Chapter 1
Pre-Participation Screening for the Sports Neurosurgeon

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Role of the Neurosurgeon in Sports

The number of neurosurgeons serving in roles as team-affiliated physicians is expanding. In recent decades, several prominent sports neurosurgeons have paved the way for future involvement (Table 1.1). While coaches, parents, and certified athletic trainers (AT) can manage many of the common injuries, having a neurosurgeon involved in athlete management can add additional expertise and perspective while also facilitating the care of more catastrophic injuries. Examples of catastrophic injuries include cranial or spinal fractures and brain or spinal cord injuries resulting in severe disability. While these types of sports injuries are rare, they often have life-changing implications. Amongst youth, collegiate and professional football between 1947 and 1999, there were 497 brain-injury related deaths, which is potentially an underestimation [1]. Additionally, 200 high school and collegiate football players suffered permanent cervical spinal cord injuries and 66 suffered permanent brain injuries during a 21 year window from 1977–1998 [2]. Neurosurgeons manage these catastrophic injuries routinely, and can seamlessly transfer their experience to provide care for the same injuries in athletes.

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Table 1.1 Prominent neurosurgeons in sports

Dr. Richard C. Schneider	Dr. Richard C. Schneider, largely considered the father of sports neurosurgery, was a collegiate swimmer and lacrosse player who would go on to be chair of the University of Michigan Neurological Surgery Department. During his career, he provided major contributions to neurosurgery as well as athletics. He would go on to describe anterior cord syndrome, clarify central cord syndrome, as well as deepen our understanding of teardrop fractures and second-impact syndrome [56–62]. He started a laboratory to model head and neck injury and was intimately involved in the development of modern-day football helmets with his work guiding major rule changes to improve player safety [63–65]
Dr. Robert C. Cantu	Dr. Robert C. Cantu trained at mass general hospital and would later serve as the team physician for a local high school, which sparked his interest in minor head injuries. He served as the first chairman of American Association of Neurological Surgeons (AANS) section on sports medicine. His work includes one of the first attempts to standardize sport-related concussion (SRC) management through a grading system with return-to-play guidelines, and everlasting emphasis on the importance of recovery in avoiding complications of SRC, including second impact syndrome [62, 66]. He remains the head of several sports injury registries and serves as a consultant to the National Football League (NFL) [63]
Dr. Joseph C. Maroon	Dr. Joseph C. Maroon was a collegiate American football player and trained at the University of Indiana. He served as a local advisor for sports teams and ultimately as the Pittsburgh Steelers' team neurosurgeon. He was the second chair of the AANS section on sports medicine. He helped to develop the immediate post-concussion assessment and cognitive test (ImPACT), one of the first, and most frequently utilized, computerized neurocognitive testing system [67, 68]. This information provided insight into the timeline of recovery. Computerized neurocognitive testing is now often considered an essential component of the return-to-play process at all levels of sports [63]. Additionally, he has published on post-concussion syndrome and possible non-pharmacological treatments [69]
Dr. Julian E. Bailes	Dr. Julian E. Bailes was an All-State high school American football player in Louisiana before playing in college at Northwestern State. He trained at Louisiana State University and would go on to be the fourth AANS Section on Sports Medicine Chair. He coedited a book *Neurological Sports Medicine: A guide for Physicians and Trainers* [70]. He also made significant contributions to rule changes made in football to improve player safety including return-to-play guidelines in spinal cord injury and delineated the risks of heatstroke in athletes [63, 71–73]. Dr. Bailes is on the forefront of chronic traumatic encephalopathy (CTE) research and was involved in the highly publicized early case reports of CTE [74, 75]. His work in this domain led to his portrayal as a leading character in the movie *Concussion*, which outlined his work and contributions to the field. His impact has extended beyond just football to other sports such as boxing where he has contributed to ringside evaluation, analyzing when to halt a match for safety concerns, and delineated the role of the neurosurgeon for the sport [76–78]
Dr. Allen K. Sills	In 2020, the Chief Medical Officer (CMO) of the NFL is also a neurosurgeon, Dr. Allen K. Sills. Dr. Sills began his career working with the Memphis Grizzlies, Mississippi State Athletics, Vanderbilt University Athletics, Southeastern Conference Sports, and the Nashville Predators. Dr. Sills has focused his leadership on sport-related concussion (SRC) and the ongoing Coronavirus pandemic

The multi-disciplinary care of athletes is an evolving area of medicine, and many healthcare practitioners provide high-level care to athletes. Orthopedic surgeons represent the classic team physician, provide an invaluable service with regards to managing musculoskeletal injuries, and often lead the medical care of athletes; however, brain injuries may be outside the scope of their training. Additional members of the sports medicine team include internists, emergency medicine doctors, oral surgeons, ophthalmologists, plastic surgeons, chiropractors, and sometimes neurologists. Furthermore, experienced nurse practitioners and physician's assistants that specialize in sports medicine can be vital members of the team [3]. Importantly, certified ATs are some of the most vital members of the sports medicine team, especially at lower levels of play, where physicians are less present. ATs have invaluable knowledge of the team and their players and are often with the team daily. A prerequisite to success for any team physician is a close relationship with the team's AT.

