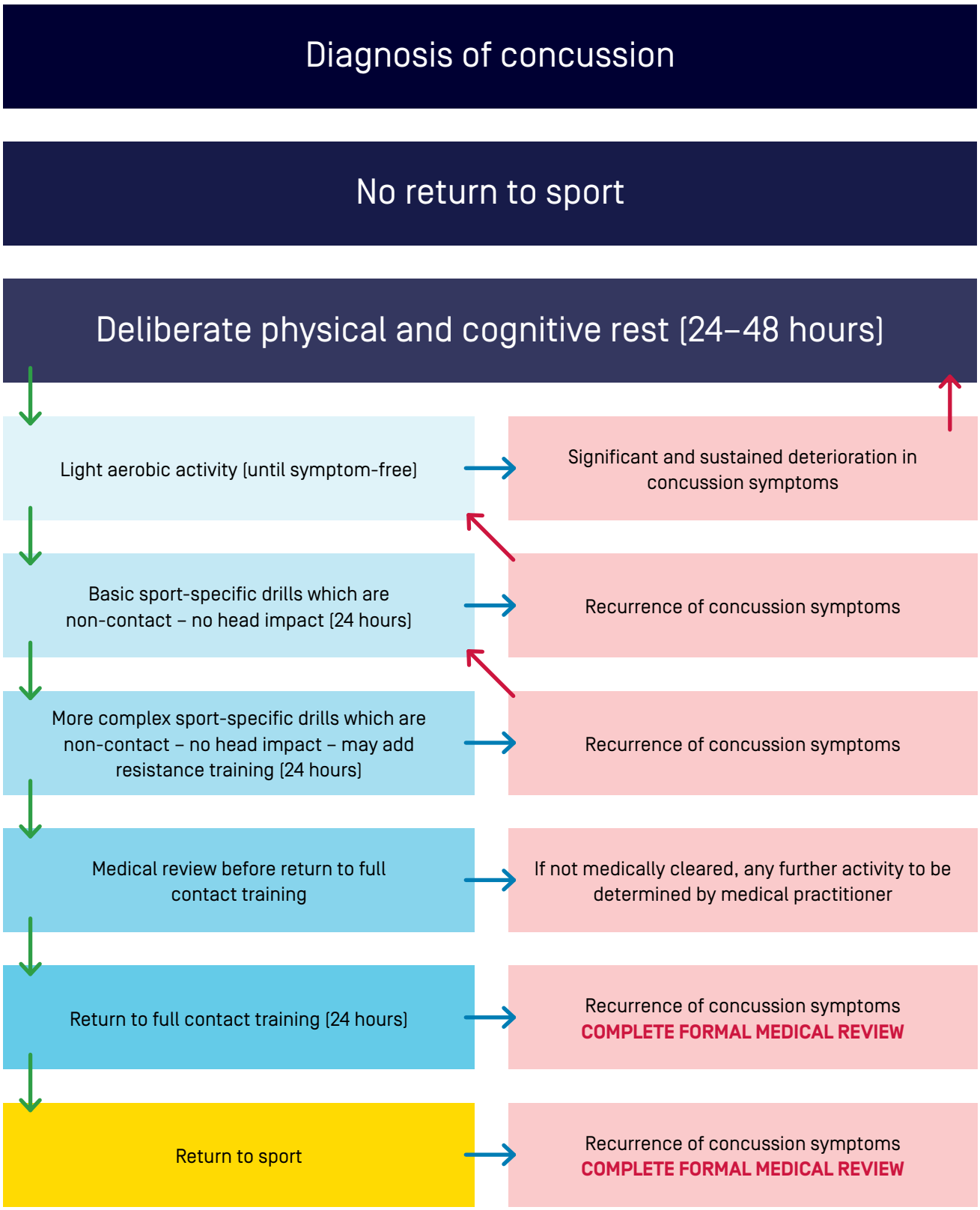


Diagram 2: Return to Sport Protocol for children 18 years of age and under

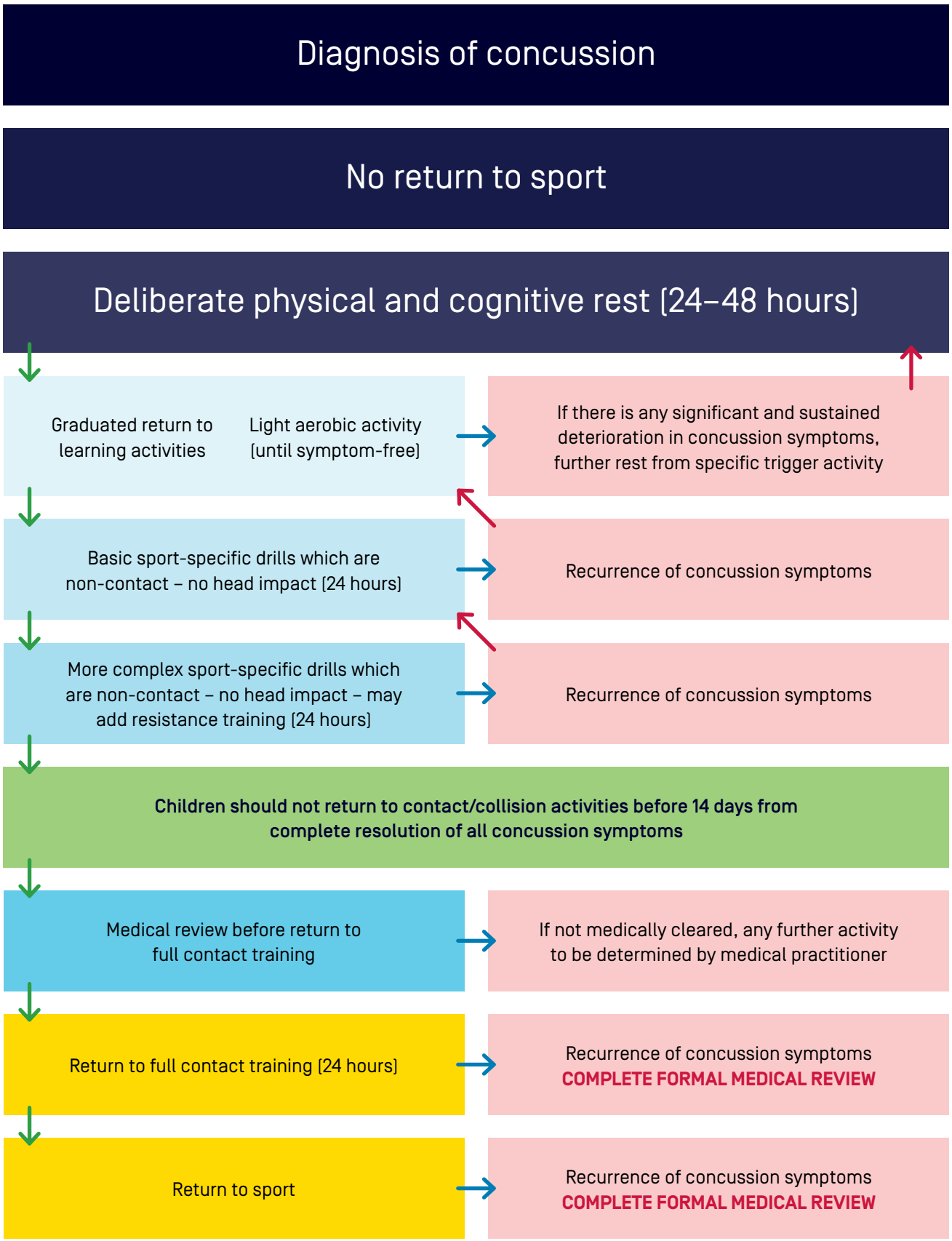


Diagram 3: Concussion management flow chart – on field
(for parents, coaches, teachers, team-mates, support staff)

