American Medical Society for Sports Medicine Position Statement on Concussion in Sport

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Abstract: Sport-related concussion (SRC) is a common injury in recreational and organized sport. Over the past 30 years, there has been significant progress in our scientific understanding of SRC, which in turn has driven the development of clinical guidelines for diagnosis, assessment, and management of SRC. In addition to a growing need for knowledgeable health care professionals to provide evidence-based care for athletes with SRC, media attention and legislation have created awareness and, in some cases, fear about many issues and unknowns surrounding SRC. The American Medical Society for Sports Medicine formed a writing group to review the existing literature on SRC, update its previous position statement,[1] and address current evidence and knowledge gaps regarding SRC. The absence of definitive outcomes-based data is challenging and requires relying on the best available evidence integrated with clinical experience and patient values. This statement reviews the definition, pathophysiology, and epidemiology of SRC, the diagnosis and management of both acute and persistent concussion symptoms, the short- and long-term risks of SRC and repetitive head impact exposure, SRC prevention strategies, and potential future directions for SRC research. The American Medical Society for Sports Medicine is committed to best clinical practices, evidence-based research, and educational initiatives that positively impact the health and safety of athletes.

Key Words: concussion, sport, athlete, youth

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BACKGROUND AND PURPOSE

The American Medical Society for Sports Medicine (AMSSM) represents more than 3800 sports medicine physicians who have completed specialty training in sports medicine after a residency program in family medicine, internal medicine, pediatrics, emergency medicine, or physical medicine and rehabilitation, many of whom have extensive expertise in concussion evaluation and management including serving as sideline team physicians at all levels of sport. Sport-related concussion (SRC) is an important topic for sports medicine physicians, and there is a rapidly expanding knowledge base in this area. Sport-related concussion has become a focus of both public concern and media attention. The purpose of this statement was to provide a narrative review of the existing literature and best practices to assist health care providers with the evaluation and management of SRC, and to establish the level of evidence, current knowledge gaps, and areas requiring additional research. The first AMSSM position statement on SRC was published in 2013, and this is an update to that statement.[1]

WRITING GROUP SELECTION AND PROCESS

The AMSSM Board of Directors appointed the chair (K.G.H.) to assemble a writing group that was carefully selected to include a balanced panel of sports medicine physicians experienced in sideline and office evaluation and management of SRC, actively engaged in SRC research, and with demonstrated leadership in the area of SRC. Select subspecialty experts were invited to provide diverse viewpoints.

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TABLE 1. Strength of Recommendation Taxonomy

Strength of Recommendation	Basis for Recommendation
A	Consistent, good-quality patient-oriented evidence
B	Inconsistent or limited-quality patient-oriented evidence
C	Consensus, disease-oriented evidence, usual practice, expert opinion, or case series for studies of diagnosis, treatment, prevention, or screening

Select members of the board, the publications committee, and the writing group were surveyed to determine topics of interest for the statement and generate an initial outline. Systematic reviews were used as primary literature sources when available. The writing group engaged in conference calls, review of the literature, and written communication before an in-person meeting in Chicago, IL, on February 9–10, 2018. There were additional conference calls, emails, and iterations of the outline and manuscript to produce the final document. This document uses the Strength of Recommendation Taxonomy to grade level of evidence[2] (Table 1).

WHO SHOULD EVALUATE AND MANAGE SPORT-RELATED CONCUSSION?

The clinical care, including assessment and management, of athletes with SRC is ideally performed by health care professionals with appropriate training and experience. Sports medicine physicians are uniquely trained to provide care along the continuum of SRC from the acute evaluation through return to learn and return to sport, and to manage both complications of SRC and coexisting medical issues. Although most of the SRCs resolve within 1 to 4 weeks, athletes with complicated or prolonged recovery may require a multidisciplinary team with specific expertise across the scope of concussion management.

DEFINITION OF CONCUSSION

Concussion is defined as a traumatically induced transient disturbance of brain function that involves a complex pathophysiologic process.[1] Concussion is a subset of mild traumatic brain injury, which is classified based on acute injury characteristics at the less severe end of the brain injury spectrum.[1] The clinical signs and symptoms of concussion cannot be otherwise explained by drug, alcohol, medication use, other injuries (such as cervical injuries or peripheral vestibular dysfunction), or other comorbidities (psychological or medical conditions).[3,4]

PATHOPHYSIOLOGY

The pathophysiology of concussion is not completely understood but has been characterized as force delivered to the brain causing disruptive stretching of neuronal cell membranes and axons resulting in a complex cascade of ionic, metabolic, and pathophysiologic events.[5] Current understanding of the pathophysiology of concussion is primarily based on animal models that have limitations when extrapolated to humans. It seems that stress applied to the neuron causes changes in intracellular ion concentrations, indiscriminate release of neurotransmitters, mitochondrial dysfunction leading to the production of reactive oxygen species, and increased utilization of glucose to restore sodium and potassium balance.[5] The increased glucose utilization combined with the injury-related decrease in resting cerebral blood flow creates an energy mismatch.[6,7] Inflammatory cell activation, axonal degeneration, and altered plasticity may occur in the subacute and chronic stages of concussion. Animal and human studies support the concept of increased brain vulnerability after an initial injury to a second brain tissue insult that can result in worsening cellular metabolic changes and more significant deficits.[8–10]

EPIDEMIOLOGY

Concussion is common in organized scholastic and nonscholastic sport, nontraditional recreational activity (eg, extreme, individual), and routine activities of daily living. A recent report using data from emergency department visits, office visits, and a high school injury surveillance system estimated 1.0 to 1.8 million SRCs per year in the age range of 0 to 18 years and a subset of about 400 000 SRCs in high school athletes.[11] Although this estimate is likely accurate, determining actual sport- or activity-based concussion rates is difficult.

Injury surveillance systems in the United States primarily study a small sample of organized college or high school sports to estimate concussion rates. Numbers are limited or not available for recreational or club sports or for activities such as bicycling, skiing, snowboarding, skateboarding, and the fighting arts or for youth/early adolescent athletes. An estimate of risk requires a numerator (the number of concussions) and a denominator (the amount of time participating in the activity). Numerators may vary based on underreporting or overreporting of concussion or inaccurate diagnosis while denominators are difficult to accurately track. Most current estimates use "athlete-exposures" as the denominator, defined as an athlete participating in one practice or game; however, estimates of risk may change dramatically if actual hours of participation are tracked or if a seasonal or annual risk of concussion is determined. Seasonal or annual risk may be a more readily understood concept. It is estimated that more than 50% of concussions in high school–aged youth are not related to organized sports, and only 20% are related to organized school team sports.[11] Between 2% and 15% of athletes participating in organized sports will suffer a concussion during one season[12–29] (Table 2).