Though the focus of this chapter is on pre-participation screening, it should be briefly noted that neurosurgeons can participate in sports through a variety of mechanisms. Additional areas of involvement include: event coverage to assess and manage acute brain and spine injuries, development and implementation of a concussion plan including return to play protocols, education within the community for other physicians, coaches, athletes, schools and/or parents, as well as participation in regulatory agencies to support these stakeholders.

Epidemiology of Sport-Related Concussion and Catastrophic Neurologic Injuries

Given the breadth of sports that require pre-participation screening, a brief discussion of the epidemiology surrounding sport-related concussion (SRC) and catastrophic injuries is helpful in contextualizing the landscape of neurologic injuries in sports. Though professional athletes receive significant attention, the majority of the burden of injury falls amongst youth and high school athletes. Moreover, resources for medical care at these lower levels are often sparse compared to the professional level.

SRC and mild traumatic brain injury (mTBI) are significant contributors to rates of injury, particularly in contact sports. It is estimated that there are between 1.6 and 3.8 million SRCs annually in the United States, which represents 5–9% of all sports injuries [4]. Additionally, this number is widely considered underreported as concussions may either go undiagnosed or an athlete may downplay symptoms, so they may continue to participate. Catastrophic neurologic injuries, defined as a severe injury to the brain or spine, are not common occurrences yet require typically emergency care and attention. Examples of these injuries include: subarachnoid hemorrhage (SAH), epidural hemorrhage (EDH), subdural hemorrhage (SDH), intraparenchymal hemorrhage (IPH), diffuse cerebral edema (DCE), and diffuse axonal injury (DAI). In a 26 year window amongst middle school and high school athletes of various sports, 980 individuals or 0.6 per 100,000 participants suffered a catastrophic injury [5]. Of note, 635 of those individuals were football players with a rate of 1.78 per 100,000 participants [5]. In high school sports, the average rate of catastrophic injury is 0.6 per 100,000 participants per year, which correlates with 37.7 catastrophic injuries per year in the U.S. Though rare, the presence of catastrophic injuries in sports of all levels allows neurosurgeons to play an important role in acutely managing these injuries, as well as to participate in the return to play process.

Pre-Participation Screening

Pre-participation screening includes a focused neurologic history with an in-depth concussion history and consideration of baseline cognitive, balance, and symptom assessments. Most scholastic-based sports require some type of preparticipation screening process, where neurosurgeons can play an important role. Much of this process is done by the athlete's pediatrician or primary care physician, yet neurosurgeons' expertise can help with complex patients with those with prior neurological conditions.

What Sports Require Screening?

Sports are often categorized into contact and non-contact sports, and contact level has major implications for subsequent brain and spine injury risk. The American Academy of Pediatrics has released analyses of medical conditions affecting sports conditions. Historically, the academy has defined sports into 3 categories of contact: contact, limited-contact, and noncontact. We have slightly modified these categorizations to differentiate collision sports that confer a higher risk of catastrophic injury (Table 1.2) [6, 7]. Based on this modified classification, collision sports includes sports with frequent and potentially high velocity player-player contact such as football and hockey, while contact sports include soccer and basketball. Limited contact sports include baseball, volleyball, and horseback riding while noncontact sports include golf, swimming, tennis, amongst others.

