Abouhashem
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REVIEW

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Neurosurgical sports injury (an established unit)

Safwat Abouhashem[1*]

Abstract

Management of Sports-related injuries have long been recognized and reported to improve medical care for sports-related injuries as well as improve athletes' health, fitness, safety, and well-being. Various anatomical regions are affected by sports activities involving the head and spine, which account for 9.4% and 8–15% of total sports injuries, respectively. Furthermore, sports-related brain injuries have been associated with a 3% mortality rate following hospitalization. Neurosurgery is the medical discipline with the greatest experience in dealing with brain and spinal damage, as all patients who report to the emergency room with head injuries are treated by neurosurgeons. There are also numerous cases of acute and chronic spinal abnormalities that are common in athletes of all ages and ability levels. The frequency of sports-related spinal and brain injuries is expected to rise as the number of individuals participating in sports activities, whether professionally or recreationally, grows. As a result, the neurosurgeon's role is projected to grow over time, covering not only hospital treatment and management of sports-related head, spine, and peripheral nerve injuries but also on-field assessment and sideline medical team, as well as participation in sports injury research. Sport neurosurgeons have more to contribute in both clinical care and research to the field of sports medicine. This role could include not only hospital care and management of sports-related head, spine, and peripheral nerve injuries, but also on-field assessment and sideline care of athletes, as well as a significant role in sports injury research. The purpose of this literature is to provide an overview of sport-specific neurosurgical injuries and treatment, and outcomes and to identify who is a sports neurosurgeons and why do they exist? Traumatic brain injuries, spinal injuries, peripheral nerve injuries, and neurological diseases that are more likely to get worse during sports seem to be examples of sports-related neurosurgical injuries. Neurosurgeons and the neurosurgical community should be concerned about the growing knowledge and evolution in the field of sports medicine, and they should embrace significant advances in our understanding of sports-related neurological syndromes, as well as sports neurosurgery should be considered as an individualized aspect of neurological surgery.

Keywords Sports medicine, Sports neurosurgeon, Sport related concussion, Athletes

Background

Sports are a major source of trauma, particularly among children and young adults, as the number of people participating in sports for enjoyment or for a living continues to rise [1–5]. In Germany, sporting activities account for 15% of total trauma cases [5], while sporting activities account for 13% of pediatric brain injuries in the United Kingdom [4] in addition, 3.5 million children under the age of 15 got medical treatment for sports-related injuries in the United States [2], with an estimated 23 million in Africa[3].

Management of sports-related injuries was known and reported a long time ago, as it was found in an old Hindu and Chinese book around 1000 B.C., which documented the first use of exercise as a treatment; it was also reported during the eras of Hippocrates and Galen,

*Correspondence:
Safwat Abouhashem
sabohashem@gmail.com
[1] Department of Neurosurgery, Faculty of Medicine, Zagazig University, Zagazig, Egypt

as well as Ibn-Sina (Avicenna), who documented the use of medical gymnastics and massage to promote injury rehabilitation[6].

Sports medicine was established to treat and prevent injuries that occur as a result of participation in sports. The modern era of sports medicine began in the United States in 1854, when Edward Hitchcock established a new system of physical education. Since then, sports medicine has advanced to provide better medical care for sports-related injuries as well as patients' health, fitness, safety, and well-being [6, 7].

Sports-related injuries affect various anatomical regions; the lower limbs seem to be the most injured, followed by the upper limbs, while sports-related head and spinal injuries accounted for 9.4% and 8–15% of all sports-related injuries, respectively; additionally, sports-related brain injuries have been linked to a 3% death rate after admission [1, 5, 8–11].

Despite the wide range of sports-related injuries, Orthopedic surgeons and athletic trainers dominate the clinical practice of sports medicine, as the American Association of Orthopedic Surgeons established a Committee on Sports Medicine in 1964 and the American Orthopedic Society for Sports Medicine in 1975 to organize and foster progress in the field of sports medicine [6, 7].

Neurosurgical care of athletes

The neurosurgeons are uniquely qualified to contribute to the field of sports medicine as the neurosurgery is the medical specialty with the most experience in dealing with brain and spinal trauma as there are approximately 13.8 million registered neurosurgical procedures each year and out of these procedures 6.1 million are related to traumatic brain injury (TBI) with another 400,000 related to traumatic spinal injury[12]. As a result, neurosurgeons already treat all patients with head injuries who present to the emergency room, as well as numerous cases of acute and chronic spinal disorders that are frequent in athletes of all ages and skill levels. Neurosurgeons are also uniquely able to assess congenital and developmental neurological abnormalities that may allow or disallow players from participating in sports [13, 14].

As the number of people engaged in sports activities, whether professionally or recreationally, develops, the frequency of sports-related spinal and brain injuries is anticipated to rise [1] Therefore, the role of the neurosurgeon is expected to expand over time, including not only hospital care and management of sports-related head, spine, and peripheral nerve injuries but also adding value to the on-field assessment and sideline medical team, as well as participating in sports injury-related research [14].

The neurologic examination is crucial in identifying potential injuries and illnesses [15], as early identification of neurologic injuries necessitates removing athletes from play for screening or monitoring, as well as transferring those with more severe injuries to medical facilities for treatment[14].