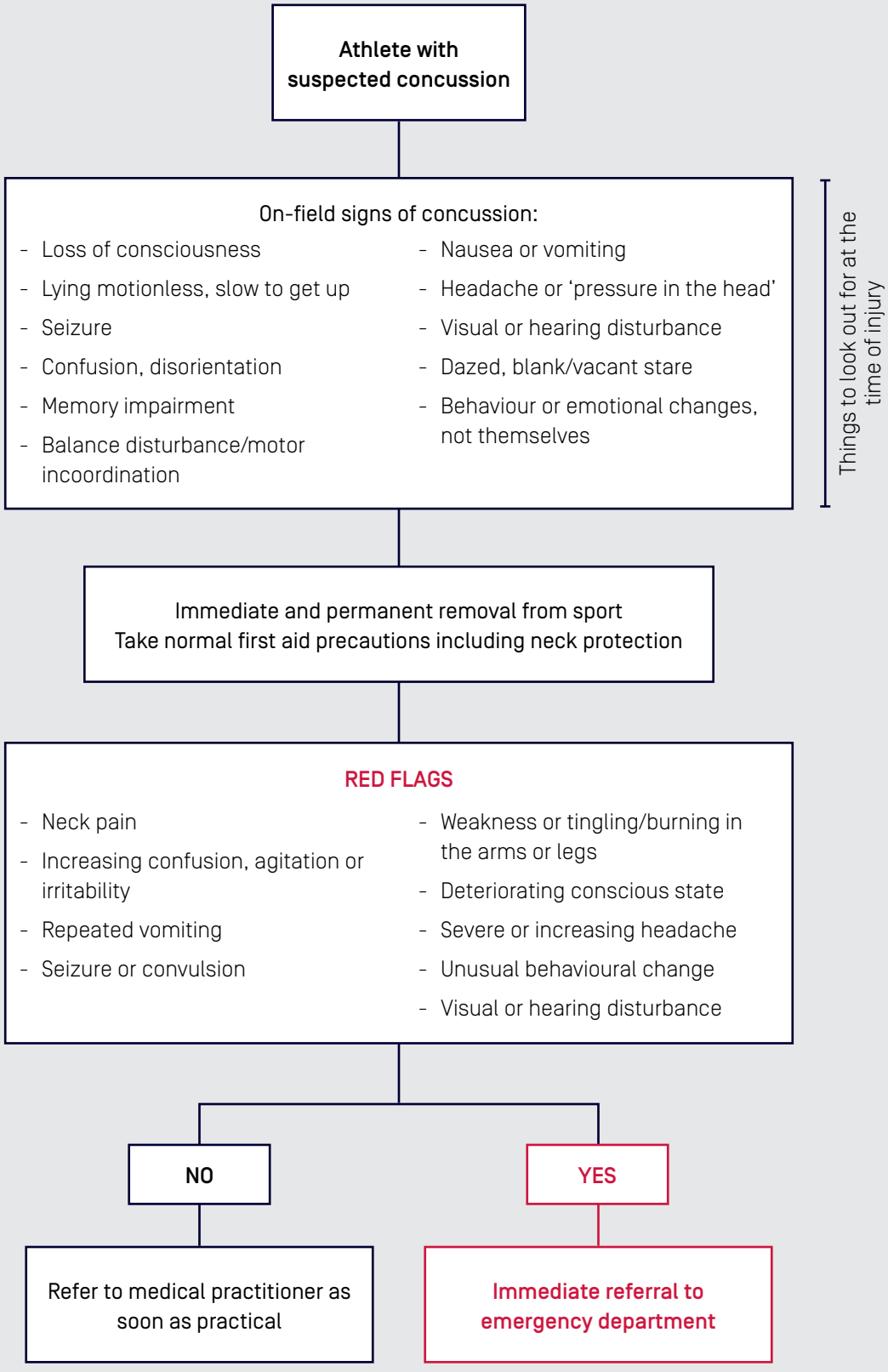


Diagram 4: Concussion management flow chart – off field
(for parents, coaches, teachers, team-mates, support staff)

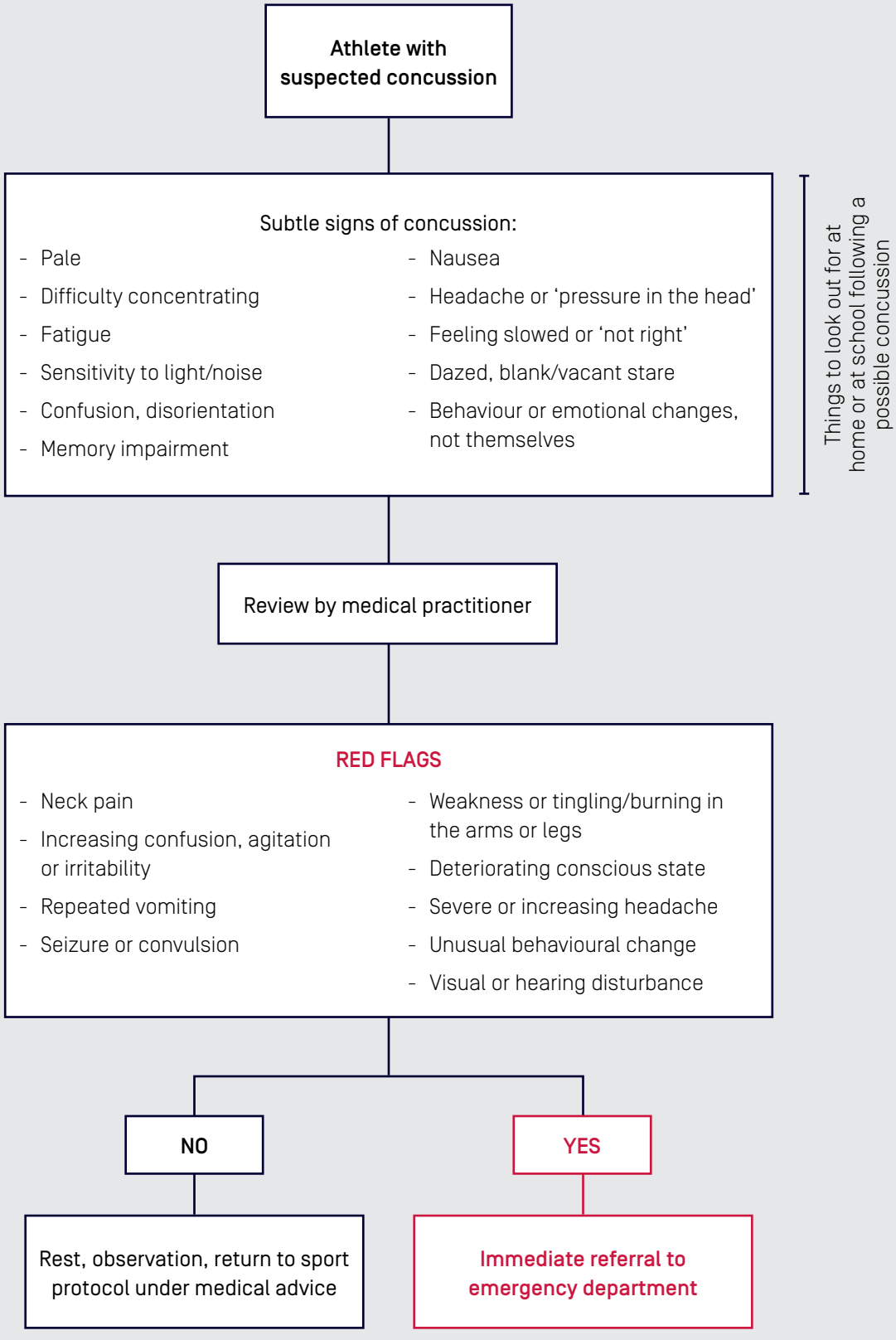


Diagram 5: Concussion management flow chart – on field
(for medical practitioners)

