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Sport-related concussion in children: a comprehensive review of current evidence

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Abstract

Background: Sport-related concussion (SRC) is a mild traumatic brain injury caused by direct or indirect forces to the head and represents a significant proportion of paediatric sports injuries.

Aim: To provide clinicians with concise, evidence-based guidance for accurate assessment and management of SRC in paediatric population and highlight areas requiring further research.

Methods: A narrative review of PubMed and Google Scholar included original studies, reviews, meta-analyses, and guidelines addressing epidemiology, risk factors, diagnosis, and management.

Results: SRC in children presents with heterogeneous symptoms, often without loss of consciousness. Common features include headache, dizziness, confusion, amnesia, visual disturbances, affective liability, and learning difficulties. Assessment can be supported by tools such as CRT6 for early recognition and SCAT6, Child SCAT6, SCOAT6, and Child SCOAT6 for structured cognitive and neurological evaluation. Protective equipment, including helmets and mouthguards, may reduce concussion risk in some sports, though evidence is mixed.

Management emphasizes timely assessment, avoidance of prolonged rest, and a gradual return-to-school and activity plan, with most children returning to school within 10 days.
Conclusions: SRC remains a major concern in paediatric population. Early recognition, structured assessment, and comprehensive prevention strategies are essential to improving outcomes.

Key words: concussion, sport-related injury, contact sports, brain injury, paediatrics, assessment tools

1. Introduction

According to the definition, a concussion is a transient disturbance of brain function induced by a trauma (Jackson WT et al., 2019). It accounts for 90% of traumatic brain injury cases (Plummer CJ 2nd et al., 2024). In 2021, Lefevre-Dognin C et al. highlighted that concussion remains a matter of controversy, both in terms of definition and terminology. The World Health Organization Centre Task Force on Mild Trauma Brain Injury identified substantial heterogeneity in the international literature, documenting 38 distinct definitions of concussion along with several terms (ex. mild traumatic brain injury, minor traumatic brain injury) used interchangeably to describe this condition (Carroll LJ et al., 2004). However, the literature most commonly characterises a concussion using three criteria: an initial Glasgow Coma Scale (GCS) score between 13-15, a post-traumatic amnesia with duration ranging from none to 24 hours, and a loss on consciousness lasting from none to 30 minutes (Levin HS et al., 2015). Importantly, GCS assessment presents challenges when applied to infants and younger children (Maas AI et al., 2011). Sport-related concussion (SRC), defined as a mild traumatic brain injury caused by a direct blow to the head or an impulse force transmitted to the head during sport activity (Echemendia RJ et al., 2023), makes up nearly 10% of all high school athletic injuries (Provance AJ et al., 2016). Guskiewicz KM et al. in 2000 summarized the epidemiology of SRC, showing that children participating in American football are at the highest risk of SRC - during a school

year, approximately one in five young athletes in this sport sustain such an injury. Elevated rates of SRC are also observed in football, rugby, hockey, and, to a lesser extent, basketball. Notably, Halstead ME et al. (2018) noticed that epidemiological data consistently indicate that girls experience SRC more frequently than boys, however underlying mechanisms for this pattern remain unclear.

2. Research materials and methods

2.1. Methodology

This literature review was conducted using a narrative synthesis approach to integrate heterogeneous evidence derived from diverse study designs. A comprehensive and structured search of two major scientific databases (PubMed and Google Scholar) was performed. Search terms included "sport-related concussion," "concussion in children," "concussion assessment instruments," and "contact sports injury." The review incorporated peer-reviewed original research articles, systematic reviews, meta-analyses, and international guidelines relevant to SRC. All records underwent an initial title and abstract screening, followed by full-text evaluation. Studies were excluded if they focused on contact sport injuries involving body regions other than the head and neck. The included literature was subsequently analysed across four primary domains: the epidemiology and incidence of SRC in children, clinical symptomatology, major risk factors, and contemporary SRC assessment tools. Data extracted from the selected studies were systematically organized, compared, and critically appraised. The findings were synthesized into an integrated narrative overview, with attention to areas of established consensus, ongoing scientific debate, and persistent gaps within the current evidence base. The primary objective of this review is to provide clinicians with clear, evidence-based information to support accurate assessment and appropriate management of sport-related concussion in the paediatric population. By consolidating current knowledge, the review aims to enhance early recognition, guide clinical decision-making, and promote safe return-to-play practices among children and adolescents.

2.2. AI.

Artificial intelligence-based language tools were employed during manuscript preparation to enhance grammatical accuracy, improve linguistic clarity, and ensure overall coherence of the text. These tools were used exclusively for stylistic refinement and did not influence data interpretation or conclusions drawn. Their use aimed to improve readability and communicative precision, thereby enhancing the overall quality and professionalism of the final manuscript.