On-field assessment in professional sports necessitates rapid triage and appropriate diagnosis and treatment. A sports neurosurgeon is qualified to assess, identify, stabilize, and monitor injured athletes as needed. This allows him to minimize the detrimental impact of neurological injuries on the field while keeping the game running smoothly. Furthermore, accurate neurological assessment is required for new screening techniques in professional sports to better identification of diverse neurological diseases that are more likely to cause injuries. So, sports neurosurgeons can help athletes figure out how likely they are to get hurt from different sports, and they will be a great addition to the medical team on the sidelines of professional sports[14–16].

Sport-related neurosurgical injuries include traumatic brain injuries, spinal injuries, and peripheral nerve injuries, in addition to the neurological conditions that may have a higher risk of complications during sports activities.

Sport related traumatic brain injury

Sports activities are common and significant causes of TBI, but despite the fact that more than 80% of sports-related head injuries are mild, resulting only in brain concussion [8], mild brain injury is not without consequences, particularly in professional athletes, because it may lead to cognitive deficit and neuropsychiatric problems that may prevent or delay the athletes' return to play and training and even may lead to career-ending in addition to its long-term consequences as it could result in chronic traumatic encephalopathy[13, 17, 18]. Concussion, second impact syndrome, and sport-related structural brain injury are examples of acute traumatic brain injuries in sports, while chronic traumatic encephalopathy is a delayed consequence.

Sports-related concussion

A disruption in brain function produced by an external force to the head that can occur during a variety of everyday activities, including sports, is known as a concussion [8, 19].

Proper assessment, early recognition, initial management, and long-term clinical decision-making are key parts of the treatment of sports-related concussions that allow for a safe return to play and training. However, because loss of consciousness and amnesia are not required to diagnose a case of concussion, recognizing and diagnosing it might be difficult. Furthermore, after a trauma, symptoms and indicators may be ambiguous, inconsistent, and not emerge immediately.[8, 20, 21].

Pathogenesis of brain concussion

Concussion of the brain was defined in 1964 by the Committee on Head Injury Nomenclature as a clinical syndrome characterized by immediate and transient impairment of neural functions due to brain stem involvement. However, this definition does not adequately describe brain concussion; thus, the International Conference on Concussion in Sport proposed a more comprehensive definition in 2001 as a complex pathophysiological process affecting the brain initiated by traumatic force leading to biomechanical, pathological, and clinical injury constructs which induce a complex cellular metabolic cascade with impairment in the neuronal membrane permeability and levels of transmitter secretion with subsequent increase in the intracellular glutamate and calcium accumulation which lead finally to impairment of neuronal function with possible cell death [20, 22, 23].

The proximity of the corrugated surface of the anterior and middle cranial fossae to the inferior and medial temporal lobes, as well as the shearing strain between the cortical surface and the cranial floor, which are involved in limbic and memory functions, suggests a possible neuroanatomic basis for emotional and memory symptoms following closed head injuries[23].

The neuron has low rigidity by nature, making it vulnerable to deformation from external forces such as shear-strain, rotation, or acceleration/deceleration, which are common in athletes. This deformation causes a change in neuronal cellular shape without affecting volume, particularly at the gray-white matter junction, corpus callosum, and brain stem, in addition to the ripping of nerve fibers and non-neuronal tissues, which is another result of rotational shear-strain [22, 23].

Trauma, on the other hand, generates a rise in glutamate and aspartate, which can occur in enormous amounts, resulting in over-excitation and neuronal death. It also causes changes in basic molecular metabolism (particularly calcium) and neurotransmitters (particularly acetylcholine, dopamine, and serotonin), as well as an increase in dangerous molecules (oxygen free radicals, nitric oxide), which together lead to changes in neuronal function and neuronal networks with subsequent behavioral and cognitive changes [22, 23].

Clinical assessment of sports-related concussion

The diagnosis of sports-related concussion is underdiagnosed since loss of consciousness is not necessary. As a result, a detailed medical history, a thorough physical examination, and thorough investigations should all be included in the evaluation of athletes [8, 19, 21, 22].

Athletes with a suspected concussion are evaluated initially on the field, with neurological and mental status tests, before the decision is made to stop the game and transfer the athletes to hospital emergency rooms, where investigations will be conducted. A history of suspected sports-related concussion should be obtained from athletes, teammates, and coaches, and should include any previous concussion symptoms or history of previous head, face, or neck injuries that may have clinical relevance to the current injury [21, 22].

Despite that headache is the most common symptom in concussion, as it was found in 85% to 92% of cases, there is a wide range of symptoms and signs, such as amnesia, headache, nervousness, dizziness, poor concentration, drowsiness, poor balance or coordination, ringing in the ears, sensitivity to light, irritability, sensitivity to noise, loss of consciousness, sleep disturbances, memory problems, vision problems, nausea, vomiting, and neck pain, and on the other hand, it is no longer necessary to have a loss of consciousness or amnesia to diagnose a concussion [17, 20–22] while headache that lasts longer than 3 h could indicate a structural brain injury [24].

Investigations for athletes with sports related concussion

Anatomical imaging

Structure neuroimaging involving brain computed tomography and magnetic resonance imaging is usually normal, but it should be used whenever suspicion of a structural brain lesion is expected, such as in prolonged disturbance of consciousness, presence of neurological deficit, convulsion, or persistent symptoms or cognitive deficit. But newer methods like MRI gradient echo, perfusion, and diffusion weighted imaging are becoming more popular [20, 22, 23].

