In recent years, particularly in sports, the issue of concussions has garnered significant public attention and concern. The media has extensively covered the experiences of high-profile athletes and aspiring young individuals engaged in a wide range of sports, from American football to rugby, soccer, ice hockey, skiing/snowboarding, and others. This growing spotlight has prompted national and international organizations to dedicate substantial efforts to disseminating comprehensive reviews, guidelines, position statements, and recommendations regarding sports-related concussions.

The primary focus in sports-related concussion management focused traditionally on preventing a premature return to contact activities and thus avoiding the risk of concussion-related complications, such as dangerous subsequent blows.
to the head and persistent postconcussion symptoms.\textsuperscript{1–13} However, an emerging concern now centers on the potential for cumulative long-term impairments resulting from recurrent concussions and sub-concussive hits sustained throughout an athlete’s career.\textsuperscript{2–14} The multifaceted medical considerations surrounding sports concussions emphasize the need for a multidisciplinary approach to assess and manage these injuries comprehensively.

Concussions, as a form of mild traumatic brain injury (mTBI), have become a significant public health concern, with an annual influx of \textasciitilde 200,000 individuals into emergency departments, as estimated by the Centers for Disease Control and Prevention (CDC).\textsuperscript{1,14–16} Diagnosing and managing concussions present complex challenges, primarily relying on clinical symptoms, physical examinations, behavioral assessments, and cognitive deficits. Precise determination of the juncture at which an athlete can safely return to competitive activities remains a formidable clinical quandary.\textsuperscript{1,14,17}

Traditional neuroimaging, in the form of computed tomography (CT) or magnetic resonance imaging (MRI), often fails to reveal structural brain injury because concussive events rarely result in macroscopic anatomical abnormalities.\textsuperscript{16–22} As a result, the contemporary management of concussions relies on other objective and subjective indicators, such as symptomatic checklists, physical examinations, comparisons with baseline testing, balance assessments, and computerized neuropsychological testing.\textsuperscript{15,17–19,23–26} Furthermore, the quantification of concussion severity is inundated with challenges, requiring an exploration of advanced diagnostic modalities and methodologies capable of providing more precise and objective measures to aid in diagnosis in and turn inform return to play (RTP) decisions.\textsuperscript{4,5,15,27}

Given the global participation of \textasciitilde 200 million individuals in organized physical activities, the development of objective diagnostic and management strategies for concussions is of paramount importance.\textsuperscript{28} Although tools like the Sport Concussion Assessment Tool have gained wide validation and adoption in sporting institutions, the limitations of conventional neuroimaging techniques highlight the need for more advanced diagnostic paradigms.\textsuperscript{29–33}

This article explores the role of imaging modalities in the context of concussion management and their potential impact on RTP decisions. It delves into the intricacies of concussion diagnosis, the constraints of existing assessment tools, and the emerging necessity to develop advanced neuroimaging methodologies capable of providing deeper insights into the pathophysiologic process.\textsuperscript{12,15,26,38} The pathophysiologic basis of concussion involves underlying changes in the brain due to the microtrauma of neuronal cell membranes.\textsuperscript{1,15,39–41} This microtrauma triggers a cascade of ionic and metabolic events: changes in intracellular ion concentrations, release of neurotransmitters, mitochondrial dysfunction leading to reactive oxygen species production, increased glucose utilization, and decreased blood flow.\textsuperscript{42–45} The cascade involves three phases: an initial period characterized by hyperglycolysis, followed by metabolic depression, culminating in a recovery phase.\textsuperscript{42,43}

Deciphering the precise point at which cerebral restitution permits the athlete’s safe return to competitive activity presents a formidable clinical dilemma. Concussion symptoms can manifest instantly or gradually over minutes to hours following the traumatic event.\textsuperscript{2,23,26,30} Symptoms typically resolve within a few days, but in some cases, they can persist for weeks.\textsuperscript{11,13,14,23,26,39} It is also important to ensure that symptoms are not attributable to other external factors, such as alcohol, drugs, medications, or additional unrelated injuries.\textsuperscript{15}

**Nonimaging Diagnosis of Concussion**

The American Medical Society for Sports Medicine’s “Position Statement on Concussions in Sports” underscores the challenges in diagnosing concussions due to the absence of validated tests and a reliance on self-reported symptoms that can be nonspecific.\textsuperscript{1,14,29} These symptoms may include headaches, fogginess, dizziness, visual changes, fatigue, neck pain, sleep changes, and more.\textsuperscript{1,6,30–32,46–49}