DIAGNOSIS OF CONCUSSION

The diagnosis of concussion is challenging and based on clinical assessment. Concussion diagnosis is complicated by a lack of validated, objective diagnostic tests, a reliance on self-reported symptoms, and confounding symptoms caused by other common conditions. Nonspecific symptoms such as headaches, mood changes, "fogginess," dizziness, visual changes, fatigue, and neck pain are all associated with concussion but can also originate from other etiologies. In addition, symptoms may be delayed in onset or initially unrecognized by the athlete. Concussion remains a clinical diagnosis made by carefully synthesizing history and physical examination findings as the injury evolves.

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TABLE 2. Seasonal Risk of Concussion in Sports

Author	Type of Athletes	Years of Study	No. of Seasons	Total No. of Athletes	Concussed	Concussed per Player/Season (%)
Football						
Barr[15]	High school and college football	1997-1999	2	1313	50	1.9
McCrea[18]	High school and college football	1998-1999	2	1325	63	2.4
McCrea[17]	High school and college football	1999-2001	3	2385	91	3.8
McCrea[19]	College football	1999-2001	2		94	3.9
Barr[16]	High school and college football	2008-2009	2	823	59	7.2
Seidman[24]	High school football	2013	1	343	9	2.6
Dompier[25]	Football	2012-2013	2	20 479	1178	5.8
	Youth football	2012-2013	2	4092	136	3.3
	High school football	2012-2013	2	11 957	767	6.4
	College football	2012-2013	2	4430	275	6.7
	College football	2011-2014	4	9718	518	5.3
Houck[26]	College football	2006-2015	9	945*	118	12.5
Bretzin[14]	High school football	2015-2016	1	39 520	1530	3.9
Total football				67 133	3192	4.8
All sports						
Galetta[27]	Football, sprint football, men's and women's soccer, and basketball	2010-2011	1	219	10	4.6
Marindes[20]	College athletes	2011-2012	1	217	30	13.8
Galetta[21]	Ice hockey/lacrosse youth and college		1	332	12	3.6
Leong[28]	Football, men's and women's basketball	2012-2013	1	127	11	8.7
Putukian[22]	College athletes	2011-2012	1	263	32	12.2
Chin[23]	High school and college athletes	2012-2014	3	2018	166	2.7
Kerr[12]	NCAA athletes	2011-2014	4	32 156	1410	4.4
	Men's baseball	2011-2014	4	1757	13	0.7
	Men's basketball	2011-2014	4	1889	74	3.9
	College football	2011-2014	4	9718	518	5.3
	Men's ice hockey	2011-2014	4	3689	253	6.9
	Men's lacrosse	2011-2014	4	1768	44	2.5
	Men's soccer	2011-2014	4	1810	29	1.6
	Men's wrestling	2011-2014	4	821	65	7.9
	Women's basketball	2011-2014	4	1690	90	5.3
	Women's ice hockey	2011-2014	4	1301	94	7.2
	Women's lacrosse	2011-2014	4	1522	49	3.2
	Women's softball	2011-2014	4	1569	38	2.4
	Women's soccer	2011-2014	4	2831	93	3.3
	Women's volleyball	2011-2014	4	1791	50	2.8
Dhawan[29]	Youth hockey		1	141	20	14.2
Tsushima[13]	Athletes grade 8-12	2013-2014	1	10 334	1250	12.1
Bretzin[14]	High school athletes in 15 sports	2015-2016	1	193 757	3352	1.7
Total				239 564	6293	2.6

** Total number of athletes estimated using 105 athletes per year on football roster.*

Preseason

Preparation for the care of athletes begins before any practice or competition with a preparticipation physical evaluation (PPE) and the development and practice of an emergency action plan.[30] The PPE should include past concussion or other traumatic brain injury history (number, recovery course, and time between injuries) as well as the presence of other premorbid/comorbid conditions, or modifiers, which may make the diagnosis or management of concussion more difficult, including a history of learning disorder, attention deficit disorder, motion sickness or sensitivity, mood disorders or a personal or family history of migraine headache disorder, and information on current medication use.

Several organizations recommend baseline evaluation before sports participation to assist with diagnosis and return-to-play decisions in an athlete with a suspected concussion.[3,31,32] Several factors require consideration before implementing any test into an evaluation program for baseline or postinjury purposes. There is considerable normal variation in test performance with repeat testing in noninjured athletes[23,33,34]; some tests are associated with a cost, and in younger athletes with rapidly developing brain function, both

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the ideal interval to repeat baseline testing and age-related differences in test performance are unknown. Common baseline evaluations include the battery of standard sideline assessment tests found in the Sports Concussion Assessment Tool 5th edition (SCAT 5) and/or computerized proprietary neuropsychological tests such as Cogsport, Automated Neuropsychological Assessment Metrics, Central Nervous System Vital Signs, or the Immediate Postconcussion Assessment and Cognitive Testing. An initial baseline evaluation including a symptom checklist, cognitive evaluation, and balance assessment has been considered "best practice" for all athletes by the National Collegiate Athletic Association. However, repeat annual baseline testing after an initial baseline evaluation is no longer recommended for collegiate athletes.[31] Baseline testing may be useful in some cases but is not necessary, required, or an accepted standard of care for the appropriate management of SRC.

Sideline Assessment

Observation of athletes during practice and competition by medical personnel is valuable for potential concussion recognition and initial management. Reasons for immediate removal and prompt evaluation include loss of consciousness (LOC), impact seizure, tonic posturing, gross motor instability, confusion, or amnesia. Any of these reported or observed signs should result in removal from practice or competition for at least the rest of the day. Concerns for more serious head injury including prolonged LOC, severe or worsening headache, repeated emesis, declining mental status, focal neurological deficit, or suspicion of significant cervical spine injury should trigger activation of the emergency action plan.

