Chapter 6

Sports Concussion: A Clinical Overview

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Abstract

Concussion is an injury risk associated with participation in collision sports. It has been identified as a research priority for many contacts and collision sports governing bodies worldwide. However, concussion remains under-researched in terms of clinical translation from both experimental models to clinical understanding, and from clinical studies to sports policy. Currently, the clinical management of concussion is largely guided by the presence or absence of symptoms with recovery indicated once all post-injury symptoms have resolved. Management of concussion includes physical and cognitive rest until acute symptoms resolve, with a graded program of exertion implemented prior to medical clearance and return-to-play. Considering the potential sequelae, the heterogeneity of symptoms, and the lack of an intervention known to prevent concussion, it is not any wonder that concussion is one of the most complex and perplexing injuries faced by medical professionals, and why making the return-to-play decision can be quite challenging. This chapter will provide an overview of the current clinical management guidelines and research literature pertaining to identification and diagnosis of injury, acute and post-acute management, and return-to-play decision-making. The traditional standard assessment process (e.g., symptom reporting, cognitive assessment, balance testing), new methods and advanced technology (e.g., ocular-motor testing, neuroimaging techniques), and biomarkers (e.g., blood plasma and serum, fluid) have led to greater insights into sports concussion and will also be briefly explored in this chapter.

Keywords: concussion, head injury, diagnosis, assessment, management, research, clinical care

1. Introduction

Modern sport is a highly competitive and lucrative commercial product, with the health of its major stakeholders, the athletes, regarded as a vital asset. The status of the athlete's cognitive health is an important factor for maintaining a high level of athletic performance and the greatest risk to an athlete's cognitive health in any contact or collision sport, is concussion [1]. In general, sports concussion is recognised as a major health concern worldwide and the management of such injuries is currently one of the most complex topics in sports medicine. Concussion has been increasingly recognised as a large burden of disease and as such has been identified as a research priority for many collision sports' governing bodies worldwide. Despite this concern, concussion is under-researched in terms of clinical translation. Currently, the clinical management of concussion is largely guided by the presence or absence of symptoms with recovery indicated once all post-injury symptoms have resolved. The international guidelines on concussion management and return-to-play recommendations are open to clinician interpretation and based primarily on expert opinion. Until more recently, the management of concussion included physical and cognitive rest until acute symptoms resolve, with a graduated program of exertion implemented prior to medical clearance and return-to-play. Now, complete rest is only considered to be beneficial in the first few days post-concussion, with relative rest and a graduated program of exertion recommended [2]. Considering the heterogeneity of concussion, the differences in presentation between individual athletes, and the lack of an intervention known to prevent concussion, it is clear why concussion is one of the most complex injuries for medical professionals to manage, and how making the return-to-play decision is challenging.

In this chapter an overview pertaining to the identification and diagnosis of injury, acute and post-acute symptom presentation and management, and return-to-activity decision-making will be provided. Specifically, key aspects including identification, diagnosis, assessment, management and return-to-play, as well as potential long-term concerns that have been associated with concussion will be reviewed.

2. Incidence rates for sport-related concussion

Obtaining reliable incidence figures for sports concussion is challenging due to methodological inconsistencies in epidemiological studies and the under-reporting of symptoms by athletes. Investigators use different data acquisition methodologies (e.g., definition of concussion, definition of injury [time loss versus no time loss], sports, sample sizes, self-report versus physician diagnosed), types of data analysis, and draw different conclusions from similar data. Variable terminology and reporting formats (e.g., injuries per 100-player exposures versus injuries per 100-player hours) also complicates comparisons across studies.

In the United States, the Centers for Disease Control and Prevention (CDCP) reported incidence rates for sports concussion of approximately 3.8 million annually [3–5]. Comprehensive collegiate injury data have been collected by the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) since 1982. The NCAA ISS reported 4.2 concussion injuries per 1000 athletic exposures, with football game injury rates at 2.2 injuries per game for a team of 50 athletes [6]. When considering all injuries sustained in NCAA competition, concussions generally account for approximately 4–10% of all injuries [7].