3. Research results

3.1. Clinical features

The clinical presentation of SRC is highly heterogenous. Notably, most concussive events occur without loss of consciousness or neurological deficits (Halstead ME et al., 2018). Confusion and amnesia are considered hallmark features, yet affected individuals may exhibit a broad range of additional post concussive symptoms, including headache, dizziness, visual disturbances, sleep disturbances, disorientation, irritability or affective lability, disturbed concentration or memory, fatigue or sensitivity to noise or light (McCrory P et al., 2009). These symptoms can significantly interfere with academic functioning, often contributing to learning difficulties and reduced classroom performance. Provance AJ et al. (2016) underlined that contemporary diagnostic approaches no longer rely on loss of consciousness as a predictor of severity of SRC. Instead, it is now understood in relation to the mechanism of head trauma, the child's functional impairment, and the duration of post concussive symptoms. Importantly, the symptom profile varies substantially across individuals, both in terms of initial onset and subsequent evolution, underscoring the need for individualized assessment and monitoring.

3.2. Diagnostic tools

3.2.1. Concussion Recognition Tool 6 (CRT6)

A number of assessment instruments are available to facilitate the recognition of SRC in children and adolescents. Echemendia RJ et al. (2023) introduced the CRT6, which is designed to aid in the identification of potential SRC in children, adolescents, and adults. The CRT6 was developed to enable consistent recognition of suspected SRC across all age groups and levels of athletic participation - from amateur to professional - while accounting for variations in educational background and cultural context. The CRT6 comprises four primary components: red flags indicating the need for urgent medical attention, visible or observable signs suggestive of concussion, self-reported concussion symptoms, and indicators of athlete awareness and orientation (Baioccato V et al., 2025). The red flags section encompasses clinical signs such as loss of consciousness, seizure activity, recurrent vomiting, severe or progressively worsening headache, focal neurological symptoms or numbness of the extremities, cervical spine pain, and visual deterioration. The presence of any of these findings indicates the need for immediate emergency medical evaluation. It is essential to emphasize, however, that the CRT6 is not a diagnostic instrument. Its purpose is to assist in the early identification of a possible concussion and to support prompt removal of the individual from physical activity.

Additionally, the CRT6 is intended for use by individuals without formal medical training such as teachers and coaches.

3.2.2. Sport Concussion Assessment Tool (SCAT)

The 2nd International Symposium on Concussion in Sport (2004) introduced the first standardized assessment instrument designed for use by clinicians to assist in the diagnosis of suspected concussion and to support patient education (McCrory P et al., 2005). The Sport Concussion Assessment Tool (SCAT) was developed by integrating several pre-existing measures, resulting in a comprehensive yet user-friendly clinical tool.

The SCAT has been formally endorsed by the Fédération Internationale de Football Association (FIFA), the International Ice Hockey Federation (IIHF), and the International Olympic Committee Medical Commission (IOC). The SCAT form includes the Post-Concussion Symptom Scale, which documents a range of concussion-related symptoms and their severity, a list of red flag features such as loss of consciousness, and structured neurological and cognitive assessments. It also provides guidance regarding delayed symptoms that may emerge within 24-48 hours following the injury. Echemendia RJ et al. (2023) presented a detailed description of current, updated sixth edition of the SCAT - SCAT6. The SCAT6 includes a revised “Recognize and Remove” section designed to assist clinicians in the accurate identification and immediate management of SRC. The SCAT6 incorporates a comprehensive neurological screening battery, including coordination testing (e.g., finger-to-nose), Maddocks questions for orientation and amnesia assessment (Maddocks DL et al., 1995), a symptom severity scale, the Standardized Assessment of Concussion for acute cognitive evaluation (McCrea M et al., 2001), and balance testing using the Modified Balance Error Scoring System (Guskiewicz KM et al., 2003) and Tandem Gait assessment (Oldham JR et al., 2021). The SCAT6 is intended for adolescents over 12 years of age and adults. A parallel instrument, the Child SCAT6, is available for evaluating SRC in children aged 8-12 years. The Child SCAT6 retains a structure comparable to the SCAT6 but incorporates developmentally appropriate instructions, as well as cognitive and memory tasks specifically adapted for paediatric populations (Davis GA et al., 2023). The SCAT6 demonstrates its highest diagnostic utility within the first 7 days post-injury, with a notable decline in clinical sensitivity after approximately 72 hours. Beyond 7 days following the injury, assessment of persistent or evolving symptoms should be performed using the SCOAT6 or Child SCOAT6, depending on the patient’s age.