Along with directly observed signs of potential concussion, if video review demonstrates findings such as LOC, motor incoordination or balance problems, or having a blank or vacant look, the athlete should be immediately removed from participation for evaluation.[35–37] A health care professional familiar with the athlete is best suited to detect subtle changes in the athlete's personality or test performance that may suggest concussion. If a concussion is suspected but not diagnosed, removal from play and serial evaluations is recommended.[38] Concussion assessment should be performed in a distraction-free environment with adequate time for examination and administration of concussion tests. If it is clear an athlete has an SRC, additional sideline testing can be discontinued. Sport-specific rules may not allow adequate time for evaluation, and modifying these rules remains an area for improvement within the governing bodies of some sports.

When the sports medicine clinician becomes aware of a potential injury, the athlete is approached and a brief history of the event is obtained from the athlete and those who witnessed the event or athlete behavior. How the athlete responds to the elements of orientation, memory, concentration, and balance is evaluated as well as speech patterns and how the athlete appears to be processing information. Cervical palpation and range of motion (ROM) are also typically performed to assess for other injury. If SRC is suspected, these preliminary evaluations are followed by a thorough and specific concussion assessment.

The psychometric properties of sideline assessment tools need to be understood to accurately interpret the results.[39] Knowledge of test reliability, or the stability of a test administered on more than one occasion, can assist in differentiating SRC changes from normal variation. The test–retest reliability of commonly used sideline concussion evaluation tests is below the generally accepted threshold for clinical utility (0.75-0.90).[33,39] Many concussion tests have a learning effect that must be factored into analysis with repeated administration of the test. The sensitivity (ability of a test to correctly identify a condition) and specificity (ability of a test to correctly identify those without a condition) of many of the individual tests used to evaluate concussion are not ideal. The area under the curve of a receiver operator characteristic curve is another way to evaluate the usefulness of a test with values greater than 0.9 considered excellent, 0.8 good, 0.7 fair, 0.6 poor, and 0.5 failing. Table 3 outlines the psychometric properties and number of subjects and concussions studied of commonly used sideline evaluation tools. There is evidence that combining tests of different functions to form a multimodal assessment increases sensitivity and specificity for diagnosis.[22,33] The age of the athlete needs to be considered when using and evaluating testing tools. Sport-related concussion is a heterogeneous injury, which contributes to the varied sensitivity of screening tools, which are often domain-specific assessments. All tests should be interpreted in combination with relevant clinical information to arrive at the most accurate conclusion.

Symptoms are the most sensitive indicator of concussion.[23,40] The reliability of athlete-reported symptoms depends on accurate reporting, which may be affected by a lack of recognition of the signs and symptoms of concussion or conscious false reporting to avoid loss of playing time. An athlete experiencing any increase in symptoms after a suspected concussion should be held from play until further evaluation can confirm or exclude SRC.

The SCAT5[41] and the Child SCAT5[42] are the evaluation tools recommended by the Concussion in Sport Group (CISG) for assessing a suspected concussion. These tests offer a standardized approach to sideline evaluation, which incorporate multiple domains of function and are widely available at no cost. The SCAT5 is composed of a brief neurological examination, a symptom checklist, a brief cognitive assessment [the Standardized Assessment of Concussion (SAC)], and a balance assessment (the modified-Balance Error Scoring System (m-BESS). The SAC in the SCAT5 offers optional 10-word lists for immediate and delayed memory and longer digit backward sequencing to minimize the ceiling effect, which was a weakness of the SCAT3.[43] There are currently no studies of the SCAT5 or Child SCAT5's sensitivity and specificity for SRC to determine whether these versions are improved over the earlier versions.

The primary end point for sideline assessment is to determine the probability that an athlete has sustained a concussion. If the athlete is deemed unlikely to have had a concussion, continued participation should be safe. If the evaluation indicates a definite or probable concussion, the athlete should be removed from participation with no same day return to play. Sport-related concussion is an evolving injury and should be serially reassessed when suspected.

Office/Subacute Assessment

An office assessment should include a comprehensive history and neurological examination including details of injury mechanism, symptom trajectory, neurocognitive functioning, sleep/wake disturbance, ocular function, vestibular function,

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TABLE 3. Psychometric Properties of Sideline Assessment Tests*

Author	Type of Athletes	# of Athletes	Concussed	Controls	Test and/or Criterion	Sensitivity (%)	Specificity (%)	Test–Retest Reliability	AUC
Symptoms									
McCrea[19]	College football	1631	94	56		89	100		
Putukian[22]	College athletes	263	32	23	SCAT-2	84	100		
Chin[23]	High school and college athletes	2018	166	164					0.88
Resch[120]	College athletes		40	40	Revised Head Injury Scale	98	100		
Garcia[40]	College athletes		733		SCAT-3	93	97		0.98
Broglio[33]	College athletes	4360						0.40†	
Total		3192	1065	283					
SAC									
Barr[15]	High school and college football	1313	50	68	3 point decline	72	94	0.55‡	
McCrea[19]	High school and college football	1325	63	55	3 point decline	78	95	0.48§	
McCrea[17]	High school and college football	2385	91		<10th percentile of normative	79			
McCrea[19]	College football	1631	94	56	?	80	91		
Echlin[121]	Ice hockey (age 16-21)	67	21	—	1 point decline	54			
Barr[16]	High school and college football	823	59	31	?	46	87		
Marinides[20]	College athletes	217	30		2 point decline	52	82		
Galetta[21]	Hockey/lacrosse youth/college	332	12	14	2 point decline	20	21		0.68
Putukian[22]	College athletes	263	32	23	<10th percentile of normative	41	91		
Chin[23]	High school and college athletes	2018	166	164				0.39†	0.56
Broglio[33]	College athletes	4874						0.39†	
Total		15 284	618	411					
Balance error scoring system (BESS)									
McCrea[19]	College football	1631	94	56	m-BESS	36	95		
Broglio[122]	Young adults	48			BESS			0.60¶	
Barr[16]	High school and college football	823	59	31	m-BESS	31	71		
Putukian[22]	College athletes	263	32	23	m-BESS	25	100		
Chin[23]	High school and college athletes	2018	166	164	m-BESS			0.54†	0.56
Broglio[33]	College athletes	2894			BESS			0.41†	
Total		4735	351	274					
Oculomotor (King-Devick)									
Galetta[27]	Football, m/w basketball	219	10		Worsening of KD time	100			
Leong[123]	Boxing				Worsening of KD >5 s	100	100	0.9†	
Galetta[21]	Hockey/lacrosse youth/college	332	12	14	Worsening of KD time	75	93		0.92
Leong[28]	College football, m/w basketball	127	11		Worsening of KD time	89		0.95†	
King[124]	Amateur rugby					94	100	0.92†	
Marinides[20]	Football, w lacrosse, soccer	217	30		Worsening of KD time	79			