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3. Identification

The identification of a potential concussion is an important initial step in the management process. Removing an athlete from the potential for further harm is thought to reduce an athlete's risk of more serious or catastrophic consequences associated with a second concussion. Importantly, an athlete does not need to be 'diagnosed' with a concussion in order for them to be removed from play, the mantra *"if in doubt, sit them out"* is quiet frequently quoted and is the conservative approach. In all suspected cases of concussion, the individual should be removed from the playing field and assessed by a physician or licenced healthcare provider [8]. Many sports' governing bodies now have a low threshold for requiring athletes to be removed from play, with 'suspected concussion' providing ample concern that the athlete must be removed from play. Many sporting bodies now apply criteria (identifiable concussion signs) at the elite and semi-professional levels that are considered 'red flags' and require immediate and permanent removal from play, or immediate removal from play and assessment. At all times parents, coaches, and officials need to act in the best interest of athlete safety and welfare by taking responsibility for the recognition, removal, and referral of athletes to a medical doctor.

The Pocket Concussion Recognition Tool™ was created and updated by the Concussion in Sport Group (CISG; a group of international sports concussion experts) to help identify possible concussion. It is a quick reference and brief tool that may be used to identify suspicion of a concussion through providing a short list of visible cues (of suspected concussion), and signs and symptoms (of suspected concussion), in addition to orientation and memory questions.

3.1. Self-reported symptoms

Athletes may themselves report experiencing a single post-concussion symptom, or a cluster of symptoms that may raise suspicion that a concussion has occurred. These symptoms can be covert (not witnessed by others), whereas other signs may be overt (observed by witnesses). Where an athlete has reported any one of the symptoms presented in **Table 1** (see for common concussion symptoms), a potential concussion may have occurred and the athlete should be managed conservatively.

In the Hunter New England Local Health District's Sports Concussion Clinic, the most commonly reported symptoms between 48 and 72 hours post-concussion by the athletes are headache, pressure in the head, dizziness, a general feeling of "not quite being right," and fatigue. Anecdotally, some athletes seem to experience a constellation of symptoms while others do not, which suggests that particular athletes may be more vulnerable to particular post-concussion symptoms than others, and that some symptoms may have an association with others. Many athletes underplay their symptoms in order to return-to-play quicker; this is why objective tests sensitive to post-concussion changes are also an important adjunct to the clinical assessment and certainly to any self-reported symptom questionnaire. Objective measures will be discussed further in sections that follow.

Difficulty remembering	“Do not quite feel right”
Headache	“Pressure in the head”
Confusion	Feeling like “in a fog”
Dizziness	Blurred vision
Sensitivity to light	Sensitivity to noise
Amnesia	Feeling slowed down
Neck pain	Difficulty concentrating
Sadness	More emotional
Nervous or anxious	Fatigue or low energy
Irritability	Nausea

Table 1. Potential symptoms of concussion.

3.2. Overt signs

Overt signs may be witnessed by others such as players, match officials, coaches, managers, other team support staff, parents, and/or fans. Potential symptoms are outlined in **Table 2**. For matches that are televised, the various broadcasters’ views are often scrutinised by the expert analysts and the general public at home. The use of video for reviewing a concussion may identify signs of injury that may have been blocked from view or otherwise missed by medical staff. A number of professional contact and collision sports have recently introduced the use of sideline video review for club medical staff to help identify and manage concussions [9]. Numerous studies of video footage have been conducted in a variety of sports; for example, rugby league [10–12], rugby union [13], and Australian rules football [9, 14, 15]. Other sports, such as boxing [16], soccer [17], taekwondo [18], ice hockey [19–22], and lacrosse [23], have also reported on the use of video footage for understanding the circumstances and mechanisms of injury unique to their sports.

Video replay analysis presents a useful tool for sports medicine professionals to identify potential concussions, but it also can be difficult to interpret and presents challenges in identifying those who have sustained a concussion. In a series of work in professional rugby league [10–12, 24–26], the use of video analysis was comprehensively evaluated. Being aware of the combinations of possible concussion signs and the likelihood that various presentations result in a concussion diagnosis can provide a useful addition to sideline concussion identification.

Loss of consciousness	Blank or vacant stare
Gait ataxia or balance problems	Seizure or convulsion
Clutching or shaking head	Vomiting

Table 2. Potential signs of concussion.