3.2.3 Sport Concussion Office Assessment Tool (SCOAT)

The 6th International Conference on Concussion in Sport developed the SCOAT6, a multimodal assessment instrument intended for the clinical evaluation of athletes during the post-concussion period (Patricios JS et al., 2023). The SCOAT6 is derived from the SCAT but is specifically designed for use by healthcare professionals in a controlled clinical setting, typically beginning 72 hours after injury - at which point the utility of the SCAT begins to decline. As with the SCAT, the SCOAT6 is formally endorsed by FIFA, the IOC, the IIHF, the Fédération Internationale de l'Automobile and World Rugby. The SCOAT6 uses a color-coding system: blue sections are completed only during the initial assessment, green sections represent the recommended core components of the evaluation, and orange sections are optional. The blue section includes details regarding the current injury, prior head injuries, and any history of neurological, psychiatric, or learning disorders. The green section encompasses a review of current medications, symptom assessment, digit span backwards, recitation of months in reverse order, and evaluation of the cervical spine and balance. The orange section addresses family history of neurological conditions, verbal cognitive testing, and screening for depression, anxiety, and sleep disturbances. As with the SCAT6, the SCOAT6 is intended for use in adolescents (older than 12 years) and adults. A corresponding Child SCOAT6 is available for children aged 8 to 12 years (Davis GA et al., 2023).

3.4 Prevention strategies

The effectiveness of protective equipment in preventing SRC has been reported with varying results. Several studies have demonstrated a benefit. Delaney JS et al. (2008) and McGuine T et al. (2020) reported that the use of headgear was associated with reduced SRC incidence. Similar findings were documented by Gamble ASD et al. (2021) in ice hockey and by Greenhill DA et al. (2016) in American football, supporting the role of properly fitted helmets and headgear in mitigating concussion risk. The use of mouthguards has also shown notable protective value. Chisholm DA et al. (2020) found that mouthguard use significantly contributed to reducing concussion occurrence among ice hockey players. In contrast, Kriz PK et al. (2012) reported that protective eyewear did not lower the rate of SRC among high school field hockey players, highlighting that not all equipment types confer equal protection against concussive injuries. Despite these variable findings, the consistent and appropriate use of protective equipment remains an essential component of concussion-prevention strategies across numerous sports. While no device can eliminate the risk of concussion, well-designed

and properly fitted equipment can lessen the magnitude of impact forces, reduce the severity of head injuries, and help prevent associated complications.

3.5 Management

When a head injury occurs during a child's participation in sport - whether in school-based activities, recreational play, or competition - the supervising adult has a critical responsibility to determine whether immediate medical evaluation is warranted. It is important to recognise that children may not reliably report their symptoms, often due to fear of peer reactions or reluctance to discontinue play. Consequently, close monitoring is essential, particularly for younger children engaged in contact or collision sports. For an initial on-field or sideline assessment, the CRT6 can be employed, as it is specifically designed for use by individuals without for medical training. However, while CRT6 aids in identifying potential signs of concussion, it should not be interpreted as a diagnostic instrument, any concerning findings should be prompt timely referral to a qualified healthcare provider for comprehensive evaluation. If medical attention is required, the initial evaluation should be performed by a primary care physician or a paediatric neurologist experienced in concussion care. The clinician may incorporate structures assessment tools such as the SCAT6 to assist in the clinical evaluation, while remembering that such instruments complement but do not replace a comprehensive clinical assessment (Echemendia RJ et al., 2023). The examination should explicitly document level of consciousness, orientation, and any acute changes in behaviour or affect, and must include targeted screening for somatic symptoms (headache, visual disturbances, emesis, vestibular symptoms). The clinician should also assess cognitive function, balance, and functional capacity (Dawson J et al., 2021). Determination of injury severity must guide disposition: children exhibiting neurologic deterioration, persistent or progressive symptoms, focal neurological symptoms, signs of skull fracture, or other clinical red flags should be referred promptly to an emergency department for urgent imaging and specialists' consultation. For less severe presentations, close outpatient follow-up in a concussion clinic or with the child's primary care provider is appropriate, with clear written instructions for caregivers regarding symptoms monitoring, return-to-school and return-to-sport precautions, and indications for re-evaluation (Reed N et al., 2019). Routine decisions about neuroimaging and additional investigations should be individualised, based on the mechanism of injury, clinical findings, and presence of risk factors for intracranial injury, however it is not required to diagnose a concussion (Osmond MH et al., 2018).

Many authors agree that strict rest beyond 24 to 48 hours following a concussion should be no longer advised, as it adds no benefit over the usual care and may prolong recovery (Thomas DG at al., 2015; DeMatteo C et al., 2020). Return-to-school (RTS) time, as well as return-to-activity (RTA) remains a subject of controversies. Consensus Statement on Concussion in Sport established during 5th International Conference on Concussion in Sport in Berlin (McCrory P et al., 2017) recommends using a "graduated strategy" consisting of four main domains:

Stage 1: short (5-15 minutes) periods of daily activities not worsening the symptoms (ex. reading, using a smartphone);

Stage 2: introducing learning activities in home - doing homework (to improve tolerance to cognitive work);

Stage 3: part-time return to school starting with few lessons a day, slowly increase as tolerated;

Stage 4: full time return.