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TABLE 3. Psychometric Properties of Sideline Assessment Tests* *(Continued)*

Author	Type of Athletes	# of Athletes	Concussed	Controls	Test and/or Criterion	Sensitivity (%)	Specificity (%)	Test–Retest Reliability	AUC
Seidman[24]	High school football	343	9		Worsening of KD time	100	100		
Dhawan[29]	Youth hockey	141	20		Worsening of KD >5 s	100	91		
Fuller[125]	Elite English rugby		145		Worsening of KD time	60	39		0.51
Hecimovich[126]	Australian football		22	22	Worsening of KD time	98	96	0.91†	
	Professional football	1223	84	63	Worsening of KD	84	62	0.88†	
Broglio[33]	College athletes	755						0.74†	
Eddy[127]	Recreational college athletes	63						0.90†	
Total		2041	310	99					
Clinical reaction time (dropped weighted stick)									
Eckner[128]	College football, wrestling, and w soccer	102						0.65†	
Eckner[47]	High school and college athletes	28	28		90% confidence interval	50	86		
Broglio[33]	College athletes	261						0.32†	
Total									

** Study selection criteria: athletes competing in any level of sport using any sideline screening assessment or studies with test–retest reliability of included assessments. All studies were high risk of bias as assessed using QUADAS-2 except for Fuller[125] which was low risk of bias.*
† Test–retest reliability: intraclass correlation coefficient.
‡ Test–retest reliability: reliable change index.
§ Test–retest reliability: Pearson's correlation coefficient.
¶ Test–retest reliability: generalizability coefficient.
AUC, area under the curve.
?, unclear what criterion/cutoff they used to develop sensitivity and specificity information.

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gait, balance, and a cervical spine examination. The utility of sideline neurocognitive and balance assessments to identify concussion decreases as early as 3 days after injury.[41] Symptom checklists can be useful to track symptom trajectory. To confirm the diagnosis of SRC, there should typically be a clear mechanism consistent with concussion; characteristic signs, symptoms, and time course of concussion; and no other cause for the constellation of clinical findings. It is not unusual for symptoms, signs, and testing to normalize by the time an office visit occurs,[44] in which case the visit should focus on recommendations for safe return to school and sport. If computerized neurocognitive tests were performed before injury, they are often repeated during this assessment period.

If an athlete has ongoing symptoms at the time of the first office visit, the visit should focus on excluding other pathologies and providing anticipatory guidance. Other pathologies such as cervicogenic pain, headache/migraine disorder, mood disorders, and peripheral vestibular conditions may either be the cause of symptoms or may represent previous pathology worsened or unmasked by concussion. A complete cervical spine evaluation, screenings for psychosocial or mental health disorders, and additional tests evaluating the vestibular and oculomotor system may be helpful in the office setting to determine the etiology of symptoms. Vestibular symptoms occur in 67% to 77%, and ocular impairment occurs in approximately 45% of SRC.[45,46] The vestibular/ocular motor screening (VOMS) tool offers a brief, standardized way to assess vestibular–ocular function that can be used in athletes aged older than 10 years.[46] It is a no-cost evaluation of symptom provocation with smooth pursuits, saccades, vestibular ocular reflex, vestibular motion sensitivity, and convergence distance.[46]

Other Considerations in the Assessment of Concussion

There is a need for definitive, objective, and clinically useful tools for the diagnosis of concussion. This interest has led to innovation and fast-paced changes with the ongoing need for refinement and validation of these efforts.

Emerging Sideline Concussion Evaluation Tools

Other sideline evaluation tools have been developed, including tests of vestibular–ocular function and reaction time. Physical examination components of the VOMS are becoming more frequently used in the office setting, but the role of formal VOMS testing on the sideline has not yet been studied. The King-Devick (KD) Test is a proprietary, timed saccadic eye movement test requiring individuals to quickly read numbers aloud.[28] The KD requires a baseline test as well as an understanding of potential learning and practice effects to be useful. Simple reaction time as a sideline screen has also been studied using a dropped weighted stick.[47] Further research including larger numbers and control subjects is needed for these tests.

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Other technologies such as app-based measures of reaction time, eye trackers, postural stability, speech pattern, quantitative electroencephalography, and various abbreviated neurocognitive tests are being developed. Some are available on portable electronic platforms with the ability to share information with multiple users. These newer technologies do not have sufficient research to establish their utility. The mention of all of these sideline tools does not imply AMSSM endorsement.

Helmeted and Nonhelmeted Impact Monitors

Current impact sensor systems indirectly monitor linear and angular acceleration forces to the brain; however, they may not consistently record head impacts or forces transmitted to the brain. Neither a device nor a specific threshold measure of force or angular acceleration can be used to diagnose concussion.[38,48] Some athletes experience high forces with no clinical symptoms of concussion, and some athletes sustain a concussion at much lower impact forces, making current impact measures a poor predictor of SRC.[49] The number, location, density, and individual thresholds of head impacts may be important parameters. At this time, impact monitors are a research tool requiring additional study and are not validated for clinical use in the diagnosis or management of SRC.

Biomarkers of Concussion

Head computerized tomography (CT) is rarely necessary in the evaluation of SRC but should be used when clinical suspicion for intracranial bleeding or macrostructural injury exists. Intracranial bleeds are rare in the context of SRC, but can occur, and CT is the standard evaluation tool for these and other suspected neurosurgical emergencies in acute and critical care. Conventional brain magnetic resonance imaging (MRI) is not commonly used in the evaluation of concussion but may have value in cases with atypical or prolonged recovery. Newer, advanced multimodal MRI technologies (eg, diffusion tensor imaging, resting state functional MRI, quantitative susceptibility imaging, magnetic resonance spectrography, and arterial spin labeling) are being studied in research protocols aimed at understanding the neurobiological effects and recovery after SRC.[50] Additional research will be required to determine the clinical utility of advanced neuroimaging in the setting of SRC.