3.3. Red flags

The signs and symptoms of concussion can sometimes be the same as more severe head injuries. It is recommended that more serious action should be taken in the event that there is evidence of loss of consciousness (LOC) or deteriorating conscious state, severe or increasing headache, neck pain, increasing confusion or irritability, repeated vomiting, unusual change in behaviour, or weakness or tingling/burning in the arms or legs. These signs and symptoms are considered to be *red flags*, and may be an indication of something more serious. If any of these signs/*red flags* occur, the athlete should immediately attend the nearest Accident and Emergency Centre.

3.4. Rugby union's 'Blue Card' system

World Rugby (the international governing body for the sport of rugby union) introduced a trial 'Blue Card' system across a number of nations over the past few seasons to increase efforts in the identification and management of concussion. The Blue Card initiative provides the on-field referee authority to issue a Blue Card to any player presenting signs of concussion during a match. After receiving a Blue Card, the player must leave the field of play for the remainder of the match and cannot return-to-rugby until they have completed a series of steps designed to ensure they make a full recovery before taking the field again (discussed further below).

4. Diagnosis

Despite considerable advancement in the field, there still remains an absence of a perfect diagnostic test or marker that can be used by clinicians for an immediate concussion diagnosis. The CISG Berlin Consensus Statement reports that "*at present there is no perfect diagnostic test or marker that clinicians can rely on for an immediate diagnosis of concussion*" [8]. Because a concussion is an evolving process, it is not possible to rule out a concussion when transient neurological symptoms occur [8]. In order to identify and diagnose an injury, a definition is required. There are numerous, varied definitions, but the diagnosis of concussion should always be a medical decision. The Concussion in Sport Group (CISG; Berlin, 2016) [8] recognises a sports concussion as a traumatic brain injury (TBI) induced by biomechanical forces.

The CISG Berlin, 2016 highlighted that there are a number of features that can be considered in clinically defining concussion:

- Concussion may be caused either by a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head.
- Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours.
- Concussion may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.

- Concussion results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases symptoms may be prolonged.
- The clinical signs and symptoms cannot be explained by drug, alcohol, medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc.), or other comorbidities (e.g., psychological factors or coexisting medical conditions) [8].

The recent consensus statement on concussion in sport [8] clarified that the final determination regarding sport-related concussion diagnosis and/or fitness to play is a medical decision based on clinical judgement.

Traditionally, loss of consciousness (LOC) was perceived by many professionals as a necessary sign for the diagnosis of concussion and many of the concussion grading scales reflected the duration of LOC as an important categorisation value [27]. Despite this, there was never a clear association between the duration of LOC and prognosis for a good versus a poor recovery. In traumatic brain injury more generally, the association has had greater support at the severe end of the severity spectrum. For example, duration of coma appeared to have some impact on both early functional outcomes at time of discharge and long-term level of disability (GOS scores at 5–7 years post-TBI). It was also shown to be a strong prognostic factor in predicting both functional and occupational long-term outcome [28]. The majority of studies reported an association between the duration of coma and outcome (i.e., the longer the duration of coma, the worse the outcome) [29–34]. More recently research has reported that LOC occurs in less than 10% of sports concussion at the high school, collegiate, and professional levels [35].

5. Assessment, management, and return–to-activity

A multimodal approach to the clinical assessment of concussed athletes is strongly recommended given concussion is a multi-dimensional injury. The following section provides a brief overview of some of the approaches to the clinical assessment. In addition, various modalities that are currently being used in a research context that may translate in to the clinic in the future are also briefly presented.

5.1. Clinical history

There are many underlying conditions that can mimic post-concussion symptoms, in addition to disorders and conditions that can prolong recovery. Therefore it is essential to the interpretation of the presentation and any assessment measures used in the clinical setting, to collect a comprehensive and thorough history of the athlete. In addition, it is important to ensure that the presenting symptoms are not readily explained by other neurological or medical conditions or disorders, and therefore may potentially be treatable [36]. Individuals without known developmental or health problems, no known history of concussion, also report some non-specific concussion-like symptoms in their daily lives. These symptoms can be related to any number of issues like stress; depression; sleep problems; chronic pain; drug and/or alcohol

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abuse; pituitary, thyroid, endocrine, or hormone deficiency; and vascular-related disorders (i.e., diabetes, blood pressure issues, cholesterol problems). Pre-morbid learning disorders, behavioural issues, or mental health problems are all known to be the source of a number of the post-concussion symptoms and clusters of symptoms [37]. For example, athletes with Attention Deficit Hyperactivity Disorder (ADHD) [38–42] or learning problems [39] have a greater lifetime history of concussion, and individuals with a prior history are at increased risk for a future concussion [43].