Because of the nuances in presentation, thorough preseason physical evaluations and consideration of factors such as a history of prior concussions or TBIs, preexisting conditions, learning disorders, attention-deficit hyperactivity disorder, motion sickness, mood disorders, migraines, and current medications are crucial.\textsuperscript{33,50} Some organizations recommend baseline evaluations using tools like SCAT5, Computerized CogSport, ANAM, CNSVS, and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).\textsuperscript{1,7,29–33,47,51}

Best practices endorsed by the National Collegiate Athletics Association include baseline assessments of symptom checklists, cognitive function, and balance.\textsuperscript{52} On the sidelines, athletes should be removed from the game if they exhibit signs such as loss of consciousness, tonic posturing, gross motor instability, confusion, amnesia, seizures, a vacant look, or balance and coordination issues.\textsuperscript{1,6,30–32,46–49} If a concussion is suspected, clinicians should conduct a brief history, assess orientation, memory, concentration, balance, and speech patterns, and perform cervical spine evaluation with palpation and range of motion checks during the evaluation process.\textsuperscript{1,6,9,10,14,29,35,33–55}

**Defining Concussion**

A sports-related concussion (SRC) is a form of TBI that occurs due to a direct blow to the head, neck, or body during a sports or exercise activity.\textsuperscript{1,7,29,34–37} This blow generates an impulse force transmitted to the brain and initiates a complex physiologic process.\textsuperscript{12,15,26,38} The pathophysiologic basis of concussion involves underlying changes in the brain due to the microtrauma of neuronal cell membranes.\textsuperscript{1,15,39–41} This microtrauma triggers a cascade of ionic and metabolic events: changes in intracellular ion concentrations, release of neurotransmitters, mitochondrial dysfunction leading to reactive oxygen species production, increased glucose utilization, and decreased blood flow.\textsuperscript{42–45} The cascade involves three phases: an initial period characterized by hyperglycolysis, followed by metabolic depression, culminating in a recovery phase.\textsuperscript{42,43}

The current RTP guidelines for SRCs have evolved significantly based on the latest research and a heightened awareness of SRC. These guidelines emphasize the importance of medical oversight and the careful management of athletes to ensure
adequate time for recovery before resuming competitive play. 8,29,56

The CDC and the National Federation of State High School Associations Sports Medicine Advisory Committee recommend a Six-Step Return to Play Progression structured to ensure athlete health and safety. 8,29,53,56 Only after being symptom free and cleared by a health care professional can athletes progress through the steps.8,29,33,56 The stepwise approach includes increasing physical activity levels, from light aerobic exercise to full competition, carefully monitoring symptoms and cognitive function at each stage.8,29,33,56 The process considers individual variability, with athletes moving between stages at their own pace, and it emphasizes the importance of medical oversight and communication among all involved parties.8,29,53,56 Each step of the process takes a minimum of 24 hours for a gradual progression.29,56

Unlike past practices that advocated for strict physical and cognitive rest, the current approach emphasized in the most recent “Consensus Statement on Concussion in Sport” encourages athletes to engage in daily activities including walking immediately after the injury. 1,6–8,14,29,34,53,56 Light physical activity and prescribed aerobic exercise within specified thresholds are introduced early in the treatment plan.29,56 Athlete symptoms, cognitive function, clinical findings, and the judgment of a health care provider guide progression through these steps.29,56 Although unrestricted RTP typically occurs within 1 month of injury, individual characteristics may extend this time frame.8,29,53,56 Overall, the current RTP guidelines emphasize a personalized, multidisciplinary approach to concussion management that considers both preexisting and postinjury factors that can impact an athlete’s recovery trajectory.8,29,53,56

### Imaging Modalities in Management

The following discussion provides a thorough understanding of the diverse and complex neuroimaging methods and approaches of neuroimaging techniques for managing and diagnosing concussions, delving into each imaging modality and discussing its potential contribution to the intricate decision-making processes associated with the return to sport in athletes. A detailed evaluation of various neuroimaging modalities has revealed their promise in augmenting the understanding of the pathophysiologic underpinnings and severity assessment of concussions, especially in cases where conventional imaging methods fall short.

The discussion synthesizes the findings and explores the clinical implications of these modalities, considering their respective strengths, limitations, and evolving roles in concussion management. But it important to note that many, if not all, of the imaging modalities discussed here are not currently ready for real-time use in clinical management. A considerable amount of additional research is necessary to refine, simplify, and validate these novel techniques.