Non-contrast CT of the head is the preferred imaging method for detecting fracture, hemorrhage, and contusion in closed head injury, while magnetic resonance imaging is more sensitive and specific than CT in the evaluation of mild closed head injury because it is superior to CT scanning for initial detection of contusions, particularly small and non-hemorrhagic ones [23, 25, 26] Diffuse axonal injury (DAI) is a condition that manifests as a cluster of small, deeply located lesions with or without central petechial bleeding that mostly affects the white matter and spares the overlying cortex. They're usually found near the intersection of gray and white matter, in the corpus callosum, and in the brain stem[23, 25, 27].

Standard MRI, which includes T1WI and T2WI images, usually shows no abnormalities in suspected concussions, but fluid attenuation inversion recovery (FLAIR) is thought to be particularly sensitive in detecting subarachnoid or parenchymal pathology. Gradient-echo imaging, for example, has a high magnetic susceptibility to hemorrhage and can identify small patches of extracellular hemosiderin that survive as a marker after previous injury [25, 27, 28]. Therefore, the current recommendation for MRI protocol consists of routine T1 and T2, a FLAIR sequence, and a gradient-echo sequence. However, even with this protocol, only 9% of concussion cases have positive findings, while diffusion weighted MRI (DWI) increased the prevalence of signal abnormalities in athletes by up to 33% because it can detect smaller areas of edema.[23, 27, 29].

Functional imaging

Functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and photon emission computed tomography (SPECT) could explain the pathophysiological and functional sequelae of injury as these types of imaging facilities can provide information about cerebral glucose metabolism, cerebral blood flow, cerebral blood volume, cerebral neurotransmitters, and protein synthesis [23, 30–32].

Positron emission tomography (PET)

PET scan can identify changes in the neuronal activity therefore it has been widely used to study glucose metabolism, CBF, blood volume, cerebral oxygen metabolism, measure neurotransmitter and tissue metabolic state. In Traumatic brain injury, PET scan revealed disturbances in the metabolism beyond the MRI and CT structural abnormalities and the degree of metabolic depression may correlate with the clinical impairment [30, 31] also, fluorodeoxyglucose (FDG)-PET scan after severe traumatic brain injury demonstrated cerebral hyper glycolysis and cerebral metabolic rate of glucose which are not closely associated to the level of consciousness [30].

Single photon emission computed tomography (SPECT)

SPECT is another method for monitoring the physiologic status of the brain, and it may be helpful in identifying abnormalities such as tissue hypoperfusion that appears normal on structural brain imaging following a head injury [23, 30–32].

Functional MRI (fMRI)

Functional MRI (fMRI) is an indirect method to measure neural activity based on the detection of blood oxygenation changes. Therefore, athletes with persisting post-concussion symptoms using fMRI can reveal an increased signal of the underlying pathology when there is a difference between the oxygen-rich blood in the vein (area of low activity with low oxygen consumption) and the deoxygenated blood in the surrounding brain tissue (high activity with high oxygen consumption). Therefore, in the future, fMRI may provide a basis for the vulnerability to further injury, predicting prognosis and assessing the cumulative effects of injury. Therefore, it will be very helpful in the decision of whether to return-to-play or retire professional athletes [23, 33].

Laboratory investigations and blood biomarkers

The expression of intracellular proteins in the affected brain contributes in the assessment and treatment of brain injury. As a corollary, the use of molecular biomarkers in the diagnosis and monitoring of TBI progress and outcomes is becoming more common in clinical practice [34] Several biomarkers provide biochemical evidence of traumatic brain injury and can be used to assess pathophysiological processes occurring within days to weeks of the injury. However, only serum S100B has been validated as a useful biomarker for TBI, with insufficient evidence for plasma glial fibrillary acidic protein (GFAP), neuron specific enolase (NSE), ubiquitin carboxy-terminal hydrolase L1 (UCH-L1), tau protein, and neurofilament proteins [34–37].

The presence of antibodies to brain-specific proteins such as GFAP antibodies is an indicator of abnormal permeability of the blood brain barrier following TBI[38]. TBI patients showed about a four-fold increase in the anti-GFAP antibody levels within the first 10 days and 6 months after injury compared to the healthy control group [36, 37].

Antibodies to brain-specific proteins, such as GFAP antibodies, are a sign of aberrant blood–brain barrier permeability following TBI, and when compared to the healthy control group, TBI patients had a four-fold increase in anti-GFAP antibody levels between the first 10 days and 6 months after injury [36–38].

MicroRNAs (miRNAs) are regulatory RNA molecules that have a significant role in regulating gene expression and have been identified as molecular modulators in traumatic brain injury, based on their roles in the regulation of various cellular functions in the brain [39, 40].

TBI was reported to alter the levels of particular miRNAs in peripheral blood and cerebrospinal fluid. This suggested that miRNAs could be used as injury biomarkers [34, 35, 38–41]. Within 48 h of injury, in comparison to healthy volunteers, there was a decrease in miR-16 and miR-92a and an increase in miR-765. Also, levels of miR-93, miR-191, and miR-499 were elevated in serum from mild, moderate, and severe TBI patients, with a significant correlation between their levels and clinical outcome at 6 months of follow-up [40–43].