5.2. Neuropsychological assessment

Over two decades ago cognitive tests were first introduced into the sports context to assist with the assessment and management of sports concussion. This paradigm has continued to develop, from the traditional pencil paper-based measures to the computer-based platform. The CISG (Zurich, 2008) advocated for the use of empirically based measures for the management of concussion, and they identified neuropsychological testing as a "cornerstone of concussion management" [44]. The utility of cognitive testing for the assessment and management of sports concussion was first demonstrated by Barth and colleagues [45], who recognised the inherent variability in individual performance on neuropsychological measures. This resulted in a within-subjects comparison to assess for cognitive change after a concussion. Comparing athletes' baseline (i.e., pre-injury/pre-season) and post-injury performance allows for detection of relative deficits, as athletes serve as their own controls. This serial assessment model has been widely accepted by researchers and adopted by many, if not most, high school, collegiate, and professional sports programs as an effective measure of evaluating cognitive impairment [46, 47]. Conventional paper-based neuropsychological testing poses several limitations for sports medicine practitioners (e.g., the extensive time requirements for administration, scoring, and interpretation; practice effects from serial presentation of a finite number of stimuli; and floor and ceiling effects [1]). Additionally, the traditional tests were never designed nor validated for serial assessment over brief periods of time. Intent on overcoming such important clinical limitations, computerised adaptations of conventional neuropsychological tests were developed. Computer-based test batteries have been recognised as an effective concussion-screening tool because of their ability to be administered simultaneously to a large group, increased timing accuracy, and decreased practice effects [1, 48]. At this point of time there are a number of commercial computerised neuropsychological tests that are available for athletes at all levels of competition. Two of the most commonly used are ImPACT (see: https://www.impacttest.com/) and CogSport (see: https://cogstate.com/featured-batteries/cogstate-brain--injury-battery/).

5.3. Neuroimaging

Computer tomography (CT) and structural magnetic resonance imaging (MRI) are typically unhelpful in athletes suffering sports concussion beyond ruling out a more severe traumatic brain injury—in individuals where it is potentially clinically indicated. However, advanced neuroimaging techniques have increasingly been used in a research context, with speculation that some of these techniques may translate to the clinical setting. Some research in acutely concussed athletes with advanced neuroimaging techniques have demonstrated an association with metabolic and physiological changes in the brain, which correlate with post-concussive symptoms and performance on cognitive testing [49].

A recent systematic review [49] found that all of the 76 eligible studies using neuroimaging and/or electrophysiological measures reported significant effects of concussion. This likely reflects the publication bias in the literature (i.e., positive findings are more often published than negative findings), the numerous output variables of these modalities that are available to the researcher for conducting multiple comparisons (which increases the likelihood of false positive findings), or that these modalities are more sensitive to post-concussion changes. The authors note that there are many issues in attempting to bring the literature together when considering each of these modalities; for example, there are a limited number of studies for any specific marker, varying post-concussion time frames when the data was collected, an absence of any standardised acquisition protocol, or post-processing and analyses. Despite these limitations, the authors identified a number of consistent patterns within certain modalities [49].

The majority of task-functional MRI (*f*MRI) studies use a working memory paradigm, and has resulted in varied findings. Increased [50, 51] and decreased activity in task-related networks (e.g., dorsolateral prefrontal cortex) have been reported [52–55]. The variability in methodology (i.e., the type and number of stimuli used [low versus high working memory 'load']) may explain apparent discordance in hypoactivation versus hyperactivation results reported [49]. In concussed athletes, activity outside of the core task regions have also been reported in a variety of tasks [52–54]. Varying methodology is also a considerable limitation in interpreting the resting-state *f*MRI (rs-*f*MRI) literature. The default mode network (DMN) is the most extensively studied network in the concussion and rs-*f*MRI literature, and results have reported both increases and decreases in connectivity between DMN regions [56–58]. Altered functional connectivity has also been observed relative to executive function, visual, and motor networks [57–60]. Reduced cerebral blood flow (CBF) has been reported during the acute and sub-acute phases (days to weeks) post-concussion [61–63], as well as at more chronic time points (approximately 5 months) [64].