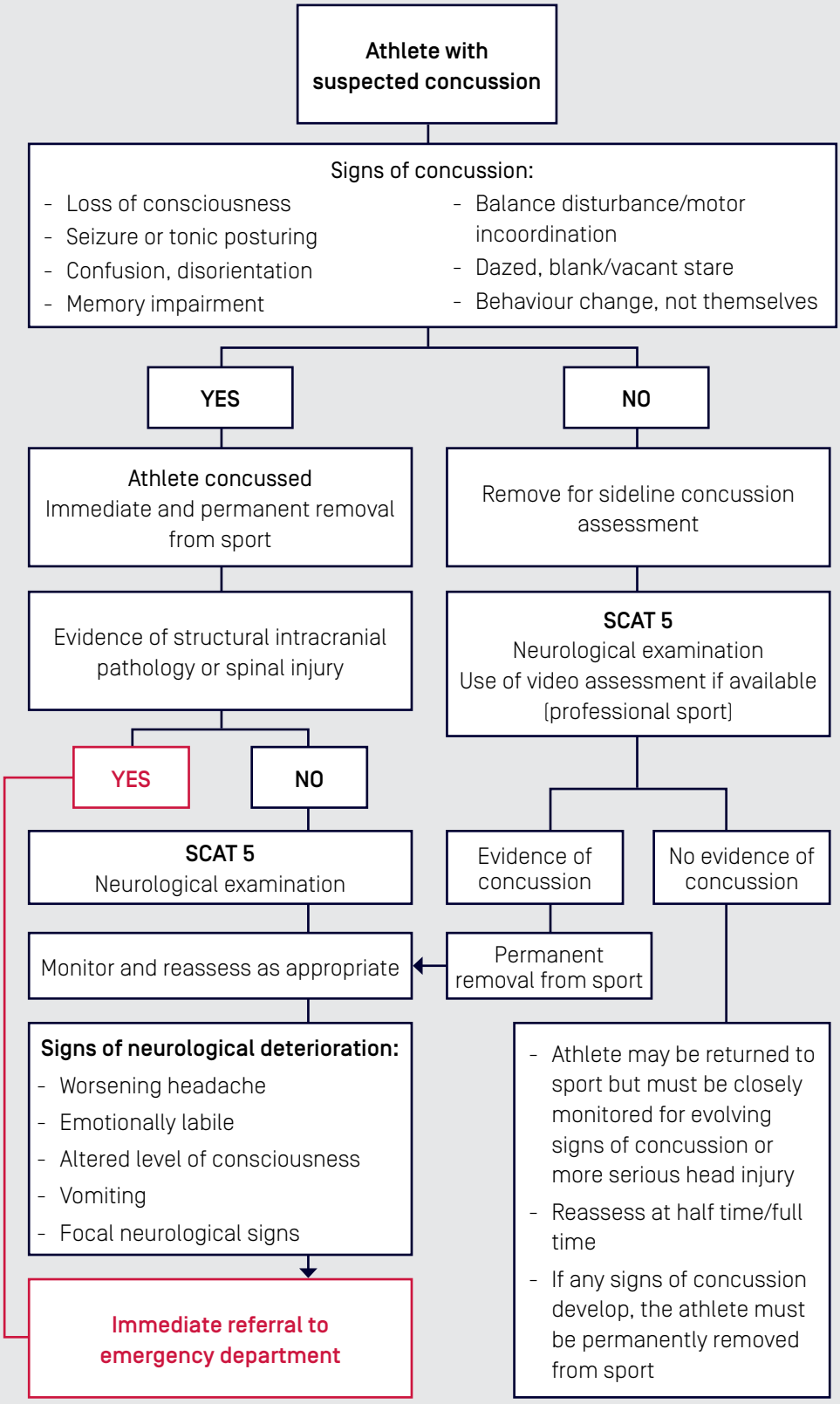
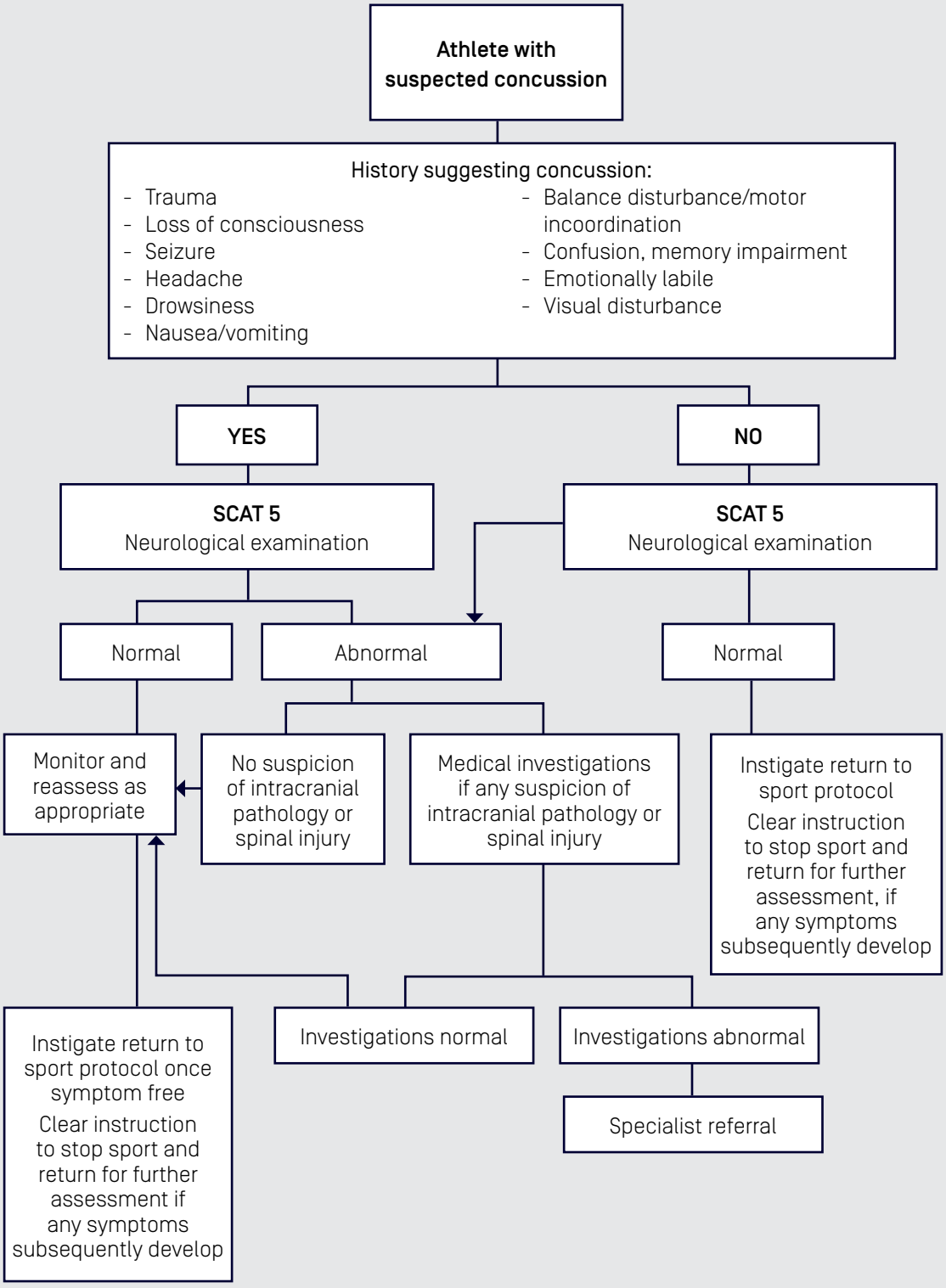


Diagram 6: Concussion management flow chart – off field
(for emergency departments and medical clinics)



OVERVIEW OF LITERATURE

Definition

Concussion is a type of brain injury. It is recognised as a complex injury that is challenging to evaluate and manage. The Concussion in Sport Group (CISG) has hosted five International Consensus Conferences since 2001. After each conference the CISG has published a statement summarising available evidence. Consensus statement recommendations from the Berlin conference in 2016 provide guidance to clinicians and others managing sport-related concussion[3]. As defined by the international Consensus Statement, sport-related concussion is 'a traumatic brain injury induced by biomechanical forces'[3,4]. It generally results from a knock – often to the head, face or neck, but may be anywhere in the body – which transmits an impulsive force to the head. Concussion commonly involves short-lived impairment of neurological function. Concussion is an evolving injury that may change over the first few hours and sometimes over a few days. In most adult cases symptoms have resolved by 14 days post injury[3].