Treatment of sports-related concussion

Concussion in professional athletes is a serious injury with the potential for long-term morbidity, so treatment strategies are rapidly evolving with a specialized multidisciplinary team, using a biopsychosocial approach with active rehabilitation strategies to manage vestibular, musculoskeletal, social, and psychological findings with specific instructions on follow-up and symptom monitoring, appropriate and inappropriate activities, a safe return to activity, and return to sports activities[20, 41, 44, 45].

Athletes should be taught to follow up on existing symptoms, considering long-term symptoms, deterioration of symptoms, or the appearance of new neurological findings may require further attention. In the acute stage, pain relievers like aspirin and NSAIDs should be avoided. Sleep aids, CNS stimulants, selective serotonin reuptake inhibitors, or anxiolytics should not be given until 3 weeks after the first injury[45].

Relative rest is essential after a concussion and should be recommended for athletes, but excessive sleep should be avoided as well. To protect athletes at danger of a second head injury, sports-related activities should be avoided. Also, activities that require high levels of cognition may increase post-concussion symptoms [20–22].

Return to sport activities

Athletes should wait 7 days, starting from the first asymptomatic day, before returning to sports activities with a slow progressive work up starting from light exercise to sport-specific activities, before game participation, with continuous monitoring for symptom reappearance, which should be avoided if it occurs [20–22].

Second-impact syndrome

Second-impact syndrome is a second concussion in a patient who has already had a concussion and is still not fully recovered, which is more common among athletes due to their early return to training. Despite its rarity, the second impact syndrome can cause severe brain swelling and has a 50% mortality rate [46].

Sport-related structural brain injury

Sport-related structural brain injuries (SRSBI) are far less common in athletes than sports-related concussions (SRC), but they are medical emergencies that can result in permanent neurologic deficits or even death. Neurosurgeons are responsible for the treatment and management of these complicated injuries that may require neurosurgical intervention, and the prognosis is heavily contingent on timely and adequate diagnosis and treatment [47].

Chronic traumatic encephalopathy

Chronic traumatic encephalopathy (CTE) is a progressive neurodegenerative syndrome characterized by headaches, behavioral and personality changes, mood disorders, cognitive difficulties, aggressive behavior, memory disturbances, Parkinsonism, as well as speech and gait abnormalities. It is more commonly diagnosed in athletes who engage in collusion and contact sports activities. Repetitive blunt head trauma is the most common cause, and radiological signs of chronic traumatic encephalopathy include atrophy of the cerebral and medial temporal lobes, ventriculomegaly, and an enlarged cavum septum pellucidum [13, 48, 49].

Spine injuries in athletes

Sports are a major cause of spinal injuries, which can occur in almost any sport. Ice hockey, football, wrestling, diving, skiing, snowboarding, rugby, cheerleading, and baseball have the highest risk of spinal injuries. In the United States, sports are responsible for 8.7% of spinal injuries, but in Japan, it is 1.95 per million per year [9, 11].

Most sports-related spinal injuries are soft-tissue injuries that do not require intrusive treatment. However, they can be fatal and result in spinal cord injury, so sport-related spinal injuries in athletes should be examined and treated carefully [9]. Chronic spinal injuries such as vertebral stress fractures, spondylosis, spondylolisthesis, and intervertebral disc herniation can occur as a result of repetitive low-energy trauma, but acute cord injuries and unstable fractures are frequently the result of high-energy trauma[50, 51].

The mechanism and forces of injury determine the location and severity of spinal injuries in athletes. However, it is clear that axial pressures associated with lateral bending or flexion, as well as extension-flexion injuries associated with whiplash, are the most common mechanisms causing spinal injuries in athletes [9, 50, 51].

Athletes' spine injuries could indeed occur at any level of the vertebral column, although the lower cervical and thoracolumbar regions are the most common [9, 11, 52].

Athletes' neck injuries

Soft tissue injury, neuropraxia, stable stress fracture, and cervical disc herniation with or without radiculopathy are all common cervical injuries in athletes. But serious neck injuries like unstable neck fractures with or without spinal cord damage have been seen and reported as direct causes of sports injuries in athletes [9, 53].

Soft tissue injury

The most prevalent cervical injuries in athletes are soft tissue injuries and neck muscle strains. Even though a normal neurologic exam may merely discover a loss of cervical lordosis on a radiological exam, these injuries frequently manifest as neck pain, paravertebral muscular spasm, and a restricted range of motion. Strains are most commonly caused by low-grade forces, such as mild whiplash injuries with rapid extension-flexion, and are normally treated conservatively with rest, physical therapy, anti-inflammatory drugs, and muscle relaxants[9, 53].

Cervical stingers

Cervical stingers are caused by forced movement of the head to the back with lateral flexion of the neck, which causes stretching of the brachial plexus or compression of the cervical nerves, resulting in electric shock-like discomfort radiating to the arms and lasting a few seconds to minutes. Although cervical stingers are self-limiting injuries that do not require intervention, the sole therapy is prevention, such as strengthening neck muscles and adequate exercise and training. However, they should be regarded as a warning flag for cervical canal stenosis and should be investigated [53, 54].