### Magnetic Resonance Imaging

As previously mentioned, routine clinical MRI sequences obtained in patients with SRC often fail to reveal structural brain injury because concussive events rarely result in macroscopic structural changes.18–22 In some cases, mTBI may result in cerebral microhemorrhage that can be detected on certain MRI sequences due to the paramagnetic properties of blood degradation compounds, specifically deoxyhemoglobin, ferritin, and hemosiderin.57 Susceptibility weighted imaging (SWI) has been found to be more sensitive for detecting microbleeds compared with T2*-weighted gradient-echo (GRE) imaging. Some evidence indicated that traumatic microbleeds predict cognitive outcome and persistent posttraumatic complaints in patients with mTBI.58 Therefore, when performing routine noncontrast brain MRI in the work-up of patients, substituting the more commonly performed T2*-weighted GRE sequence with SWI is highly recommended ( Fig. 1).

**Magnetic Resonance Spectroscopy**

Proton magnetic resonance spectroscopy (MRS), a noninvasive technique, has displayed substantial promise by shedding light on neurochemical changes that might remain hidden when relying solely on conventional MRI for structural assessments. Specifically, MRS has uncovered crucial alterations in critical metabolites such as N-acetyl aspartate (NAA), choline (Cho), and creatine-phosphocreatine (Cr) ratios, even when no discernible structural injury is apparent.

![Fig. 1](image-url) A 45-year-old former football player with a history of multiple prior concussions. Axial susceptibility weighted imaging minimum intensity projection image reveals a small focus of susceptibility artifact in the anterior right frontal lobe (arrow), consistent with prior microhemorrhage. Other routinely obtained magnetic resonance imaging sequences in this patient revealed no other structural or anatomical abnormality.
on standard MRI. Studies focusing on SRCs have demonstrated the diminished NAA-to-Cr ratio during the acute phase of injury that signifies metabolic disturbances.

Importantly, these ratios have shown signs of recovery within 30 days postinjury, underlining the potential of MRS to monitor metabolic changes longitudinally and thus potential application to RTP decision making. NAA relates to neuronal and axonal integrity. Altered NAA levels provide insights into neuronal loss, metabolic disruptions, or myelin repair processes. Cho levels, in contrast, tend to increase after head trauma, pointing to dynamic cell membrane turnover. At the same time, the Cr peak emerges as a reliable reference peak for calculations of the NAA-to-Cr ratio and Cho-to-Cr ratios.

Despite the wealth of information MRS provides, there is a notable gap in research on mTBIs both in SRC and non-sports-related forms. Existing studies have predominantly focused on moderate to severe TBI. Although common trends in MRS studies of mTBI, both in SRC and non-sports-related incidents, often involve reduced NAA and increased Cho levels, with Cr levels presumed to be stable, emerging research suggests that this presumed stability may not hold true. In conclusion, using MRS in the context of concussion management and RTP decision making offers a valuable peak into the dynamic metabolic changes occurring in the brain after injury. Understanding the subtle abnormalities inherent in concussive injuries is important and emphasizes the need for further research in this area.

**Diffusion Tensor Imaging**

Diffusion tensor imaging (DTI), an advanced MRI technique that harnesses the directional analysis of water diffusion within white matter (Fig. 2), offers a unique window into the brain’s microstructural changes following concussions. Studies using DTI have mainly centered on nonathletes, providing valuable insights into the alterations occurring in white matter regions. DTI has shown a remarkable ability to detect white matter injuries even when conventional MRI sequences appear normal, making it a valuable tool for concussion assessment. More recently, quantitative DTI, and one key metric in particular, fractional anisotropy (FA), showed potential for assessing the severity of concussions. Reduced FA is correlated with more severe symptoms, even in subjects with structurally normal imaging. Abnormal findings on quantitative DTI correlate with impaired reaction time, emphasizing its practical relevance in concussion management.

Despite the potential of DTI, its utility is influenced by various factors, including the timing of imaging postinjury. Studies indicate that the results of DTI can vary as time elapses from the initial insult. Understanding the complex and dynamic nature of brain injuries, particularly SRC, is vital when interpreting DTI findings. The heterogeneity of results observed in different studies underscores the importance of considering the time elapsed since the injury, the age of the patient, and the presence of previous concussions when analyzing DTI data.