It is yet unclear whether concussion involves mild structural changes, which would position it within the traumatic brain injury spectrum, or only physiological changes[3]. As discussed below, some epidemiological data, particularly hospital data, do not distinguish between traumatic brain injury and concussion.

Epidemiology

Sport-related concussion is a public health concern in Australia. Precise data on the incidence of sport-related concussion in Australia is lacking. Potential limitations to obtaining accurate data on incidence include lack of recognition of symptoms, under-reporting by athletes and failing to seek medical advice. A study examining the annual rate of hospitalisations for sport-related concussions in Victoria demonstrated a significant increase in frequency from 443 per year in 2002-03 to 621 in 2010-11, an increase of 60.5 per cent over the nine-year period[1]. This was not explained by increased participation, since rates of concussion per 100,000 participants also increased significantly during this time (38.5 per cent). Hospitalisation rates for concussion across different sports have been examined, and when adjustments were made for participation rates, the sports with the highest concussion rates were determined to be motor sports (181 per 100,000 participants), equestrian (130 per 100,000 participants), Australian football (80 per 100,000 participants), all codes of rugby (50 per 100,000 participants), and roller sports (45 per 100,000 participants)[1].

Sport-related concussion rates in the United States are estimated to be up to 3.8 million per year[33]. The condition is thought to be under-reported, making the actual incidence of concussion in the community difficult to quantify[34]. This problem is further complicated by the lack of an objective laboratory or diagnostic test for concussion and the reliance on more subjective methods of diagnosis[14]. Aside from health concerns, concussions and traumatic brain injuries represent a significant economic cost to the community. There are few figures available for hospital costs specific to concussion.

The majority of traumatic brain injuries occur in the 15-64 year age group, representing the group most likely to be in the workforce[35]. Victorian data for nine years (2002-11) estimated the costs of hospital admissions for sport-related concussions as $1,993,867 per annum[1]. These figures represent only a portion of the economic costs involved, as they do not reflect costs to the individual, income and productivity losses, or that of other regions within Australia.

Pathophysiology

The pathophysiology of concussion is not yet completely understood. Theoretical models are based on animal research and functional neuroimaging studies. Evidence points toward a series of interrelated changes that result in impaired neuronal function[6,7]. It is thought that biomechanical forces cause neuronal cell membrane disruption and axonal stretching. The ion channels on the cell membranes become dysregulated and allow an indiscriminate flux of ions. Potassium efflux and calcium influx will result in depolarisation leading to the indiscriminate release of the excitatory neurotransmitter glutamate. In an attempt to restore the resting membrane potential, ATP-dependent membrane ion pumps become overactive. This increases glucose demand resulting in a temporary depletion of intracellular energy reserves. There may also be a reduction in cerebral blood flow during this time that can worsen the energy shortage. The intracellular accumulation of calcium due to uncontrolled influx may result in sequestration of calcium within the mitochondria. Mitochondrial calcium overload causes mitochondrial

dysfunction, which would further aggravate energy supply issues. These changes are also thought to result in increased free radical production and inflammatory processes, which may be implicated in some of the longer-term symptoms associated with concussion.

Functional imaging studies have been used to assess physiological alterations underlying concussion and their time course post-injury. Most of these imaging modalities suggest long-term alterations beyond the return to normality in clinical and neuropsychological measures. As such, they may be useful in a research setting to detect changes consistent with concussion and monitor progress beyond recovery of symptoms, however the current level of evidence in favour of their clinical application is low. They include magnetic resonance spectroscopy (MRS), functional MRI (fMRI), diffusion tensor imaging, cerebral blood flow measurements, electrophysiology[36] and positron emission tomography (PET) scanning[37]. MRS can detect metabolic changes associated with concussion up to day 30 post-concussion. fMRI has found differences in functional brain activation patterns from three days up to 23 months post-concussion in concussed athletes compared to controls. Different diffusion tensor imaging methods have revealed changes in white matter orientation up to six months after concussion. Alterations in cerebral blood flow resolved 30–40 days post-concussion and electrophysiology did not return to normal levels until 45 days after the injury. PET scans have revealed changes in cerebral glucose metabolism in some brain regions when comparing military veterans with post-concussive symptoms to controls. This suggests metabolic abnormalities may be implicated in post-concussive symptoms[38]. These neuroimaging modalities suggest the presence of physiological alterations beyond clinical recovery from concussion. However, they are currently limited to characterising the pathophysiology of concussion, not to be used as tools for clinical assessment. Increased availability and further research and reliability assessment are required before implementation in a clinical setting[36].

An improved understanding of the pathophysiology of concussion will allow more accurate diagnosis and evidence-based management of the condition. It may provide enhanced appreciation of the long-term consequences of concussion and particularly recurrent concussion, to inform risk profiling and mitigation.

Assessment of suspected sport-related concussion

The diagnosis of concussion can be difficult[13]. There is no specific diagnostic test which confirms the presence or otherwise of concussion. Diagnosis of concussion relies on clinical assessment of symptoms and signs, including cognitive and behavioural disturbance.

In some instances, it will be obvious that there has been a significant injury where the athlete loses consciousness, has a seizure or has significant balance difficulties. Symptoms of concussion, however, can be very subtle and may present as nothing more than the athlete reporting that they do not 'feel right'. Symptoms commonly reported by concussed athletes include visual disturbance, feeling 'foggy', lethargic or slow, having sensitivity to light or noise, feeling dizzy or nauseous, or headache.

Signs of concussion are also variable and may be difficult to detect. The athlete may appear normal apart from appearing vacant, dazed or stunned. The athlete may be disoriented and unable to recall team plays, scores, who the opponent is or be disoriented in terms of place and time. Parents, coaches and attending medical personnel need to be alert for evidence that an athlete is behaving unusually or out of character, or exhibits signs of disorientation, clumsiness or loss of balance. Amnesia is common in the setting of concussion. The athlete may ask questions repeatedly about what happened or what the score is. Concussed athletes will often have difficulty concentrating and answering specific questions.

It is critical that all individuals dealing with potentially concussed athletes understand that concussion is an evolving phenomenon. Subtle symptoms and signs often become far more significant in the hours and days following the injury.

Due to the evolving nature of the injury and the varied and potentially subtle symptoms and signs, the critical criteria for the diagnosis have been published based on a systematic review of the literature[3,13]. The recommendations include an assessment looking at a variety of domains – loss of consciousness, symptoms, cognition, neurobehavioural symptoms, and balance – with any abnormality being a potential sign of concussion. Due to the complexity of the injury and the diagnostic challenge it can present, one of the outcomes from the series of International Consensus Conferences on Concussion in Sport was the development of the Sport Concussion Assessment Tool [(SCAT5)] aimed at improving identification, clinical assessment and diagnosis of sport-related concussion[9,14]. It is important to note that the diagnostic utility of the SCAT tool decreases 3–5 days post-concussion[14].