Cervical neuropraxia

Cervical neuropraxia is a transitory loss of motor or sensory function of the spinal cord tracts that occurs without a spinal fracture. Hyperflexion or extension in a primary or secondary stenotic spinal canal is the most common cause. Cervical stenosis has been shown to be an important factor in the occurrence and severity of these neurological injuries. The symptoms aren't permanent and aren't linked to a spinal fracture. It was found that football players with cervical canal stenosis were more likely to get stingers and neuropraxia, which can be a career-ending injury in those athletes [54, 55].

Cervical radiculopathy and intervertebral herniated discs

The diagnosis and management of cervical disc herniation and radiculopathy in athletes is difficult, and it necessitates careful evaluation and rational decision-making to reduce the risk of catastrophic injury while playing and training. Furthermore, the return to play and career-ending decisions should be carefully considered. As a result, history-taking, physical examination, suitable imaging, and neurophysiological investigations should all be included in the evaluation of athletes with radiculopathy [9, 50, 54, 56]. Pain, reduced range of motion, and sensory and motor impairments are all common clinical findings. MRI is required to confirm the diagnosis and characterize the degree and extent of disc herniation, despite the fact that a neurological examination can locate the level of the herniated disc [53, 57].

Conservative treatments such as NSAIDS, relative rest, steroids, and physical therapy can help athletes with cervical disc herniation, but surgery is strongly advised for athletes who develop transient neuropraxia, long-tract findings, resistant and progressive symptoms, or fail to respond to conservative treatment[9, 53, 55]. The surgical standard of therapy is anterior cervical discectomy and fusion (ACDF). However, for improved physiological recovery, posterior foraminotomy or cervical disc arthroplasty can be employed [9, 11, 54, 55].

In the management of cervical disc disorders in athletes, the decision to return to play or stop one's career is crucial. Athletes with recurrent neurapraxia were previously prohibited from participating in contact sports; however, treatment and return to play are now variable and individualized based on clinical and radiological findings. For example, athletes with focal compression caused by a herniated disc at a single level may be able to play football again after surgery [54–56].

Sport-related cervical fractures

Although vertebral fractures can occur anywhere throughout the spine, cervical spine fractures are more frequent at the lower levels (C4 to C7). X-rays and CT scans are helpful in excluding spinal fractures, but MRI may be required if the clinician has a high suspicion of cervical injuries because it not only helps to rule out spinal fractures and soft tissue injuries, but it also helps to detect the details of the spinal injuries for appropriate care planning[9, 11].

With a cervical orthosis and symptomatic treatment, stable fractures such as anterior compression fractures affecting less than 25% of the vertebra can be treated non-operatively. Clay shoveler's fractures, which most commonly occur in football players and power lifters and involve avulsion of the cervical spinous process at the C7 level due to forceful flexion of the cervical spine, are quite stable and usually treated with a cervical orthosis, whereas compression fractures involving more than 50% are frequently associated with posterior ligamentous disruption, are usually unstable, and require surgical fixation[9].

Spinal cord injuries

Spinal cord injury (SCI) is a catastrophic type of cervical spine injury that results in a transient or permanent loss of neurological function, usually due to unstable fractures and rarely due to acute cervical disc herniation. To prevent or at least lessen long-term damage and disability, it is important to get proper neurosurgical care right away after these kinds of injuries [11, 50].

Athletes' spinal cord injuries can range from spinal cord neuropraxia (SCN) with reversible symptoms to catastrophic injury with permanent spinal cord injury (SCI), and SCN can be classified according to the duration of symptoms: SCI Grade I has symptoms that last less than 15 min, Grade II has symptoms that last 15 min to 24 h, and SCI Grade III has symptoms that last more than 24 h [9, 54, 55].

Complete cord injuries resulting in quadriplegia and complete loss of neurological function below the afflicted level are possible, as well as incomplete cord injuries such as central cord syndrome, Brown-Sequard syndrome, and anterior and posterior cord syndromes, which are all different types of spinal cord syndrome based on the damaged location of the cord. However, due to the frequent axial pressures associated with lateral bending or flexion, as well as extension-flexion with whiplash, central cord syndrome is the most common sports-related cervical injury, especially when the athlete has primary or secondary cervical stenosis, which was confirmed as a significant risk factor [9, 53, 57, 58].

On field assessment and management of cervical injuries

The conscious level, cervical pain, and range of motion should be assessed on the field, but passive movement should be avoided. Upper and lower extremity pain, weakness, and numbness should all be assessed. If neck pain comes on suddenly during a game, it could be a sign of cervical cord neuropraxia, a broken cervical spine, or a ligament injury. The head and neck should be immobilized before the player is taken off the field and taken to the emergency room for further investigations [9, 51, 56].

Return to play after cervical injuries

Following proven and adequate clinical and radiological clearance, return to play after cervical injuries that are managed conservatively is achievable and safe. While athletes' returns to play after operative treatment of cervical injuries is debatable, in general, most athletes can return to sport after anterior cervical discectomy and fusion for single level herniation. However, when using the arthroplasty technique or in multilevel fusion, the decision of whether to return to play or even end their careers is debatable as well. Athletes with cervical stenosis or pseudarthrosis may or may not be able to return to play [56].