The use of diffusion tensor imaging (DTI) has increased substantially over the past few years. In 2012, a systematic review of the DTI and concussion literature [65] reported on eight studies and raised concern in the literature at the time that there was so much variability in the methodology bringing together the findings of the diverse range of work and attempting to interpret the results was challenging. A more recent DTI and concussion systematic review [49] suggested that the most consistent findings were decreased mean diffusivity and/or an increase in fractional anisotropy in white matter within 6 months post-concussion [66–70], but these findings are not universal (i.e., the opposite patterns have also been reported in other studies) [56, 62, 71]. In addition, reduced radial diffusivity has been reported [68, 72–74], but increase and decrease in axial diffusivity have been described [68, 69].

The magnetic resonance spectroscopy (MRS) and sports concussion literature was systematically reviewed in 2013 [75]. The review included 11 eligible studies. The authors of the systematic review raised concerns regarding the absence of studies examining sensitivity and specificity of MRS for concussion and the lack of longitudinal studies involving a reasonably large cohort of injured athletes. One of the greatest shortcomings, was that there was no way of determining how to interpret reliable or clinically significant changes in neurometabolites in individual athletes, because there were no studies involving test-retest reliability. Unfortunately almost 5 years later, this shortcoming has not been resolved. In addition, there is no consensus pertaining to the ideal methodology, with a variety of methods used to measure metabolite concentrations. The availability of additional metabolites, such as Glutamate (Glu) and myo-inositol (mI), might add to the sensitivity and specificity of MRS measures (as shown in severe traumatic brain injury). Therefore, adoption of short echo time methods or other means of obtaining additional biochemical measures would be advantageous [75]. In general, MRS results have found reduced N-acetylaspartate (NAA; relative to creatine and/or choline) predominately in white matter [64, 76–78], with some evidence of acute reduction with subsequent recovery by 30 days post-injury in the MRS literature [76, 79]. There is also evidence that NAA may be decreased more chronically [64, 80].

Several studies have demonstrated the effects of concussion on electroencephalogram (EEG)/quantitative-EEG (qEEG) at rest or during various task conditions. Measures from qEEG have also been shown to be altered at 8 days post-concussion relative to baseline [81], and have been associated with concussion severity, underlining the potential of electrophysiological measurements in the assessment of concussion [82].

In view of the limitations of the literature (e.g., lack of generalisability due to the inclusion of limited age ranges, male athletes focus and/or limited sample sizes, lack of appropriate control groups, lack of pre-injury enrolment and potential for measurement bias due to limited information regarding the definition/diagnosis of mTBI/SRC), the authors of the systematic review on advanced neuroimaging from the CISG Berlin, 2016 suggested that "*the level of evidence for the role of these neuroimaging and electrophysiological measures in the clinical assessment of concussion is low because the most studies reviewed were not designed to specifically assess clinical potential.*" However, the authors also suggested that "*there is a significant role for neuroimaging and electrophysiological measures in characterising the pathophysiology of concussion*" [49].

5.4. Blood and fluid biomarkers

Blood (plasma or serum), saliva, and cerebral spinal fluid (CSF) have become an increasingly utilised method for analysing various biomarkers post-concussion. Proteomics (the study of proteins) has advanced in such a manner that many researchers and clinicians are becoming increasingly interested in collecting samples from athletes. A recent systematic review [49] reported 11 studies found significant alterations in one or more of the following blood biomarkers that could potentially aid in the diagnosis of concussion: α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor peptide (AMPAR) [83], S100 calcium binding protein B (s100B) [84, 85], total tau [85], marinobufagenin [86], plasma soluble cellular prion protein [87], glial fibrillary acidic protein [87], neuron-specific enolase (NSE) [88], calpain-derived αII-spectrin N-terminal fragment (SNTF) [89], tau-C79, and metabolomics profiling [90].