The role of fluid biomarkers (blood, saliva, and cerebrospinal fluid) in the diagnosis of SRC is also under active investigation.[50] Proteomic markers of injury and recovery in more severe forms of civilian neurotrauma and traumatic brain injury have shown some promise; however, in recent systematic reviews, the overall level of evidence is low for using fluid biomarkers for diagnosis of SRC.[50] Fluid biomarkers have potential for informing the pathophysiology of concussion and neurobiological recovery, but more research is required to determine their clinical utility.[50] Recent Federal Drug Administration (FDA) approval of a two-protein brain trauma indicator with glial fibrillary acidic protein and ubiquitin carboxy-terminal hydrolase L1 (UCHL1), and clinical use of S100 calcium-binding protein β (s100β) in Europe, show promise for ruling out intracranial bleeds and structural damage to reduce utilization of head CTs in the emergency department setting. At this time, none of these tests has a role in the diagnosis or management of SRC.

There is currently no scientific support for genetic testing in the evaluation and management of athletes with SRC, and additional research is needed to determine how genetic factors influence risk of injury and recovery after SRC.[50]

Clinical Profiles

The recognition of heterogeneity among concussion presentations has led to the concept of "clinical profiles" or "clinical domains" with the potential for more specific prognostic value and targeted treatment.[51–53] It must be stressed that this is an emerging concept and does not represent clinical standards or norms but may serve to facilitate individualized patient management. Although SRC may present with symptoms representing only one clinical profile, it is more often that SRC presents with symptoms and impairment supporting multiple profiles. It is currently unknown at what postinjury time point these profiles become clinically important as most SRCs resolve with time. Thus, clinical profiles may be more applicable to athletes with persistent symptoms. More research in this area is needed. The diverse symptoms and functional impairments of SRC are variously categorized with overlapping symptom clinical profiles that may include cognitive, affective (anxiety/mood), fatigue, migraine/headache, vestibular, and ocular[52–54] (Figure 1). How clinical profiles fit into the clinical care of SRC warrants additional research.

Management of Concussion

Sport-related concussion clinical symptoms typically resolve spontaneously with 80% to 90% of concussed older adolescents and adults returning to preinjury levels of clinical function within 2 weeks.[55] In younger athletes, clinical recovery may take longer, with return to preinjury levels of function within 4 weeks.[56] It is important to communicate the usual time course and outcome to patients and families to relieve the anxiety that often accompanies this injury. Symptom checklists are useful for tracking symptomatic recovery. Clinical recovery based on our current evaluation methods and SRC testing may not coincide with complete physiological recovery, although the functional, clinical, and long-term significance of persistent imaging findings and subtle neuropsychological deficits on tests used in research settings is unknown.[44]

Predicting Recovery

The most consistent predictor of recovery from concussion is the number and severity of acute and subacute symptoms.[57] Subacute headache or depression after injury are risk factors for symptoms persisting for >1 month.[57] A preinjury history of mental health problems, particularly depression, seems to increase the risk of prolonged symptoms.[56] Athletes with learning disabilities or attention deficit/hyperactivity disorder do not seem to be at risk of prolonged recovery.[57] More research is needed to address other SRC modifiers, including age and sex, although some studies demonstrate a longer period of reported symptoms in females compared to males and for adolescent athletes.[57] Newer research suggests that a lower symptom-limited heart rate threshold during graded exercise testing within a week of SRC in adolescents predicts a longer recovery time.[58]

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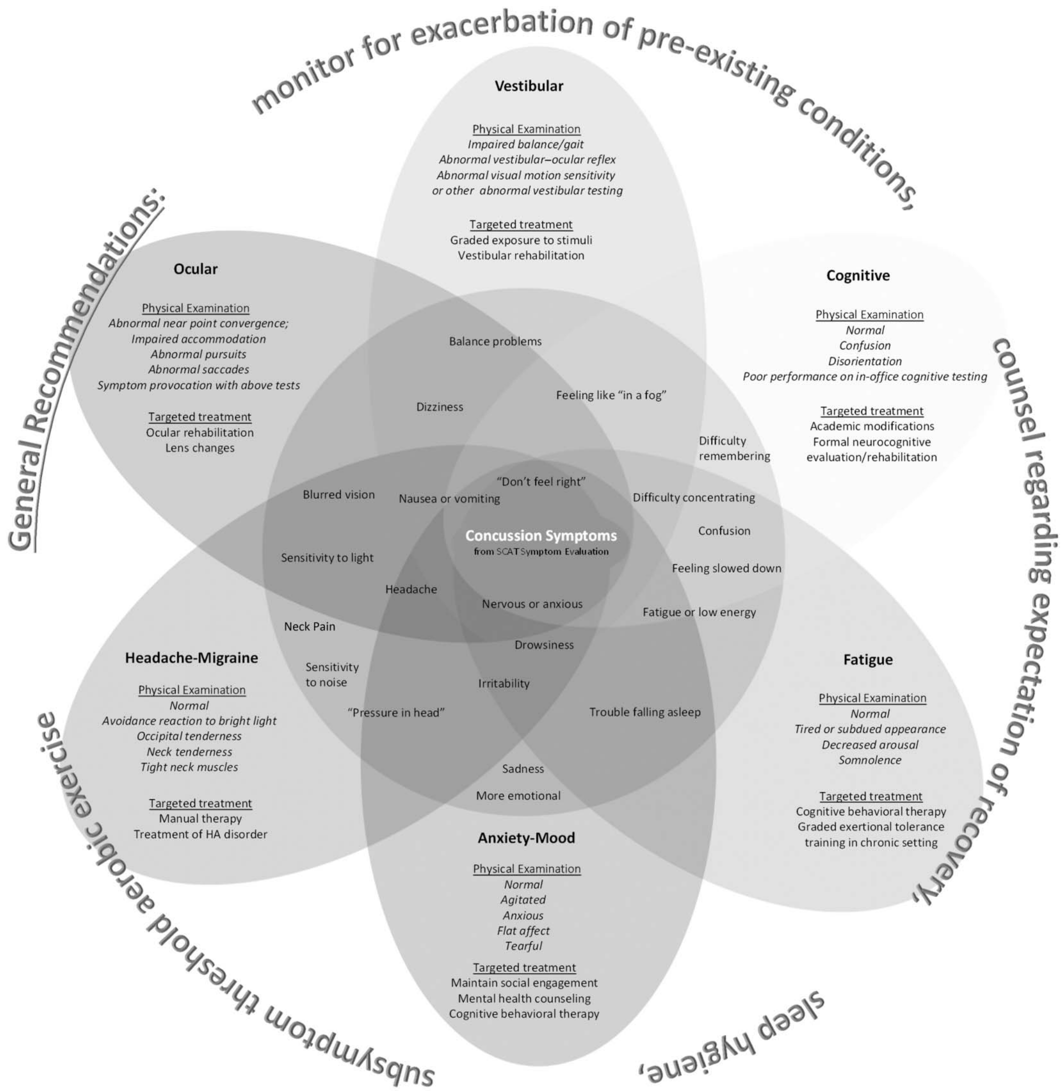