Sport related thoracolumbar injuries

Although the majority of sports-related thoracolumbar injuries are benign and respond well to conservative therapy, they can be debilitating and negatively impair an athlete's career. In general, bone fractures, myofascial strain, ligamentous injury, intervertebral disc herniation, spondylosis, and spondylolisthesis react well to therapy, although the impact on athletes is variable in terms of return to play and career ending [52, 59].

The thoracolumbar spine's function during physical activity is to maintain mechanical stability and adjust for compression, distraction, torsion, and shearing stresses, but extrinsic forces that surpass this intrinsic stability induce spinal injury [9, 52, 59]. Chronic overuse and repetitive low-energy trauma to the thoracolumbar spine in athletes induce stress reactions such as disc degeneration, spondylolisthesis, spinous process apophysitis, and vertebral stress fractures, while high-energy trauma can induce thoracolumbar fractures [52, 59–61].

Sports-related thoracolumbar injuries necessitate a rapid and focused field assessment to rule out catastrophic injuries with neurological involvement, followed by a detailed history and physical examination with appropriate imaging studies involving dynamic radiography, CT, and MRI to delineate the details and extent of injury at a later point [52, 59, 60].

Thoracolumbar syndrome

Thoracolumbar syndrome is caused by prolonged posturing with flexed hips and an upward extended head during sports practice, such as in American football. It is treated with muscle balancing and stabilization exercises. The syndrome, which can be diagnosed by point tenderness over the affected level radiating along a segmental nerve distribution, However, the syndrome is often overlooked and misdiagnosed, but an image guided provocative injection at the joint of the involved segment can provide a definitive diagnosis [61].

Apophyseal ring fracture

Apophyseal ring fracture is a breakage of the fibrocartilaginous junction between the apophyseal ring and the vertebral body that usually occurs in the immature skeleton before ossification. Therefore, this fracture is commonly found in youth with vigorous sports activity before skeletal maturity, such as in gymnasts and wrestlers. Involvement of the apophyseal ring with disc herniation towards the canal may lead to pain with or without neurological symptoms and can be confirmed by CT or MR. Treatment of apophyseal ring fracture is non-operative with rest, physical therapy, and bracing [62].

Spinous process apophysitis

Repetitive microtrauma to the apophyses of the spinous processes during hyperextension movements in skeletally immature athletes, with repetitive impingement between the spinous processes and the attaching soft tissues, leads to inflammation, pain, swelling, and abnormal growth, but it is a benign self-limited condition that responds well to physical rest and anti-inflammatory medication [63].

Sports-related thoraco-lumbar fractures

Major fractures such as compression fractures, fracture-dislocations, burst fractures, and seat-belt fractures are rarely seen in sports activities. Thoracolumbar fractures in athletes are usually minor fractures due to repeated minor trauma known as stress fractures, most commonly involving the articular process, pars interarticularis, transverse process, and spinous process. The majority of thoraco-lumbar stress fractures in athletes can be managed non-operatively with rest, NSAIDs, and muscle relaxants in addition to bracing, whereas unstable fractures are treated surgically as in the general population [52, 61].

Spondylolysis and spondylolisthesis

Repetitive extension and twisting of the lumbar spine increase the liability and early progression of lumbar spondylosis, as it was found that up to 47% of young athletes with low back pain have been diagnosed with spondylolysis [64] Playing soccer, gymnastics, and football are the most common sports associated with spondylolysis, and more serious injuries such as spondylolisthesis can also be found [65]. The diagnosis of spondylolysis and spondylolisthesis in athletes with back pain starts with a lumbar spine X-ray. However, MRI is the definitive diagnostic tool as it can detect pars edema without exposing athletes to radiation, as CT and SPECT do [65, 66].

Physical therapy with a graduated exercise program and external stabilization are among the conservative treatments for spondylosis and acute pars defects while surgery is reserved for athletes who do not improve, are unable to return to sport for more than 6 months, or have worsening spondylolisthesis, which is more common with bilateral pars fracture [65, 67, 68].

Despite the fact that lumbar fusion for athletes may result in a career ending, athletes with spondylolisthesis or disc degeneration may need spinal fusion therefore If there is no evident disc pathology, pars repair and debridement of the fibrous defect may be sufficient, and athletes can return to play after 6–12 months [64, 69].

Intervertebral disc herniation

Sports such as soccer, American football, ice hockey, and basketball, which require repetitive flexion and compression during training and practice, are frequently associated with lumbar disc degeneration and herniation, which present with the same symptoms as in the general population, including low back pain, radicular pain, with or without neurologic deficits [65].

Both surgical and conservative treatment for LDP in athletes have high rate of recovery and return to play [65] Symptomatic treatment, early activity, strengthening exercises, and additional sport-specific activity are all part of the conservative management of athletes with LDP[9] and epidural injections may have a role in shortening the duration of treatment [70]. Return to play in athletes after traditional surgical treatment (laminectomy and microdiscectomy) of LDP is comparable to patients treated with non-surgical options, with a significant increase in games and years played. However, the effect of minimally invasive techniques on return to play has not yet been fully elucidated. However, decreased soft tissue manipulation may lead to faster recovery with a subsequent earlier return to play [71–75].

Return-to-play after thoracolumbar injuries

Generally, return-to-play after thoracolumbar injuries requires resolution of symptoms with full range of lumbar motion, and the ability to perform sports-specific movements and training without pain[65] while Athletes who have neurologic symptoms lasting more than 36 h, recurrent episodes of spinal neuropraxia, or MRI evidence of cord defect, cord edema, or ligamentous instability, should be excluded from return to contact sports[9].