5.5. Oculomotor and vestibular function

The vestibular and oculomotor systems are important in sensing angular and linear acceleration of the head and eyes, which enables a moving individual to maintain gaze on a stable target or a stationary individual to focus on a moving target. Sports concussion clinical researchers have observed vestibular and oculomotor pathway involvement in the recovery from concussion in certain athletes. As such, many concussion-screening programs now include vestibular and oculomotor testing. Vestibular and oculomotor screening may include an assessment of pursuits, saccades, vestibular ocular reflex, visual motion sensitivity, and convergence via symptom provocation and measurement of near-point convergence. Vestibular and oculomotor impairment and symptoms may be associated with worse outcomes after sports concussion, including prolonged recovery [91]. Identifying clinical profiles may help to inform better treatment and earlier intervention to reduce recovery time after concussion [92]. As such, screening for and subsequent monitoring of vestibular and oculomotor impairment and symptoms are critical to assessing and informing subsequent referral, treatment, and return-to-play. Combining these assessments with others that examine whole-body behavioural output of vestibular, visual, and somatosensory integration (e. g., postural balance) may increase sensitivity and greatly improve concussion management. McDevitt and colleagues [93] reported that using a condensed set of balance, and vestibular and oculomotor tests resulted in the greatest accuracy for detecting concussion.

5.6. Dual-tasks

Not only has a multimodal approach to the assessment of athletes suffering concussion been endorsed, but the assessment of multiple domains simultaneously has been considered to be more sensitive to post-concussion sequelae as a means of stressing the system. As noted above, *f*MRI studies using dual-task paradigms have demonstrated recruitment of many neuroanatomical areas outside of the typical structures known to service certain cognitive functions. In addition, the introduction of a cognitive task while walking has been shown to distinguish concussed from non-concussed athletes and may be used as a paradigm for monitoring recovery post-concussion [94–96].

5.7. Rest

Many of the original guidelines and consensus and agreement statements for managing sports concussion have recommended that athletes rest until they have made a complete recovery (i.e., symptom free) [44, 97–99]. As such, rest has been almost universally recommended as part of the 'treatment' process [100, 101]. However, 'rest' is a misnomer; it is not possible for an athlete to be at complete rest (both physically and cognitively), so it is more accurate to label the recommendation as 'relative rest.' Rest has been assumed to ease discomfort during the acute recovery period by mitigating post-concussion symptoms and/or that rest may promote recovery by minimising brain energy demands following concussion [102]. The most recent systematic review on rest and treatment conducted by a number of leading clinicians and researchers from the Concussion in Sport Group [102] and the consensus statement [8] reported that "*there is currently insufficient evidence that prescribing complete rest achieves these objectives. After a brief period of rest during the acute phase* (*24–48 hours*) *after injury, patients can be encouraged to become gradually and progressively more active while staying below their cognitive and physical symptom-exacerbation thresholds* (*i.e., activity level should not bring on or worsen their symptoms*)." Refraining from engaging in vigorous exertion while an athlete is recovering is

Stage	Aim	Activity	Goal of each step
1	Symptom-limited activity	Daily activities that do not provoke symptoms	Gradual reintroduction of work/ school activities
2	Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training	Increased heart rate
3	Sport-specific exercise	Running or skating drills. No head impact activities	Add movement
4	Non-contact training drills	Harder training drills, for example, passing drills. May start progressive resistance training	Exercise, coordination and increased thinking
5	Full contact training	Following medical clearance, participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6	Return-to-sport	Normal game play	

Note: This table has been modified from the CISG Consensus Statement (Berlin, 2016) [8]. An initial period of 24–48 hours of both relative physical rest and cognitive rest is recommended before commencing the GRTP process.

Table 3. Graded return-to-play (GRTP).

recommended, however, the extent of exercise and duration of rest, or relative rest, is not yet well defined and requires further study [102].