Some of the football codes, including the Australian Football League, National Rugby League and Australian Rugby Union, have developed criteria for mandatory removal of athletes from sport following head trauma. These criteria are intended to provide a decision-making algorithm for doctors to determine the requirement for removal from sport. The criteria are subdivided into

those that require 'immediate removal and no return to sport' and those indicating 'immediate removal from sport for further assessment with concussion assessment tools'. Clinical features that mandate 'immediate removal and no return to sport' include loss of consciousness; no protective action in fall to the ground observed directly or on video; impact seizure or tonic posturing; confusion; disorientation; memory impairment (e.g. fails Maddocks questions – see below); balance disturbance (e.g. ataxia); athlete reports significant new or progressive concussion symptoms; dazed; blank/vacant stare; not their normal selves; or observed behaviour change.

Where resources allow, sporting organisations could use modern technology such as instant video replay to enhance the ability to detect and manage concussion. However, as promising as video is for the detection of concussion, there is currently not enough evidence to recommend its widespread use[14].

Evidence-based assessment tools

The Sport Concussion Assessment Tool 5th Edition (SCAT5) is the most recent version of the internationally recommended assessment tool updated at the Berlin 2016 International Consensus Conference on Concussion in Sport[3,9,14]. The SCAT5 has been designed to assist medical professionals in the diagnosis of concussion. It is available online at bjsm.bmj.com/content/bjsports/early/2017/04/26/bjsports-2017-097506SCAT5.full.pdf. It is not intended to replace clinical judgement which remains the cornerstone of diagnosis for this condition. The tool encompasses a sideline assessment to be used at the time of the concussion, which includes a brief history of the injury, a Glasgow Coma Score and a series of questions known as Maddocks questions. These questions have been validated as an indicator of sport-related concussion and are more sensitive in this context than the standard orientation questions[8]. The questions assess athlete orientation (in time and place) and they should be preceded by: 'I am going to ask you a few questions, please listen carefully and give your best effort.'

The modified Maddocks questions are:

- What venue are we at today?
- Which half is it now?
- Who scored last in this match?
- What team did you play last week/game?
- Did your team win the last game?

The remainder of the SCAT5 is for use off the field, as a sideline concussion assessment, in the medical room, or in the consulting room after a referral for suspected concussion has been made.

A Child SCAT5 was also updated at the Berlin 2016 meeting of the Concussion in Sport Group. It is a modified version of the SCAT5 for children aged 5–12 years. The key differences are that the symptom evaluation is written in language more appropriate for this age group and the severity score is marked out of three rather than six. The Child SCAT5 also includes a parent's report of symptoms and severity. The cognitive assessment is slightly simplified and the balance testing excludes the single leg stance. It has recently been suggested that the SCAT5 and other guidelines should also include modifications for use with athletes with disability[39,40].

The Concussion Recognition Tool 5 (CRT5) is a simplified summary of the key signs and symptoms that should raise concern about a possible concussion[11,12]. The tool is designed for use by any member of the community, unlike the SCAT5 which is only intended for use by medical professionals. The tool is aimed at identifying concussions. Once a possible concussion is identified, the tool advises that the person must be removed from sport immediately and not be allowed to return to activity until they are assessed medically. This tool also lists 'red flags' that should prompt emergency medical review.

Many other assessment tools are currently available. The King-Devick test measures eye movement impairment, and a number of prospective case-control studies have indicated high sensitivity and specificity[13,14]. Balance tests such as the Balance Error Scoring System (BESS) also show potential for concussion assessment, primarily in the acute stage[14,41]. Neurocognitive testing may also assist in the diagnosis and monitoring of concussion[41]. Such testing is increasingly becoming computer-based. There are several products available for quantitative neurocognitive testing. These products aim to quantify various aspects of cognitive function including speed of psychomotor processing, learning and memory, vigilance and attention. Neurocognitive testing provides a more objective assessment of neurological function than scoring of patient-reported symptoms, which are often under-reported[42]. This testing is also more detailed than the abbreviated cognitive component of the SCAT5. As with other diagnostic tools, it should not be used in isolation, but may form part of the clinical history and examination. Computerised neuropsychological tests such as ImPACT (impacttest.com) or Axon (axonsports.com) are validated for use in concussion and are an easily accessible resource for use in clinics. A fee is usually charged to the patient for each test undertaken.

Management

There is broad agreement regarding key principles of concussion management policies by organisations, including the Concussion in Sport Group, American Academy of Neurology, Centre for Disease Control and sporting organisations.

Acute assessment of the concussed athlete at the time of injury should observe normal protocols of first aid treatment. Where the athlete is unconscious or incapable of providing intelligible responses, cervical spine injury should be assumed and treated appropriately with in-line stabilisation, until cervical spine injury can be excluded. Attention to airway, breathing and circulation should be followed as per accepted first aid protocols.

Athletes suspected or confirmed of sustaining a concussion should be removed from the sporting environment and should not be allowed to return to physical activity until they have been assessed by a medical practitioner. Referral to a medical practitioner should occur as a matter of priority. Where suspicion remains or concussion is confirmed, the athlete must not return to sport on the day of injury.

Given that concussion is an evolving injury, the athlete should be observed by a responsible adult for several hours following the concussion. Symptoms suggesting the need for urgent medical review include deteriorating neurological function, neck pain, worsening nausea, vomiting, worsening headache and loss of consciousness.

Any athlete with a suspected or confirmed concussion should not be allowed to drive and should remain in the company of a responsible adult. They should be advised to avoid alcohol, and any medications unless medically prescribed. Concussed athletes should specifically avoid aspirin, anti-inflammatory medications, sleeping tablets or sedating pain medication.

Any athlete with suspected or confirmed concussion should be referred immediately to the nearest emergency department if they develop any of the following clinical features:

- neck pain
- increasing confusion, agitation or irritability
- repeated vomiting
- seizure or convulsion
- weakness or tingling/burning in the arms or legs
- deteriorating conscious state
- severe or increasing headache
- unusual behavioural change
- double vision.

The current principles of concussion management involve rest during the acute period post-injury, followed by a gradual increase in cognitive activity and then physical activity[5]. The optimal duration of the period of rest is not clear, but the most current evidence supports rest during the acute period (24–48 hours post-injury)[18,43]. Strict rest beyond the initial period is not recommended based on recent studies, including a randomised clinical trial showing that subjects who were prescribed strict rest reported more symptoms and recovered more slowly than those who engaged in some physical activity[43].

Patients with symptoms persisting longer than 14 days for adults or four weeks for children require careful reassessment. Persisting symptoms can be due to a range of pre-existing confounding issues. The specific contributors to symptom persistence may be difficult to identify. Every effort should be made to structure a treatment program which addresses any medical, physical or psychosocial factors identified on assessment. Those who can tolerate a short duration of light exercise may benefit from a closely monitored and graduated aerobic rehabilitation program[3,44]. When there is any evidence of cervical spinal vestibular dysfunction, referral to a physiotherapist with specific skills in cervical/vestibular rehabilitation is appropriate. Mood or behavioural issues may respond to cognitive behavioural therapy[5].

Children and adolescents

Sport concussions are common in children and adolescents[45]. Concussion warrants special consideration in this age group and a more conservative approach to diagnosis and management is recommended[17,19]. The physical, cognitive and emotional characteristics of young children require that assessment tools be targeted to this population[46]. The Child Sport Concussion Assessment Tool (Child SCAT5) by the Concussion in Sport Group for children aged 5–12 years intends to address these concerns[46]. Children and adolescents may be more susceptible to concussion due to a variety of factors, including decreased myelination, poor cervical musculature, and increased head to neck ratio, but the evidence for this remains inconclusive and inconsistent. The role of cerebral blood flow alterations in the pathophysiology of concussion may be more significant in children than in adults[47]. A growing amount of evidence suggests that adolescents in particular may experience longer recovery times[16,17]. The implications of this are not clear and further studies are required to confirm or refute these data.