Athletes with spinal fractures need to be clinically and radiologically confirmed as having a stable, healed compression fracture or spinous process avulsion with a painless, full range of motion and without neurologic deficits before permission for the return to play is granted [9].

Return to play after surgical or non-surgical treatment of lumbar disc herniation is common and safe but with different recovery periods, which have been reported from 2.8 to 8.7 months and career length from 2.6 to 4.8 years after lumbar discectomy[65, 73]while after conservative treatment, the athletes need between 4 to 12 weeks before return to play[67, 68].

Athletes with spondylolisthesis can return to play following a pars repair in 6–12 months, whereas athletes with spinal fusion require up to 12 months of physiotherapy and rehabilitation, with a less predictable return to play[65, 75].

Sports-related peripheral nerve injury

Peripheral nerve injuries in sports activities are uncommon, accounting for less than 0.5% of all sports-related injuries, but they can cause severe functional impairment with a long and variable recovery time [76]. Nerve injuries could be acute, subacute, or chronic damage and may be neurapraxia, axonotmesis, or neurotmesis [77]. In athletes, overtraining, bad technique or positioning, contact-related injuries, tissue swelling, and inadequate or ill-fitting protective equipment could cause stretching, compression, or laceration of the peripheral nerves in the upper or lower limbs, resulting in acute or chronic nerve damage [76–79].

Acute nerve injuries are caused by sudden forces acting on the nerve, going to cause compression, stretch, or laceration, whereas subacute and chronic nerve injuries are caused by overuse of certain joints or muscles, such as constant repetition of violent movements or constant muscular contraction, as in an athletic training regimen [76–79].

History-taking, physical examination, electrodiagnostic investigations, and particular imaging modalities such as MRI and ultrasound are used to diagnose peripheral nerve injuries. However, diagnostic nerve blocks may be required for sports-related nerve injuries [77].

The goal of treatment for sports-related nerve injuries, whether surgical or conservative, is to improve functionality and restore the patient to sporting activities. Most cases are treated conservatively with physiotherapy for patients who show functional and electrodiagnostic improvement after multiple tests. Injuries that don't show any signs of healing after a physical exam and electrodiagnostic testing are treated surgically [76, 77, 79].

The prognosis for neurologic recovery of peripheral nerve injuries is lower with proximal nerve damage however, full recovery is expected within 12 weeks after neurapraxia while there is no chance of spontaneous recovery in neurotmesis with full loss of nerve continuity[77].

In the upper limbs, specific nerves such as the spinal accessory nerve, long thoracic nerve, suprascapular nerve, axillary nerve, median nerve, ulnar nerve, and radial nerve are more prone to sport-related injury, whereas in the lower limbs, the lateral cutaneous nerve of the thigh, femoral nerve, peroneal nerve, tibial nerve, and pudendal nerve can be injured during sports activities [77–82].

Spinal accessory nerve injury

The spinal part of the accessory nerve is liable to direct impact damage during contact sports such as judo, karate, kickboxing, football, and hockey as it lies in the region of the neck just behind the scalene muscles. This leads to weakness in the trapezius which needs physical therapy until recovery, but if weakness persists for more than 6 weeks, EMG with nerve conduction studies is mandatory with surgical treatment. If there is no reinnervation potential and you return to sports training after normalization of shoulder function [77, 80].

Long thoracic nerve injury

The long thoracic nerve is vulnerable to injury in sports with heavy shoulder strains, such as archery, bodybuilding, tennis, volleyball, wrestling, and golf, due to its partial superficial route over the anterolateral chest wall[77]. The common clinical finding is a winged scapula, while EMG and nerve conduction studies reveal a neurogenic lesion in the serratus anterior. Physical therapy is used to treat the condition, and the process will take about two years [80].

Suprascapular nerve injury

Recurrent hyperabduction of the shoulder in baseball, volleyball, and tennis can harm the suprascapular nerve, resulting in shoulder discomfort and atrophy of the infraspinous and supraspinous nerves. The most common treatments are rest and physical therapy, but if those don't work, surgery may be needed [81].

Axillary nerve injury

Axillary nerve damage is caused by a fracture or dislocation of the humerus, and it causes deltoid muscle atrophy. Physical treatment can help with partial impairment, but complete damage necessitates surgery. Before returning to play, a complete recovery is required [77, 81].

Median nerve injury

Carpal tunnel syndrome is the most common nerve entrapment syndrome in the general population as well as in athletes, especially in golfers, tennis, cyclists, archery, bodybuilding, weightlifting, and wrestling, while pronator teres syndrome has been described in baseball, archery, weightlifting, and racket sports due to the need for excessive and repetitive movements. Pain in the forearm while pronating and sometimes weakness of the flexor pollicis and abductor pollicis brevis are the most common symptoms. To confirm and pinpoint the site of compression, EMG, nerve conduction tests, and ultrasound imaging are used in the diagnosis. Physical treatment is frequently used, and discomfort can occasionally be relieved with a local injection of corticosteroids, although surgical decompression can only be used in refractory cases [77].