As DTI continues to gain prominence in concussion research, it is essential to address the need for data collection and analysis standardization. Uniformity in DTI protocols and data interpretation across different platforms remain critical challenges. The emergence of other advanced diffusion imaging techniques, such as diffusion spectrum imaging, hybrid diffusion imaging (HYDI), q-ball imaging, and high angular resolution diffusion imaging (HARDI), presents new avenues for improving our understanding of concussions. DTI has already made significant contributions to the field of sports-related forms. Existing studies have predominantly focused on moderate to severe TBI. Although common trends in MRS studies of mTBI, both in SRC and non-sports-related incidents, often involve reduced NAA and increased Cho levels, with Cr levels presumed to be stable, emerging research suggests that this presumed stability may not hold true.

In conclusion, using MRS in the context of concussion management and RTP decision making offers a valuable window into the dynamic metabolic changes occurring in the brain after injury. Understanding the subtle abnormalities inherent in concussive injuries is important and emphasizes the need for further research in this area.

**Fig. 2** Usage of hybrid diffusion imaging (HYDI) to detect white matter microstructure alterations in patients with chronic traumatic brain injury (TBI). Tract-based spatial statistics (TBSS) maps of significant differences of intra-cellular volume fraction (Vic) between TBI patients and healthy controls. Red-orange voxels indicate regions with significantly lower Vic values in TBI versus controls, whereas green voxels indicate no significant differences. Abnormal fiber tract diffusion metrics are useful for detecting long-term alterations of declining neurite density. Specifically, decreased Vic within the posterior periventricular regions may be disruptive to the overall integrative of the whole-brain white matter network, which can help explain long-term cognitive and behavioral symptoms after TBI. Image courtesy of Dr. Andrew B. Newberg.
the field, but ongoing research and advancements in neuroimaging will likely further enhance our ability to assess and manage concussions effectively.

**Functional Magnetic Resonance Imaging**

Functional magnetic resonance imaging (fMRI) uses the blood oxygen level-dependent (BOLD) contrast to provide insights into neuronal activity within the brain (Fig. 3). The BOLD signal in fMRI is sensitive to blood-based properties, particularly the magnetic susceptibility produced by deoxyhemoglobin. The fundamental principle underlying fMRI is that increased neuronal activity in a specific brain region leads to an elevation in local blood flow, resulting in reduced deoxyhemoglobin concentrations in nearby vessels. The heightened presence of oxyhemoglobin, corresponding to neuronal activity, results in higher signal intensities, allowing for the indirect assessment of neuronal responses to cognitive and sensorimotor tasks.

Despite its proven efficacy in probing brain function, discussions continue regarding the clinical utility of fMRI in concussion assessment, especially in the context of SRC. Studies using fMRI in individuals with mTBI have shown alterations in the BOLD signal during various cognitive tasks, including working memory, attention, and sensorimotor functions. Task-related fMRI may be a sensitive tool for evaluating residual motor and cognitive deficits in the subacute phase of mTBI.

The prefrontal cortex, particularly the dorsolateral prefrontal cortex (DLPFC), consistently exhibits increased neural activity in response to cognitive tasks in patients with postconcussive symptoms. This phenomenon, often termed “neural inefficiency,” may be linked to diminished cognitive performance in SRC patients. Recent research delving into spatial memory navigation tasks using fMRI in athletes with SRC demonstrated distinctive brain activation patterns. Although no significant differences in task performance were observed between concussed individuals and neurologically normal controls, fMRI revealed more extensive cortical networks with additional activation outside the study’s regions of interest. The enhanced activation was evident in the parietal cortex, right DLPFC, and right hippocampus.

The bilateral recruitment of the DLPFC in concussed subjects further emphasized the complexity of neural responses following SRC. The increased neural recruitment observed in studies of working memory dysfunction in SRC can be attributed to three possible explanations: “brain reorganization,” “neural compensation,” and the “latent support hypothesis.” These explanations

![Fig. 3](image-url) **Increased fractional amplitude of low-frequency fluctuations (fALFF) on blood-oxygen-level-dependent (BOLD) imaging in mild traumatic brain injury (mTBI) patients compared with healthy controls.** Hot colors denote areas of increased fALFF in the mTBI group, including the circled regions in the right supramarginal gyrus (top row) and the left inferior parietal region (bottom row). Areas of significantly different resting functional connectivity reflect increased spontaneous brain activity at rest. Image courtesy of Dr. Andrew B. Newberg.
differ in their interpretations of the permanence and purpose of additional neural recruitment in response to cognitive challenges. Research findings in this area have been somewhat controversial, with some studies suggesting hypometabolism in specific brain regions, particularly the mid-DLPFC, and variations in activation patterns based on the presence of depression in concussed athletes.27,63,73,75