The guidelines surrounding management of concussion from the Concussion in Sport Group Consensus Statement 2016 include prioritising return to school and learning before commencing return to sport[3]. Modification of school attendance and activities may be required. In children and adolescents, the graduated return to sport protocol should be extended to allow a longer asymptomatic period before return to full contact activities. A more cautious return to sport protocol is recommended when factors associated with slower recovery are evident[3,16]. World Rugby recommends that children and adolescents 18 years or younger not return to contact training or competitive sport for at least two weeks after resolution of concussion symptoms[48].

Investigations

There are no reliable radiological or blood investigations that assist with the diagnosis of uncomplicated concussion[15]. Where symptoms persist for a prolonged period of time (more than 14 days for adults and more than four weeks for children) or where there is evidence of deteriorating neurological function, CT or MRI of the head may be indicated to exclude other serious pathologies such as fracture or intracranial bleed. There are no biomarkers which indicate the presence or otherwise of uncomplicated concussion[15].

Neurocognitive testing can form part of the clinical assessment process, but such testing in isolation is not sufficient to diagnose or exclude concussion[41].

Predictors of clinical recovery

A number of 'concussion modifiers', including pre-injury factors and initial injury severity indicators such as loss of consciousness or amnesia, have been studied to assess their association with prolonged recovery of symptoms or worse outcome[3,16]. The evidence relating to the impact of many of these factors on prolonged recovery is inconclusive[16]. Overall, the most consistent risk factor for slower recovery is acute and subacute symptom burden. While there is no clear evidence that loss of consciousness or post-concussive seizure is associated with a worse outcome, prolonged loss of consciousness (more than one minute) or prolonged seizure (more than one minute) following head trauma should raise suspicion of a more serious injury such as intracranial haemorrhage.

Several studies have shown previous concussion to be a risk for further concussion, and the clinician should take a conservative approach where there is a history of repeated concussion or concussions occurring in close time proximity[16,49]. Recurrent concussion is sometimes associated with reduced threshold for concussion and this should alert the clinician to potential increased vulnerability to further concussive episodes.

Children take longer to recover from a concussion injury[20,21]. Age-appropriate assessment and a more cautious approach to return to play or sport should be adopted with children and adolescents aged 18 and under[19,46].

The assessing clinician should be mindful of comorbidities including pre-existing mental illness such as depression, migraine, learning disability, ADHD or sleep disturbances. Similarly, a high level of vigilance should be observed in a situation where the athlete is taking medication such as psychoactive drugs or anticoagulant medication. The majority of concussions in adults resolve within 10–14 days[3]. Medical investigation and re-evaluation to assess mental and cognitive health, and the development of an individualised management plan are required where there are a high number of concussive symptoms, the concussive symptoms are of high severity, or the symptoms last longer than 14 days for adults or longer than four weeks for children[3,50].

Special considerations in concussion

The issue of concussion has received significant media attention in recent years. The focus of a large part of this attention has been on chronic traumatic encephalopathy (CTE), particularly in retired athletes from the National Football League in the USA[23]. CTE can only be diagnosed by post-mortem observation, and it is described by McKee et al.[51] as a 'progressive neurodegeneration clinically associated with memory disturbances, behavioural and personality change, Parkinsonism, and speech and gait abnormalities'[51]. Neuropathological criteria for the diagnosis of CTE have recently been defined at a consensus meeting to be the abnormal accumulation of hyperphosphorylated tau protein in the brain[52]. Some researchers have presented preliminary evidence that repeated head trauma causes the condition[51], but there is significant selection bias in many of the reported cases[23]. The link between sport-related concussion and CTE is based on low-level evidence. Research is limited to case reports, case series and retrospective analyses which cannot adequately determine causality or risk factors. The potential contribution of confounders, such as genetic predisposition, psychiatric illness, alcohol and drug use or co-existing dementia, is not adequately accounted for in the current literature[53]. While there is significant concern about CTE and its possible relationship with concussion, it is important to note that no causative link has been clearly established.

Recent public health concerns about CTE and the desire to prevent these complications have, to a large extent, driven the increased focus on developing best-practice guidelines for the identification, diagnosis and management of sport-related concussion. Further research is needed to understand what type of trauma, how much force and what frequency are required for the pathological changes of CTE to develop. It is also not clear why only some athletes are affected with these symptoms. Properly designed prospective studies, which control for potential confounding variables, are required to improve our understanding of CTE and confirm if there are any links to prior concussion[53-55].

Acute cerebral oedema, also referred to as second impact syndrome, is another condition that has received a lot of media attention due to its catastrophic outcomes. This condition, along with CTE, appears to have driven much of the public awareness around concussion. Acute cerebral oedema refers to rapid cerebral swelling that can occur when a second concussive injury is sustained during a 'vulnerable' period when the brain has not recovered from an initial insult[56]. Animal models have demonstrated that there is a period of vulnerability during which further injury can result in significant axonal injury with associated ion channel damage[57]. It is thought that a second impact may not be needed for the swelling to develop. The condition is rare and the only available literature consists of case studies which are inadequate to provide a good understanding of the mechanisms and risk factors. Further research is needed to better understand the pathophysiology and risk factors for 'second impact syndrome'.

Education and prevention

Improved education and awareness is critical to improving diagnosis and management of concussion. Such education must include all stakeholders – athletes, parents, coaches, teachers and healthcare professionals.

A number of studies have demonstrated that general knowledge about concussion is inadequate. A large survey of community-based Australian coaches and trainers in Australian football and rugby league conducted in 2012 found concussion knowledge to be poor. This indicated that key messages were not reaching community-level sport[58]. In 2017, a similar study qualified the public level of knowledge as moderate[26]. Education programs must target the various groups involved in sport-related concussion in order to effectively improve awareness and understanding in the community[31]. To be effective, materials used in concussion education programs should be able to provide clear guidance[59].

Athletes need to have a good understanding of concussion in order to appreciate the importance of reporting symptoms and complying with rest and return to sport advice[32]. Under-reporting of concussion by athletes still appears to be a problem and legislation alone, without education of the athletes, has proved ineffective in addressing this problem[60]. Accordingly, a recent systematic review showed that players who had undergone concussion education were more likely to report a suspected concussion[30]. Another study revealed that a sample of young adults, while showing awareness of the risks of playing sport with a concussion, expressed a willingness to risk playing with a concussion themselves[27]. Parents and coaches must be able to recognise the symptoms and signs of concussion in order to detect concussions at the community-sport level where there is no medical supervision present.

Concussion knowledge among healthcare workers should be improved with provision of readily accessible information and resources to those managing concussion. Athletes' parents have expressed concern about medical doctors' knowledge of concussion management[28], and recently it has been shown that only 18 per cent of medical aides involved in community rugby union acknowledged the need to use field-side assessment tools[31].

Measures which may assist in preventing concussion include the use of protective equipment and rule changes in high-risk sporting codes[29]. That being said, the use of protective equipment such as helmets, mouth guards or other protective devices are most appropriate for prevention of traumatic brain injuries such as skull fracture and subdural haematoma. They offer little, if any, benefit in the prevention of concussion[29].

Sporting organisations in Australia have responded to the increased concern regarding concussion. The four major football codes (Australian football, rugby league, rugby union and soccer) have introduced rule changes in recent years to ensure more thorough clinical assessment of the athlete with suspected concussion and to enforce guidelines around management of the concussed athlete. All sporting organisations should ensure that medical and support staff covering sporting events have adequate education and training in the immediate and long-term management of concussion.