In a meta-analysis, Putukian M et al. (2023) determined that the RTS time is relatively short, with an average of 8.3 days. The study found that 93% of the young athletes were able to resume full school activity within 10 days. DeMatteo C et al. (2020) underlined that the available data on RTS and RTA time in paediatric population is limited and inconclusive and more rigorous studies are needed to clearly establish the optimal timing for RTS in children.

4. Discussion

The diagnosis and management of SRC in children remain complex, requiring timely decision-making and coordinated communication to ensure safety and well-being. Provance AJ et al. (2016) highlighted that SRC in children and adolescents poses challenges for healthcare providers, as decisions regarding return to activity, academic demands, and the risk of second impact syndrome must be carefully balanced. Determining when a young athlete needs urgent emergency assessment, referral to a specialized clinic, or consultation with additional specialists can be difficult. Beyond the medical setting, subtle, variable, or delayed symptoms can leave parents, teachers, and coaches uncertain about the child's condition, emphasising the need for practical tools like the CRT6, SCAT6, and Child SCAT6 to aid initial suspicion and diagnosis. Deciding RTS time is a key component of recovery. While brief cognitive rest (1-2 days) is commonly recommended, systematic reviews suggest that prolonged inactivity may delay recovery (DeMatteo C et al., 2020). Current guidelines advocate for a gradual, symptom-limited return to school and activity, tailored to the child's age, symptoms, and risk profile (McCrory P et al., 2017; Davis GA et al., 2024). Overly extended time away from school can have negative psychosocial and academic consequences (Iverson GL et al., 2016). Emerging

consensus supports early, symptom-limited physical activity combined with reduced, but not eliminated, cognitive load and individualized RTS planning.

What is important, research on paediatric SRC is disproportionately focused on older children and adolescents (13-18 years), with younger children (5-12 years) underrepresented, particularly in the acute stage (<72 hours). Davis GA et al. (2024) note only five studies evaluating the Child SCAT in this age group, none of which focused on sport-related concussion. This highlights the need for research validating age-specific diagnostic tools and management strategies to ensure timely and accurate care for younger children.

From a policy and clinical perspective, schools play a critical role in concussion management. Concussion management teams, proactive communication with healthcare providers, and structured accommodation plans-including mandatory protective equipment—are essential. Interdisciplinary collaboration among healthcare professionals, educators, parents, and athletic staff is key to safe recovery and academic continuity.

Future research should focus on well-designed interventional studies testing RTS strategies, development of paediatric-specific outcome tools, expanding knowledge about underrepresented age groups and long-term follow-up to assess academic and psychosocial outcomes. In sum, a conservative, symptom-guided, and individualised approach supported by coordinated school-healthcare partnerships is essential to optimise both clinical recovery and academic reintegration.

5. Conclusions

SRC remains a significant health concern within the paediatric population, particularly among children engaged in contact and collision sports. Although a universally accepted definition of concussion is lacking, its contribution to head injury incidence in children is consistently high. The clinical presentation of SRC is heterogeneous, encompassing somatic, cognitive, emotional, and vestibuloocular symptoms that may substantially impair overall functioning, academic performance, and neurocognitive abilities. A range of validated assessment tools has been developed to facilitate accurate identification and management of SRC in children. The CRT6 supports recognition and immediate removal from play by non-medical personnel, while healthcare professionals may utilise more comprehensive instruments, including the SCAT6, Child SCAT6, SCOAT6, and Child SCOAT6. These tools are structured to guide clinicians through a systematic evaluation of symptoms, cognition, balance, and neurological function, thereby supporting appropriate diagnosis and evidence-based management. Preventive strategies, including the use of protective equipment such as headgear, may offer

limited but potentially meaningful reductions in SRC risk among physically active children and adolescents. However, equipment alone is insufficient, and a multifaceted approach, incorporating education, rule enforcement, and proper technique, remains essential in mitigating concussion incidence in youth sports. Further large-scale studies are required to establish consistent, evidence-based guidelines for the diagnosis and management of SRC in the paediatric population.

Disclosure

Author's Contribution:

Conceptualization and Methodology: MM, MS, KW, WK, KK, AM, MSz, AH, MJ, MP

Investigation; MM, MS, KW, WK, KK, AM, MSz, AH, MJ, MP

Resources: Not applicable.

Writing - rough preparation: MM, MS, KW, WK, KK, AM, MSz, AH, MJ, MP

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