**Positron Emission Tomography**
Positron emission tomography (PET) imaging, with its capability to measure brain metabolism, has emerged as a powerful neuroimaging technique for assessing metabolic disturbances.18,24,74,79–83 This technology offers a unique window into the functional alterations in the brain and holds particular promise for SRCs. Conventional imaging modalities such as MRI or CT lack the ability to capture the nuanced metabolic changes seen in SRC.18–22 PET provides a more thorough understanding of the metabolic activity of brain regions and their correlation with the associated neurovascular changes linked to symptomatology through the use of radionucleotide tracer fludeoxyglucose F18 (abbreviated as 18F-FDG) that measures local glucose metabolism in various brain regions.74,84,85 PET imaging can be combined with CT or MRI for anatomical localization (Fig. 4 and Fig. 5).

A recent study compared patients with a single blunt mTBI from a vehicle accident with age-matched controls. The study revealed a complex pattern of hypometabolism in some brain regions (parahippocampal gyrus, middle temporal gyrus, cingulate, precuneus, and brainstem) and concurrent hypometabolism in others (angular gyrus, calcarine cortex, and middle/superior frontal brain regions).84 This novel approach highlighted the association between hypometabolism in frontal brain regions and decreased cognitive scores. These results provided clear evidence for the sensitivity of 18F-FDG PET in linking changes in glucose metabolism with cognitive function.84 The lack of specificity of 18F-FDG PET, combined with the complexity of understanding changes in glucose metabolism, raises questions about its utility as a diagnostic biomarker for SRC.24,84

Tau PET imaging has emerged as a promising avenue of research in this field, especially for assessing tau pathology in patients with TBI.76,79,80,83,84 Following a single TBI, of any type, including sports-related concussion, pathologic findings suggest that a third of subjects exhibit neurofibrillary tangles at autopsy years after injury.86 Currently, research indicates that axonal injury leads to tau hyperphosphorylation and aggregation.79,83 However, the precise mechanisms remain unclear. Recent advancements in tau-selective radiotracers have provided opportunities to visualize tau pathology in patients with TBI. The most widely used tau PET tracer, 18F-AV-1451 (18F-flortaucipir), was evaluated in patients with a single moderate to severe TBI history.84 The findings revealed significant differences in the spatial extent of 18F-flortaucipir signals in gray and white matter regions compared with age-matched controls, suggesting distinctive tau deposition patterns in TBI patients.84

Various radiotracers have provided insights into the dynamics of β-amyloid deposition within the brain.87–89 Recent case reports using 18F-florbetapir have demonstrated intriguing patterns of β-amyloid deposition in the aftermath of TBI.84 Although there is an initial increase, this deposition appears to clear over time in specific brain regions.87,88 These findings highlight the complexity of β-amyloid accumulation dynamics following TBI and emphasize the need for comprehensive investigation.87,88 If researchers can quantify β-amyloid deposition models, it would be possible to develop the ability to monitor SRC in cases of subclinical symptomatology. Factors beyond the occurrence of TBI, such as age, genetic risk, or vascular factors, may influence β-amyloid deposition and need to be controlled for in future studies and could hinder potential future applications.84,87,88

In the context of SRC, PET has the potential to provide invaluable insights into the metabolic and functional alterations in the brain. The challenges of interpreting these findings within the broader clinical context further emphasize the multifaceted nature of RTS decision making. As research in this field continues to evolve, PET remains a promising tool with the potential to enhance our understanding.
Vestibulo-Ocular Dysfunction and Eye Tracking

The prevalence of vestibulo-ocular dysfunction in concussions is evident, with vestibular and oculomotor symptoms frequently reported. Screening using tools like vestibular/ocular motor screening (VOMS) has shown promise in detecting changes in symptom provocation and components of vestibular function. Eye tracking, although challenging to implement on the sidelines, can detect abnormal ocular motility patterns associated with concussions, necessitating establishing appropriate error thresholds and optimizing sensitivity and specificity. Emerging technology that attempts to track eye movements digitally and produce imaging reports shows significant promise and will allow further objective assessment of eye movements that can be combined with reported symptom provocation related to eye-tracking testing.

Chronic Traumatic Encephalopathy

Chronic traumatic encephalopathy (CTE) is a neurodegenerative disease linked to repetitive head impacts. CTE, which occurs predominantly in contact sports and military service, presents a significant challenge because a diagnosis can only be made postmortem at this time. This limitation prevents intervention and comprehensive patient care.