GUIDELINES IN AUSTRALIAN SPORTING ORGANISATIONS

Given the increasing awareness of sport-related concussion and the associated community concern about this condition, many sporting organisations have developed their own guidelines for its management. These guidelines are constantly evolving through ongoing review. There is a high degree of congruency and alignment across the various sporting organisations, supported by the latest scientific evidence on concussion diagnosis and management. Readers should refer to sport-specific websites for further information.

Australian Football League
aflcommunityclub.com.au/index.php?id=66

Australian Rugby Union
http://www.aru.com.au/runningrugby/PolicyRegister/ConcussionProcedureManagement.aspx

Basketball Australia
http://www.basketball.net.au/wp-content/uploads/2014/05/Concussion-Guideline.pdf

Boxing Australia
http://www.boxing.org.au/documents/aiba-rules--regulations

Football Federation Australia
https://www.ffa.com.au/sites/ffa/files/2018-01/18-0102%20FFA%20Concussion%20Guidelines%20%28final%29.pdf?_ga=2.113230029.818472769.1533772800-1702376216.1531715461

National Rugby League
https://playnrl.com/media/2604/the-management-of-concussion-in-rugby-league-final.pdf

Olympic Winter Institute of Australia
http://www.owia.org/uploads/3/9/6/0/39609871/owia_concussion_policy_with_appendix_a-g_v1_2015_12_16.pdf

OTHER CONCUSSION RESOURCES

Medical groups and sporting bodies, both nationally and internationally, are developing their own guidelines or position statements on concussion. There is broad acknowledgement of the complexity of sport-related concussion and the challenge this task poses for medical practitioners.

Australian

Brain Foundation Australia
http://brainfoundation.org.au/disorders/concussion

Brain Injury Australia
http://www.braininjuryaustralia.org.au/docs/CONCUSSIONpolicypaperFINAL.pdf

Sports Concussion Australasia Headsmart Sports Concussion Programme
http://www.headsmart.me

Sports Medicine Australia
sma.org.au/wp-content/uploads/2015/09/SMA-Position-Statement_Concussion-190815.pdf

Sports Medicine Australia
https://sma.org.au/sma-site-content/uploads/2018/03/Concussion-Policy-2018.pdf

International

American Academy of Neurology
http://www.neurology.org/content/80/24/2250.full

American Medical Society for Sports Medicine
http://bjsm.bmj.com/content/47/1/15.long

Centre for Disease Control (USA)
http://www.cdc.gov/headsup/index.html

Faculty of Sport and Exercise Medicine UK
https://www.fsem.ac.uk/position_statement/concussion-management/

CONCUSSION RESEARCH PRIORITIES

The issue of a potential link between concussion and Chronic Traumatic Encephalopathy (CTE) has caused significant concern in Australia and around the world[23]. Despite claims by some researchers, there is a paucity of evidence supporting a causative link between these two conditions[61]. Potential long-term health ramifications from sport-related concussion need to be an area of focal research attention[61]. The design of research initiatives must be thoughtfully considered to ensure that any data arising from such research is meaningful and reliable. It is crucial to the welfare of Australian athletes that any potential long-term health implications associated with concussion are clearly identified and understood.

Little is known about the biological mechanisms underlying the symptoms and signs of concussion[62]. Improving the understanding of biological processes underlying concussion will increase the certainty with which doctors can advise athletes, parents and sporting bodies regarding prevention, management and safe return to sport. Improved understanding of concussion biology may also lead to the discovery of reliable biomarkers or imaging modalities to assist in indicating the presence or otherwise of concussion, and/or satisfactory recovery from concussion[15].

A key part of any health initiative must be improving the knowledge and information transfer to those who are most affected by the condition[29]. While most concussion position papers support the role of education, there is little good evidence which indicates what the current level of community knowledge is in relation to concussion[32]. It is important that future research projects seek to quantify current community knowledge on concussion so that interventions which seek to educate athletes and other stakeholders can be assessed for their efficacy and validity.

Evidence suggests that children take longer than adults to recover from concussion[19], so there is a need to better understand the variability in concussion recovery patterns between different sporting subpopulations. An improved understanding will enable prevention and management strategies to be based on the specific risk profile of particular sporting subgroups, including children.

There have been great advances over the past decade in the clinical tools that are available for use in the diagnosis and management of concussion[41]. However, no single tool can diagnose concussion or indicate conclusively when it is safe for an athlete to return to sport. It is vital therefore that research continues to focus on improving clinical tools to enable accurate diagnosis of concussion and to inform appropriate return to sport.

REFERENCES

1. Finch CF, Clapperton AJ, McCrory P. Increasing incidence of hospitalisation for sport-related concussion in Victoria, Australia. Med J Aust. 2013; 198(8):427-30.
2. Clay MB, Glover KL, Lowe DT. Epidemiology of concussion in sport: a literature review. J Chiropr Med. 2013; 12(4):230-51.
3. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017; Published Online First: 26 April 2017. doi: 10.1136/bjsports-2017-097699.
4. McCrory P, Feddermann-Demont N, Dvorák J, et al. What is the definition of sports-related concussion: a systematic review. Br J Sports Med. 2017; 51(11):877-87.
5. Schneider KJ, Leddy JJ, Guskiewicz KM, et al. Rest and treatment/rehabilitation following sport-related concussion: a systematic review. Br J Sports Med. 2017.
6. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. Neurosurgery. 2014; 75 Suppl 4:S24-33.
7. Martin G. Traumatic brain injury: The first 15 milliseconds. Brain Inj. 2016; 30(13-14):1517-24.
8. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995; 5(1):32-5.
9. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5). Br J Sports Med. 2017.
10. Sport concussion assessment tool - 5th edition. Br J Sports Med. 2017; 51(11):851-58.
11. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Concussion Recognition Tool 5th Edition (CRT5). Br J Sports Med. 2017.
12. Concussion recognition tool 5(c). Br J Sports Med. 2017.
13. Patricios J, Fuller GW, Ellenbogen R, et al. What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review. Br J Sports Med. 2017; 51(11):888-94.
14. Echemendia RJ, Broglio SP, Davis GA, et al. What tests and measures should be added to the SCAT3 and related tests to improve their reliability, sensitivity and/or specificity in sideline concussion diagnosis? A systematic review. Br J Sports Med. 2017; 51(11):895-901.
15. McCrea M, Meier T, Huber D, et al. Role of advanced neuroimaging, fluid biomarkers and genetic testing in the assessment of sport-related concussion: a systematic review. Br J Sports Med. 2017; 51(12):919-29.
16. Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. Br J Sports Med. 2017; 51(12):941-48.
17. Manzanero S, Elkington LJ, Praet SF, Lovell G, Waddington G, Hughes DC. Post-concussion recovery in children and adolescents: A narrative review. J Concussion. 2017; 1:2059700217726874.
18. McLeod TC, Lewis JH, Whelihan K, Bacon CE. Rest and Return to Activity After Sport-Related Concussion: A Systematic Review of the Literature. J Athl Train. 2017; 52(3):262-87.
19. Davis GA, Anderson V, Babl FE, et al. What is the difference in concussion management in children as compared with adults? A systematic review. Br J Sports Med. 2017; 51(12):949-57.
20. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. J Pediatr. 2003; 142(5):546-553.
21. Crowe L, Collie A, Hearps S, et al. Cognitive and physical symptoms of concussive injury in children: a detailed longitudinal recovery study. Br J Sports Med. 2016; 50(5):311-16.
22. Manley G, Gardner AJ, Schneider KJ, et al. A systematic review of potential long-term effects of sport-related concussion. Br J Sports Med. 2017; 51(12):969-77.
23. Mez J, Daneshvar DH, Kiernan PT, et al. Clinicopathological evaluation of chronic traumatic encephalopathy in players of American football. JAMA. 2017; 318(4):360-70.
24. Belanger HG, Vanderploeg RD, McAllister T. Subconcussive Blows to the Head: A Formative Review of Short-term Clinical Outcomes. J Head Trauma Rehabil. 2016; 31(3):159-66.
25. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. Neurosurgery. 2005; 57(4):719-726; discussion 719-26.
26. Gardner AJ, Kay-Lambkin F, Shultz SR, Iverson GL. Level of knowledge and attitude towards sport-related concussion among the general?public. Br J Sports Med. 2017; 1(11):A68-A68.
27. Pearce AJ, Young JA, Parrington L, Aimers N. Do as I say: contradicting beliefs and attitudes towards sports concussion in Australia. J Sports Sci. 2017; 35(19):1911-9.
28. White PE, Register-Mihalik J, Donaldson A, Sullivan SJ, Finch CF. Concussion guideline implementation perceptions and experiences among parents of community-level Australian Football junior players. BMJ Open Sport Exerc Med. 2017; 3(1).
29. Emery CA, Black AM, Kolstad A, et al. What strategies can be used to effectively reduce the risk of concussion in sport? A systematic review. Br J Sports Med. 2017; 51(12):978-84.
30. Taylor ME, Sanner JE. The Relationship Between Concussion Knowledge and the High School Athlete's Intention to Report Traumatic Brain Injury Symptoms. J Sch Nurs. 2017; 33(1):73-81.
31. Clacy A, Goode N, Sharman R, Lovell GP, Salmon P. A systems approach to understanding the identification and treatment of sport-related concussion in community rugby union. Appl Ergon. 2017.
32. White PE, Donaldson A, Sullivan SJ, Newton J, Finch CF. Australian Football League concussion guidelines: what do community players think? BMJ Open Sport Exerc Med. 2016; 2(1).

33. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil. 2006; 21(5):375-78.

34. Kroshus E, Garnett B, Hawrilenko M, Baugh CM, Calzo JP. Concussion under-reporting and pressure from coaches, teammates, fans, and parents. Soc Sci Med. 2015; 134:66-75.

35. Helps Y, Henley G, Harrison J. Hospital separations due to traumatic brain injury, Australia 2004-05. Adelaide, Australia: Australian Institute of Health and Welfare; 2008. AIHW Cat. No. INJCAT 116; Injury Research and Statistics Series No. 45. http://content.webarchive.nla.gov.au/gov/wayback/20120405044750/http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=6442458806. Accessed 19 September 2017.

36. Kamins J, Bigler E, Covassin T, et al. What is the physiological time to recovery after concussion? A systematic review. Br J Sports Med. 2017; 51(12):935-40.

37. Byrnes KR, Wilson CM, Brabazon F, et al. FDG-PET imaging in mild traumatic brain injury: a critical review. Front Neuroenergetics. 2013; 5:13.

38. Peskind ER, Petrie EC, Cross DJ, et al. Cerebrocerebellar hypometabolism associated with repetitive blast exposure mild traumatic brain injury in 12 Iraq war Veterans with persistent post-concussive symptoms. NeuroImage. 2011; 54 Suppl 1:S76-82.

39. Webborn N, Blauwet CA, Derman W, et al. Heads up on concussion in para sport. Br J Sports Med. 2017.

40. West LR, Griffin S, Weiler R, Ahmed OH. Management of concussion in disability sport: a different ball game? Br J Sports Med. 2017; 51(14):1050-1.

41. Feddermann-Demont N, Echemendia RJ, Schneider KJ, et al. What domains of clinical function should be assessed after sport-related concussion? A systematic review. Br J Sports Med. 2017; 51(11):903-18.

42. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: implications for prevention. Clin J Sport Med. 2004; 14(1):13-7.

43. Thomas DG, Apps JN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: a randomized controlled trial. Pediatrics. 2015; 135(2):213-23.

44. Gagnon I, Galli C, Friedman D, Grilli L, Iverson GL. Active rehabilitation for children who are slow to recover following sport-related concussion. Brain Inj. 2009; 23(12):956-64.

45. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of Health Care Entry for Youth With Concussion Within a Large Pediatric Care Network. JAMA Pediatr. 2016; 170(7):e160294.

46. Davis GA, Purcell L, Schneider KJ, et al. The Child Sport Concussion Assessment Tool 5th Edition (Child SCAT5). Br J Sports Med. 2017.

47. Maugans TA, Farley C, Altaye M, Leach J, Cecil KM. Pediatric sports-related concussion produces cerebral blood flow alterations. Pediatrics. 2012; 129(1):28-37.

48. World Rugby. Concussion Guidance. http://playerwelfare.worldrugby.org/content/getfile.php?h=d66f98b9815023fbf00e8ef28b20cdb6&p=pdfs/World_Rugby_Concussion_Guidance_EN.pdf. Accessed 19 September 2017.

49. Hollis SJ, Stevenson MR, McIntosh AS, Shores EA, Collins MW, Taylor CB. Incidence, risk, and protective factors of mild traumatic brain injury in a cohort of Australian nonprofessional male rugby players. Am J Sports Med. 2009; 37(12):2328-33.

50. Makdissi M, Schneider KJ, Feddermann-Demont N, et al. Approach to investigation and treatment of persistent symptoms following sport-related concussion: a systematic review. Br J Sports Med. 2017; 51(12):958-68.

51. McKee AC, Cantu RC, Nowinski CJ, et al. Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. J Neuropathol Exp Neurol. 2009; 68(7):709-35.

52. McKee AC, Cairns NJ, Dickson DW, et al. The first NINDS/NIBIB consensus meeting to define neuropathological criteria for the diagnosis of chronic traumatic encephalopathy. Acta neuropathol. 2016; 131(1):75-86.

53. McCrory P, Meeuwisse WH, Kutcher JS, Jordan BD, Gardner A. What is the evidence for chronic concussion-related changes in retired athletes: behavioural, pathological and clinical outcomes? Br J Sports Med. 2013; 47(5):327-30.

54. Hazrati LN, Tartaglia MC, Diamandis P, et al. Absence of chronic traumatic encephalopathy in retired football players with multiple concussions and neurological symptomatology. Frontiers in human neuroscience. 2013; 7:222.

55. Tartaglia MC, Hazrati LN, Davis KD, et al. Chronic traumatic encephalopathy and other neurodegenerative proteinopathies. Front Hum Neurosci. 2014; 8:30.

56. McCrory PR, Berkovic SF. Second impact syndrome. Neurology. 1998; 50(3):677-83.

57. Grady MF, Master CL, Gioia GA. Concussion pathophysiology: rationale for physical and cognitive rest. Pediatr Ann. 2012; 41(9):377-82.

58. White PE, Newton JD, Makdissi M, et al. Knowledge about sports-related concussion: is the message getting through to coaches and trainers? Br J Sports Med. 2014; 48(2):119-24.

59. Kroshus E, Daneshvar DH, Baugh CM, Nowinski CJ, Cantu RC. NCAA concussion education in ice hockey: an ineffective mandate. Br J Sports Med. 2014; 48(2):135-40.

60. Rivara FP, Schiff MA, Chrisman SP, Chung SK, Ellenbogen RG, Herring SA. The effect of coach education on reporting of concussions among high school athletes after passage of a concussion law. Am J Sports Med. 2014; 42(5):1197-203.

61. Carson A. Concussion, dementia and CTE: are we getting it very wrong? J Neurol Neurosurg Psychiatry. 2017; 88(6):462-64.

62. Barkhoudarian G, Hovda DA, Giza CC. The Molecular Pathophysiology of Concussive Brain Injury - an Update. Phys Med Rehabil Clin N Am. 2016; 27(2):373-93.

SportAUS.gov.au

@sportaustralia
@SportAUS
Sport Australia
Sport Australia
@SportAUS
@australian_institute_of_sport

Leverrier Street Bruce ACT 2617
PO Box 176 Belconnen ACT 2616
+61 2 6214 1111
info@sportaus.gov.au

SPORTAUS