Ulnar nerve injury

Direct trauma to the elbow can cause an acute nerve injury to the ulnar nerve. If there is no loss of continuity, the nerve can be treated conservatively for 8 weeks. If there is a loss of continuity, the nerve must be explored and surgically repaired [77]. Ulnar nerve entrapment at the level of the elbow joint is more common than acute injury, while ulnar nerve entrapment on Guyon's canal can be found in cyclists, wheelchair athletes, skiers, and snowmobilers [82, 83]. Initial treatment of ulnar nerve entrapment in athletes includes rest, physical therapy, functional rehabilitation, use of specialized gloves, and supportive braces during training and competition. Corticosteroid local injections may improve the symptoms and facilitate recovery and return to play, while surgical treatment is indicated in refractory cases [77, 82, 83].

Radial nerve injury

The radial nerve is most commonly affected in the radial sulcus on the upper arm, although it can also be damaged in athletes due to excessive and repetitive elbow extension, such as in racket sports and tennis. Rest and physical therapy are common treatments, but in resistant cases, surgery may be required [77].

Lateral femoral cutaneous nerve injury

The lateral femoral cutaneous nerve can be injured by contact trauma in football and rugby, as well as repetitive hip flexion and extension in jumping sports, and compression from external gear in diving [79, 82]. Paresthesia is the most common complaint. Since electrophysiological studies are difficult to perform, most diagnostics are clinical, and treatment includes a mandated modification in training and the use of appropriate sports equipment, in addition to medical therapy for neuropathic pain. In certain circumstances, local corticosteroids can help relieve symptoms[83].

Femoral nerve injury

Inguinal pain, numbness in the thigh, and sometimes leg weakness with lost knee reflex are all symptoms of femoral nerve injury, which can happen in sports like gymnastics, football, long jumping, basketball, bodybuilding, and skiing [77].

Tibial nerve injury

Tibial nerve can be injured by compression in the tarsal tunnel or upon ankle injury. pain and paresthesia in the sole of the foot, and the thumb, more at night and after long standing, walking or running are pathognomonic features. Analgesics, rest and corticosteroids injections are used but in refractory cases, neurolysis can improve the symptoms[84, 85].

Peroneal nerve injury

Common peroneal nerve injury in athletes could be acute injury or chronic overuse injury as in hockey, football and soccer. The nerve can be injured at the level of the knee or the ankle with subsequent pain and weakness. is physical therapy being the initial treatment of choice but EMG and NCV should be performed at 3–4 weeks [86]. In runners there is special clinical finding in which the nerve is compressed by the muscle fascia with normal motor power during rest and walking but foot drop develops during running therefor in this condition NCV before and after running will confirm the diagnosis which can be improved by fasciotomy. Deep peroneal nerve can be injured in skaters and skiers if inappropriate sports equipment compresses the nerve in the area of crossing from the ankle to the foot which improve without consequences after using the proper sports equipment [95].

Acute or chronic overuse injuries, such as those seen among hockey, football, and soccer players, are common causes of peroneal nerve injuries in athletes. The nerve can be injured at the knee or ankle level, resulting in discomfort and paralysis. Physical therapy is the first treatment of choice, but EMG and NCV tests should be done every 3–4 weeks during treatment and follow-up[84]. In runners, there is a special clinical finding in which the nerve is compressed by the muscle fascia with normal motor power during rest and walking but foot drop develops during running. Therefore, in this condition, NCV before and after running will confirm the diagnosis, which can be improved by fasciotomy. Skaters and skiers can be injured if inappropriate sports equipment compresses the nerve in the area of crossing from the ankle to the foot, which improves without consequences after using the proper sports equipment [86].

Pudendal nerve injury

Pudendal nerve entrapment is caused by prolonged sitting on a bicycle seat, such as in cyclists, and is characterized by pelvic pain, frequency, genital pain, and, in rare cases, urinary incontinence and erectile dysfunction. However, these symptoms disappear with rest and rarely last for weeks or months[87].

Conclusions

Sport neurosurgeons have more to contribute in both clinical care and research to the field of sports medicine. This role could include not only hospital care and management of sports-related head, spine, and peripheral nerve injuries, but also on-field assessment and sideline care of athletes, as well as a significant role in sports injury research.

Neurosurgeons and the neurosurgical community should be concerned about the growing knowledge and evolution in the field of sports medicine, and they should embrace significant advances in our understanding of sports-related neurological syndromes and sports neurosurgeons should be considered as an individualized aspect of neurological surgery.

Abbreviations

TBI	Traumatic brain injury
SRSBI	Sport-related structural brain injuries
SRC	Sports-related concussions
CTE	Chronic traumatic encephalopathy
SCI	Spinal cord injury
CT	Computed tomography
MRI	Magnetic resonance imaging
DAI	Diffuse axonal injury
FLAIR	Fluid attenuation inversion recovery
DWI	Diffusion weighted Image
fMRI	Functional magnetic resonance imaging
PET	Positron emission tomography
SPECT	Single photon emission computed tomography
GFAP	Plasma glial fibrillary acidic protein
NSE	Neuron specific enolase
UCH-L1	Ubiquitin carboxy-terminal hydrolase L1
miRNAs	MicroRNAs
ACDF	Anterior cervical discectomy and fusion

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All procedures performed in this article were in accordance with the ethical standards of the institutional research committee (zagazig university) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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I certify that i have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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