Figure 1. Overlapping clinical profiles: An emerging concept to facilitate individualized management after SRC. Most patients have features of multiple profiles.

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Treatment of Sport-Related Concussion

In this section the role of rest, physical activity and nutraceuticals are discussed.

Prescribed Rest

Prescribed cognitive and physical rest has been the mainstay of treatment for the past several decades despite insufficient evidence to support this approach.[59,60] Earlier animal data suggested that uncontrolled or forced early exercise is detrimental to recovery[61–63]; however, recent data in aerobically trained animals given early access to exercise showed improved outcomes compared with no or delayed exercise or to social isolation.[64] In human studies, strict rest after SRC slowed recovery and led to an increased chance of prolonged symptoms.[65,66] Total rest, that is, "the dark room" or "cocoon therapy," may have detrimental effects similar to social isolation effects seen in animal studies and is no longer recommended.[3,51] Consensus guidelines endorse 24 to 48 hours of symptom-limited cognitive and physical rest followed by a gradual increase in activity, staying below symptom-exacerbation thresholds.[3] Further research is needed to define the role of prescribed rest in recovery.

Activity and Exercise

Exercise intolerance is an objective physiological sign of acute concussion that seems to reflect impaired autonomic function and control of cerebral blood flow.[67,68] Exercise improves autonomic nervous system balance and CO_2 sensitivity, cerebral blood flow regulation, brain-derived neurotropic factor gene upregulation, and both mood and sleep.[69,70] Emerging data suggest that symptom-limited activity, including activities of daily living and noncontact aerobic exercise, may begin as soon as tolerated after an initial brief period (24-48 hours) of cognitive and physical relative rest.[3] There is some preliminary evidence that subsymptom threshold exercise improves recovery in acute concussion,[71,72] and early symptom-limited graded exercise testing seems to be safe in athletes.[58] Understanding for whom and when to begin early exercise after SRC remains an ongoing area of exploration. Early activity and exercise do not take the place of a graded return to sport.

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Role of Nutraceuticals

Interest in nutraceuticals for prevention and treatment of concussion is high. There is emerging evidence in animal models of concussion that some supplements may protect or speed recovery from concussion; specifically focused on certain B vitamins, omega-3 fatty acids, vitamin D, progesterone, N-methyl-D-aspartate, exogenous ketones, and dietary manipulations (eg ketogenic diet).[73–75] There is a gap, however, between experimentally produced injury in an animal model and the heterogeneous mechanisms that cause human concussion during sports activities. There is no human evidence that nutraceuticals prevent or ameliorate concussion in athletes.[76] Supplements are not FDA regulated, and potential for harm or contamination should be considered. This is an area that requires significantly more research to guide future recommendations.

Persistent Postconcussive Symptoms

Postconcussion syndrome or disorder are terms that have been frequently used to describe patients with lingering symptoms after a sport- or recreation-related concussion, but often those patients do not meet diagnostic criteria for these diagnoses. A preferred term is persistent postconcussive symptoms (PPCS), defined as symptoms that persist beyond the expected recovery time frame (>2 weeks in adults, >4 weeks in children).[44] Persistent symptoms do not necessarily represent ongoing concussive injury to the brain. It is not unusual for common symptoms to be inappropriately or mistakenly attributed to concussion; therefore, it is critical to understand pre-existing or coexisting symptoms and conditions in the evaluation of PPCS.

Targeted Treatments

Recent systematic reviews have advocated including vestibular, oculomotor, psychological, sleep, cervical and autonomic nervous system evaluations in the assessment to facilitate individualized and targeted management of PPCS.[77]

Exercise for Persistent Postconcussive Symptom

Activity and exercise that does not exacerbate symptoms are recommended for those with PPCS. A formal symptom-limited aerobic exercise program has been shown to be safe and improve resolution of persistent symptoms compared with controls and should be considered in athletes with symptoms lasting longer than expected.[78–80] The Buffalo Concussion Exercise Treatment Protocol, a progressive sub-symptom threshold aerobic exercise program based on systematically establishing the level of exercise tolerance on the Buffalo Concussion Treadmill Test, is the most studied controlled exercise program.[81] It is ideal for those with PPCS to be evaluated by a provider or multidisciplinary team with expertise in complicated concussion management.

Physical Therapy, Vestibular Therapy, and Collaborative Care

Athletes with migraine/headache should be evaluated for underlying headache disorders, cervical dysfunction causing headache, and other possible contributors, and treated appropriately with nonpharmacologic and pharmacologic treatments.[77] Vestibular therapy should focus on specific deficits identified and use an "expose-recover" model performed by clinicians with expertise in vestibular rehabilitation.[51,82] There is preliminary evidence that addressing cervical spine and/or vestibular dysfunction with a targeted physical therapy program improves outcomes in those with PPCS.[83,84] Cognitive work should be modified or limited to that which does not exacerbate symptoms.[60] In athletes with sleep disturbances after an SRC, sleep hygiene should be addressed, sleep monitored, and treated with nonpharmacologic or pharmacologic strategies.[85] Individuals experiencing psychological symptoms such as irritability, sadness, and anxiety should be evaluated and offered appropriate treatment. A collaborative care model including cognitive behavioral therapy can improve outcomes in those with PPCS.[86]

Return to Learn

Sport-related concussions can induce changes in attention, cognitive processing speed, learning, short-term memory, and executive function that make learning difficult.[87] Return to learn is the process of transitioning back to the classroom after concussion using individualized academic adjustments[87,88] (Table 4). School personnel should be informed of the injury and implement an initial school support plan without delay.[89] Many concussed athletes recover quickly enough to return to the classroom with no or very brief adjustment of academic activities, but schools should be prepared to provide additional support in the event that recovery takes longer. Athletes with persisting symptoms should be provided an individualized return-to-learn accommodation plan that allows for symptom-limited learning activity similar to return to physical activity protocols. Early introduction of symptom-limited physical activity is appropriate; however, return to sport training activities should follow a successful return to the classroom for student-athletes.