The emerging role of neuroimaging techniques in the in vivo diagnosis of CTE is a promising development. MRI has revealed significant alterations in brain structure and function among individuals with CTE including changes in brain volume, ventricular enlargement, cerebral atrophy, white matter organization, cortical thinning, and functional connectivity. These findings are indicative of the neuropathologic changes associated with CTE and provide a potential tool for early diagnosis and intervention.

MRS has proven to be sensitive in detecting neuroinflammation, neuronal loss, and axonal injury, all of which are characteristics observed in CTE. Studies indicate that MRS can correlate neurochemical changes associated with neuroinflammation with mood symptoms and behavioral changes in former NFL players. Advancements in two-dimensional MRS allow more precise measurements of metabolites and neurotransmitters. A further subtype of MRS, localized correlated spectroscopy, allows detection of different brain metabolites in various brain regions.

PET and radionuclides are promising future methods of diagnosing CTE by detecting tau aggregates. Radionuclide 18F-FDDNP has shown potential in distinguishing CTE from other conditions. The limitation of these methods includes financial coverage, nonspecific binding, and safety concerns. In Shin's 2023 review in the National High School Journal of Science, there is a discussion about the need for personalized models of tau-induced atrophy in CTE, allowing clinicians to understand the trajectory of individual disease processes and intervene accordingly. Diagnosing CTE in living patients...
remains a significant challenge, but neuroimaging will likely emerge as the center point of in vivo diagnosis.

Conclusion

The management and RTP decision making in SRCs have evolved significantly over recent years, driven by increasing public awareness and the multidisciplinary approach adopted by medical professionals, researchers, and sports organizations. This article illuminated the multifaceted nature of concussions, emphasizing the significance of various imaging modalities in enhancing our understanding of these injuries.

The discussion surrounding imaging modalities, including MRS, quantitative DTI, IMRI, PET, and VOMS, highlighted their potential to offer valuable insights into the pathophysiological processes and severity assessment of concussions. These technologies offer a dynamic and comprehensive perspective on brain function and structure, with each modality contributing to a more complete understanding of the intricacies of concussions.

Despite the progress made in the field of concussion-related neuroimaging, significant challenges and gaps in research remain. The need for standardization in data collection and analysis within the development of advanced imaging techniques, such as tau PET imaging, are ongoing areas of exploration. Additionally, integrating imaging data with clinical assessments and neuropsychological tests is crucial for making informed RTP decisions and monitoring recovery. Thus all of the imaging modalities described here remain outside the scope of standard practice and are primarily limited to research applications.

This literature review underscored the evolving landscape of concussion management, guided by the promise of advanced imaging modalities in elucidating the complex nature of concussions. As research continues to advance, these tools hold the potential to improve the accuracy of diagnosis, inform treatment strategies, and ultimately enhance the welfare of athletes who sustain head trauma. Integrating these imaging techniques into the broader context of clinical care and RTP decision making would represent a significant step forward in mitigating the short- and long-term consequences of SRCs.

Conflict of Interest

None declared.

References

2 Harmon KG. Assessment and management of concussion in sports. Am Fam Physician 1999;60(03):887–892, 894
6 Kutukian M. Clinical evaluation of the concussed athlete: a view from the sideline. J Athl Train 2017;52(03):236–244
13 Bytomska J. Sports medicine: concussion. FP Essent 2022;518:11–17
25 Abraham L, Bell KR. The use of neuroimaging by community physicians in children with mild traumatic brain injuries. Presented at: 13th World Congress on Brain Injury, March 13–16, 2019; Toronto, ON, Canada
40 Makdissi M, Cantu RC, Johnston KM, McCrory P, McAllister WH. The difficult concussion patient: what is the best approach to investigation and management of persistent (> 10 days) post-concussive symptoms? Available at: https://bjsm.bmj.com/content/47/5/308.short. Accessed October 30, 2023
48 Echemendia RJ, Broglio SP, Davis GA, et al. Test what and measures should be added to the SCAT3 and related tests to improve their reliability, sensitivity and or specificity in sideline concussion diagnosis? A systematic review [abstract]. Available at: https://bjsm.bmj.com/content/51/11/895. Accessed October 30, 2023
50 McCrea M. Standardized mental status testing on the sideline after sport-related concussion. J Athl Train 2001;36(03):274–279
56 Centers for Disease Control and Prevention. Managing return to activities. Available at: https://www.cdc.gov/headsup/provis{return}_to_activities.html. Accessed October 30, 2023