5.8. The graduated return–to-play (GRTP)

The graduated return-to-play (GRTP) is a six-stage program of increased intensity that is completed over a minimum of 6 days (i.e., each stage should take at least 24 hours). If an athlete who is engaged in the GRTP process experiences a return of any post-concussion symptoms, then the athlete is to return to the previous step. In the 2016 consensus statement, the CISG added clarification regarding athletes who experience persisting symptoms (i.e., symptoms lasting more than 10–14 days in adults or more than 1 month in children), stating that the athlete should be referred to a healthcare professional who is an expert in the management of concussion. The CISG also clarified that resistance training should be added only in the later stages (stage 3 or 4 at the earliest). A summary of the GRTP recommendations for each of these stages is presented in **Table 3**.

6. Potential longer term concerns

Understanding the possible long-term effects of concussions sustained during a career in contact sports has become an area of considerable interest. Repetitive neurotrauma sustained during a career in boxing has been reported to be associated with chronic brain damage in some former athletes since the 1920s [103], but it has only been associated with former National Football League (NFL) players more recently. A review on this issue conducted by Manley and colleagues [104] reported that there is emerging evidence that some retired NFL players have mild cognitive impairment [105, 106], neuroimaging abnormalities [107, 108], and differences in brain metabolism [109] disproportionate to their age. Autopsy cases of former professional football players (among others also in the sample) have revealed diverse forms of neuropathology, including immunoreactivity for hyperphosphorylated tau (p-tau) in a specific pattern (e.g., irregularly distributed in depths of cortical sulci) in which p-tau is not expected to be present through normal ageing or in association with frontotemporal dementia or Alzheimer's disease [110]. For a comprehensive review of this literature see Manley et al. [104], Iverson et al. [111], Gardner et al. [112], Randolph et al. [113], and McCrory et al. [114].

In view of the speculation pertaining to the possible consequences concussion may have on the health of some athletes later in their life, current athletes often raise concerns regarding the issue of retirement. In the clinical setting, athletes are regularly presenting following a single, or in some instances multiple, concussion history with information fuelled by the media's speculative presentation of this topic, concerned that they are at high-risk of long-term issues. It is not possible at the current time to predict or diagnose CTE in-life. The diagnosis is made through neuropathological examination on autopsy. There are a number of research groups around the world currently conducting prospective, longitudinal studies to further understand this disease, but it will take a generation of players (or longer) to fully comprehend the extent of the issue, and the factors that place some athletes at risk versus others who appear to be resilient. Providing athletes with information to empower them to make a well-informed decision regarding retirement is a complex issue. Currently no evidenced-based, scientifically validated guidelines for forming the basis of such a decision exist [115]. In the absence of strong empirical evidence to support recommendations, clinical decision-making must be individualised and should involve a multidisciplinary team of experts in concussion and traumatic brain injury [36, 115]. Involving a multidisciplinary team enables a thorough investigation of all domains, and where clinical indications are present, it enables all possible differential diagnoses to be appropriately considered [36].

7. Conclusion

Sports concussion remains one of the most challenging conditions to diagnose, assess, and manage for the sports medicine professional. The acute effects, but also the potential long-term issues, need to be considered when managing athletes through a safe return-to-activity. A comprehensive clinical assessment of a concussed athlete involves a multimodal approach, but it is critical that the clinician understands what each tool being used is measuring and how to interpret the results. For some measures a pre-injury, post-injury paradigm is appropriate for interpreting the results, but for others post-injury performances can be interpreted with the use of normative data. A conservative approach to the return-to-play is recommended, and the final return-to-activity decision should be made by a medical professional.

8. Links to further material for reviewing clinically related subject matter on sports concussion

The following links provide further detail pertaining to the information presented in this chapter:

World Rugby (WR): http://playerwelfare.worldrugby.org/concussion

National Collegiate Athletics Association (NCAA): http://www.ncaa.org/sport-science-institute/concussion

Consensus Statement on Concussion in Sport—the 5th International Conference on Concussion in Sport (Berlin, 2016): https://bjsm.bmj.com/content/bjsports/early/2017/04/26/bjsports-2017-097699.full.pdf

Sports Concussion Assessment Tool—Fifth Edition: http://dx.doi.org/10.1136/bjsports-2017-097506SCAT5

The Pocket Concussion Recognition Tool™: http://bjsm.bmj.com/content/bjsports/47/5/267.full.pdf

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