Return to Sport

Concussion-related symptoms and signs should be resolved before returning to sport. A return-to-play progression involves a gradual, stepwise increase in physical demands and sport-specific activities without return of symptoms before the final introduction of exposure to contact (Table 5). The athlete should also demonstrate psychological readiness for returning to play. The return-to-sport progression is individualized and is a function of the injury, the athlete's age, history of SRC and level of play, and the ability to provide close supervision during the return to activity. The return-to-sport progression presented by the CISG is widely accepted but empiric, without evidence to support either the progression sequence or the time spent in each stage. In general, for young athletes, each stage of the progression should be at least 24 hours without return of symptoms before progressing to the next stage.

Return to Driving

In addition to return to learning and sporting environments, older athletes may need to return to driving, where subtle deficits could compromise safety. Most sports medicine physicians do not counsel athletes with SRC about driving.[90] Driving is a complex process involving coordination of cognitive, visual, and motor skills as well as concentration, attention, visual perception, insight, and memory that can all

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TABLE 4. Return to Learn

Facilitate communication and transition back to school	
• Notify school personnel after injury to prepare for return to school	
Obtain consent for communication between medical and school teams	
• Designate point person to monitor student's status related to academics, recovery, and coping with injury and communicate with medical team	
School health professional, guidance counselor, administrator, and athletic trainer	
• Develop plan for missed assignments and examinations	
• Adjust schedule to accommodate reduced or modified attendance if needed	
Classroom adjustments	School environment adjustments
• Breaks as needed during school day	• Allow the use of headphones/ear plugs to reduce noise sensitivity
• Reduce in-class assignments and homework	• Allow the use of sunglasses/hat to reduce light sensitivity
• Allow increased time for completion of assignments and testing	• Limit the use of electronic screens or adjust screen settings, including font size, as needed
• Delay exams until student is adequately prepared and symptoms do not interfere with testing	• Allow student to leave class early to avoid crowded hallways
• Allow testing in a separate, distraction-free environment	• Avoid busy, crowded, or noisy environments—music room, hallways, lunch room, vocational classes, and assemblies
• Modify due dates or requirements for major projects	
• Provide preprinted notes or allow peer notetaker	
• Avoid high risk or strenuous physical activity	

Clinicians should individualize adjustments based on patient-specific symptoms, symptom severity, academic demands, and pre-existing conditions, such as mood disorder, learning disability, or attention deficit/hyperactivity disorder.[87,88]
Athletes with complicated or prolonged recovery may require a multidisciplinary team with specific expertise across the scope of concussion management.

be affected by SRC.[90] Little is known about the risk of driving after SRC, but preliminary data suggest some impairment exists when concussion patients report they are asymptomatic.[91] Currently, no widely accepted return to driving protocols exist; however, in athletes who drive, discussing the potential risks and harms is appropriate.

RISKS RELATED TO CONCUSSION

Short and long-term risks of concussion are an area of growing concern.

Short-Term Risks of Continued Exposure After Concussion or Premature Return to Play

Continuing to play immediately after a concussion is a risk of increased symptom burden, worsening of the injury, and prolonged recovery.[92–95] Athletes who return to sport before full recovery are at increased risk of repeat concussion.[96] Some research has demonstrated that athletes who return to sport after SRC following standard return to sport protocols had an increased rate of musculoskeletal injury.[97,98] The "Second Impact Syndrome" is both rare and controversial. It is considered by some to be a potentially life-threatening complication of

TABLE 5. Return to Sport

Stage	Description	Objective
1	Symptom-limited activity	Reintroduction of normal activities of daily living. Symptoms should not worsen with activity.
2	Light aerobic exercise	Walking, stationary biking, and controlled activities that increase heart rate.
3	Sport-specific exercise	Running, skating, or other sport-specific aerobic exercise avoiding risk of head impact.
4	Noncontact training drills	Sport-specific noncontact training drills that involve increased coordination and thinking. Progressive introduction of resistance training.
5	Full-contact practice	Return to normal training activities. Assess psychological readiness.
6	Return to sport	

RTS progressions should be individualized based on the injury, athlete's age, history, and level of play, and the ability to provide close supervision during the return to activity and progressions may vary between athletes. Each stage is generally 24 hours without return of concussion symptoms. Consider written clearance from a health care professional before RTS as directed by local laws and regulations.[3]

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reinjury during the initial postinjury period that is not fully understood and seems primarily limited to pediatric and adolescent athletes.[99]

Long-Term Risks After Concussion

Mental Health Problems and Depression

Sport and exercise are protective against depression.[100] Most studies examining the relationship of contact sports to mental health problems or depression later in life have low methodological quality, high risk of bias, or both.[101–103] Several studies have reported that National Football League (NFL) and college football athletes with a history of concussion are more likely to experience depression, although the risk of mental health issues, including suicide, among former NFL players is lower than age-matched controls.[101–103] Former high school football players show no difference in cognitive function testing and have lower depression scores when compared with noncontact sport controls.[104] Mental health issues are common, multifactorial, and often present independent of participation in contact or collision sport. Longitudinal research on contact sport athletes, which addresses multiple variables, is needed to understand the long-term risks.

Chronic Traumatic Encephalopathy

Chronic traumatic encephalopathy (CTE) and other neurodegenerative diseases have been described in former athletes with a history of concussion or repetitive head impact exposure, typically accompanied by behavioral change. The incidence and prevalence of CTE in the general population, in former athletes, or in former athletes with a history of concussion or repetitive head impact exposure is unknown. A cause and effect relationship between postmortem CTE changes and antemortem behavioral and cognitive manifestations has not been demonstrated, and, asymptomatic players have had confirmed CTE pathology at autopsy.[105,106] It is also unknown whether CTE is a progressive disease and whether tau deposition is the cause of CTE or a byproduct or marker of a disease.[107]

The expression of CTE-associated symptoms may be related to impact load and type, duration of career, underlying genetic factors, or other lifestyle behaviors including alcohol, drug and anabolic steroid use, general health, psychiatric disease, and other factors. Some retrospective studies have reported increased risk of neurodegenerative disease in former professional football players; however, former high school football players do not show a higher prevalence of neurodegenerative disease when compared with nonfootball peers.[108,109] The most widely described risk factor to date is extensive exposure to both multiple concussions and repetitive head impacts, but the degree of necessary exposure is likely specific to the individual and subject to multiple modifying risk factors.[110] Athletes and former athletes who present with neuropsychiatric symptoms and signs that have been ascribed to CTE should be evaluated for potentially treatable comorbid conditions that share symptoms and not be assumed to have CTE.[111]

Repetitive Head Impacts

Subconcussive or nonconcussive head impacts have been discussed as an entity apart from concussion history that may create risk of long-term neurologic sequelae. Subconcussive impacts are defined as transfer of mechanical energy to the brain causing presumed axonal or neuronal injury in the absence of clinical signs or symptoms.[112] It is unclear whether a biomechanical threshold or other factors lead to injury or whether this entity qualifies as injury, as it does not seem to be associated with neuropsychological changes.[113] Although subconcussive impacts have been associated with CTE, the short- and long-term effects of repetitive head impacts, similar to SRC, cannot be accurately characterized using current technology. Future research will depend on developing technologies that can assess brain changes after repetitive asymptomatic head trauma in living subjects.

DISQUALIFICATION FROM SPORT

There are no evidence-based guidelines for disqualifying or retiring an athlete from sport after concussion; therefore, each athlete should be carefully and individually assessed to determine the safety and potential long-term health consequences of continued participation. There is no "set" number of concussions or repetitive head impact exposures that should force retirement from a season or from sport, and it is likely that athletes with higher numbers of diagnosed concussions will be seen in clinical settings as the recognition and awareness of concussion is improved.

Considerations for retirement from sport include the length of concussion recovery (progressively longer time intervals for symptom resolution), patterns of developing concussion with less force, or increasing severity of concussions, as well as the athlete's readiness or apprehension regarding to return to sport. Additional contraindications for continued participation may include behavioral changes, post-traumatic seizures, persistent neurological deficit, or imaging findings suggesting additional/other pathology. Individual and family tolerance of risk and perception of the benefit of sport participation (eg, personal identify and financial motivation) should be considered and explored in a process of shared decision-making.[114]

PREVENTION

Prevention of SRC is ultimately more effective in reducing the burden of this condition than any treatment, and although primary prevention of all SRC is not possible, measures to decrease the number and severity of concussions are of value. Rule changes, enforcement of existing rules, technique changes, neck strengthening, and equipment modifications have been the primary focus of prevention. There is moderate evidence that delaying the introduction of body checking in youth hockey reduces concussion rates.[115–117] The effectiveness of rule changes in youth soccer and football to reduce concussion incidence is not clear; however, there is initial evidence that practice modification and changes in tackling technique may reduce injury.[118,119] There is conflicting evidence regarding mouthguards and concussion reduction, and mouthguards should primarily be used for preventing dental trauma.[117] Helmets prevent skull trauma and intracranial bleeding, but their protective effects for concussion are less pronounced. Some football helmet designs have improved the ability to absorb force, but it is unknown whether this will reduce concussion incidence. Studies of headgear in other sports have produced mixed results. Player behavior can change when athletes wear new or "improved" protective equipment, encouraging a more aggressive style of play, potentially increasing the risk of injury.

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FUTURE RESEARCH DIRECTIONS

The panel has identified these key areas for further study:

1. High-quality epidemiologic studies in younger athletes, recreational activities, nontraditional sports, and non-school sponsored team sports (select, recreational) should be considered.
2. Continued studies of high school, college, and professional athletes to better understand concussion rates, repetitive head impact exposure, mechanisms, recovery patterns, risk factors, and the success of specific intervention and prevention strategies.
3. Research regarding objective tests, including neuroimaging and fluid biomarkers, to determine their diagnostic and prognostic utility over and above current clinical assessment methods.
4. Research regarding specific factors or modifiers that are associated with prolonged recovery.
5. Investigation into the utility of clinical profiles/concussion domains for diagnosis, prognosis, and treatment.
6. Research on the role, if any, of nutraceuticals in the prevention and treatment of acute concussion and for those with prolonged symptoms.
7. The role of aerobic exercise, physical therapy (treatment of associated injuries such as cervical and vestibular abnormalities), and psychological therapy in the treatment of SRC.
8. Advanced studies to increase understanding of neurobiological effects and recovery after SRC.
9. Development of evidence-based return-to-learn and return-to-sport paradigms.
10. Exploration of the potential long-term effects of SRC and repetitive subconcussive impacts on neurological health through prospective longitudinal studies and laboratory research.
11. The role of genetic susceptibility to acute and chronic effects of SRC and subconcussive impacts.
12. Further development and implementation of primary and secondary prevention measures.

CONCLUSIONS

Sport-related concussion is common among athletes and a common reason for medical encounters with sports medicine physicians. Concussion is a complex, heterogeneous brain injury that typically clinically resolves in 1 to 4 weeks. The diagnosis of concussion is challenging because it relies on self-reported symptoms that can be caused by other common conditions, and there are no readily available objective diagnostic tests to confirm the diagnosis. Sports medicine physicians and others who diagnose concussion should be familiar with the psychometric properties of the sideline and office assessment tools they are using. After a brief period of rest, acutely concussed patients can be encouraged to gradually and progressively increase physical and cognitive activity while staying below their symptom-exacerbation thresholds. In cases of prolonged symptoms, a multidisciplinary team experienced in the diagnosis and treatment of concussion should be considered. Further research is necessary to better understand the potential long-term effects from concussions and repetitive subconcussive impacts as well as incidence, prevalence, and modifiable risk factors. There are many beneficial aspects to participation in sport and exercise that should be balanced against the concern for concussion. The American Medical Society for Sports Medicine supports continued research in the area of SRC to enhance safe participation in sport.

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