All sports require screening. Typically, SRC screening focuses on collision sports that are often most popular, such as football, soccer, hockey, and basketball; however, the impact of SRC extends far beyond these common sports. Amongst collegiate athletes, rates of concussion were highest among wrestlers, occurring

Table 1.2 Classification of sport

Collision	Contact and Collision	Limited Contact	Noncontact
Boxing	Basketball	Baseball/softball	Archery
Football (tackle)	Diving	Bicycling	Badminton
Ice hockey	Field hockey	Cheerleading	Body building
Lacrosse (men's)	Lacrosse (women's)	Canoeing/kayaking (white water)	Bowling
Martial arts	Ski jumping	Fencing	Canoeing/kayaking (flat water)
Rodeo	Soccer	Field events	Crew or rowing
Rugby	Team handball	Floor hockey	Curling
Wrestling	Water polo	Football (flag)	Dancing
		Gymnastics	Track and Field
		Handball	Golf
		Horseback riding	Weightlifting
		Racquetball	Race walking
		Skating	Riflery
		Skiing[a]	Rope jumping
		Skateboarding[a]	Running
		Snowboarding[a]	Sailing
		Squash	Scuba diving
		Surfing (water/wind)	Swimming
		Ultimate Frisbee	Table tennis
		Volleyball	Tennis
			Track
			Weightlifting

[a]It should be noted that these "extreme sports" require helmets and have a higher risk for severe injuries, though they are limited contact
Adapted from two sources: [6, 79]

almost 11 times per 10,000 athletic events [8]. Though American football bears the highest SRC rate across all high school sports, it ranks 13th amongst National Collegiate Athletic Association (NCAA) sports in recurrent concussions, which are often the source of long-term symptoms and delayed return to school and play [8, 9]. Other NCAA sports such as men's ice hockey, women's field hockey, men's basketball, and women's soccer all had higher rates of repeat concussions in a study from 2009–2014 [8].

With respect to SRC, mechanisms of injury vary significantly between sports. In contact and collision sports, the most common injury is player-player contact, but many injuries seen in limited contact and noncontact sports such as baseball, swimming, gymnastics, and tennis are a product of player-surface or contact with equipment during competition [8]. Additionally, SRC are not limited to team sports. For example, many head injuries suffered during equestrian sports are severe and represent a significant health burden that should not be overlooked [10].

Neurological History

Knowing a patient's neurological history can assist medical decision-making, clearance, and return to play [11]. Often times, the historical information used in the decision-making process is based on subtle differences and clarifications that may not be elicited by individuals who are not aware of those subtleties. Important aspects of the neurological history for an athlete include:

– *Any major brain or spine injuries*: Any type of severe cranial trauma or spine trauma related to sports or any other accidents such as motor vehicle collisions must be identified.
– *Concussion history:* Quantification and qualification of this history is essential. The athlete's number of prior concussions, approximate time missed for the concussion, and severity of symptoms must be delineated. It is important to be holistic and not focus solely on the athletic impact. Concussions can affect school, relationships, and psychologic status. These can also serve as adjuncts to assess for severity of concussion in patients unable to recall specific symptoms [11].
– *Seizure history*: Athlete's seizure history is important to document as patients who have TBI are at an increased risk of having seizures. Having a baseline seizure disorder including febrile seizures are important as they may suggest an increased likelihood of seizure in the setting of concussion or TBI [12].
– *Headache history*: Knowing an athlete's headache status is important for symptomatic management. Understanding the specifics of headache type, frequency and quality are critical for evaluation of post-injury headaches. A poor understanding of baseline headache history can lead to an athlete returning to play too soon or being held out of competition longer than is necessary. Additionally, athletes who have conditions such as headache are more likely to develop post-concussion syndrome [11].
– *Psychiatry conditions/medications*: Athletes who have a psychiatric condition or are on any type of mood-altering drug should be thoroughly assessed. This gives a baseline symptom and medication requirement that can be used for comparison in post injury management. Additionally, athletes with a family or personal history of psychiatric conditions are more than 5 times as likely to develop post-concussion symptoms [13].
– *History of learning disability*: Athletes with learning disabilities including attention deficit hyperactivity disorder (ADHD), as well as those who need special education, and/or require repetition of grades may demonstrate higher rates of concussion, lower baseline neurocognitive test scores, more baseline and post-concussion symptoms and/or prolonged recovery [13–18].
– *Hydrocephalus or shunt device*: Athletes having a history of these conditions are more complex medically in the setting of injury and symptomatic presentation from their baseline condition may overlap with concussion symptoms [12, 19].
– *Family history of medical conditions*: First degree family histories of headache, epilepsy, and psychiatric conditions are of critical importance as athletes in

youth sports may have a predisposition or undiagnosed condition given varying age of onset of different conditions. The family history may provide a way to screen for development of these baseline conditions that can affect post-concussion assessment [13].

It is incredibly important to be specific in assessing all these aspects of the athlete's history. Often, asking a blanket question regarding an athlete's neurological history may lead to missed or incorrect information, most often due to simple misunderstanding of what is important to mention. Athletes tend to focus more on their history of musculoskeletal injury and may minimize their prior neurologic issues due to the perception of lack of severity or minimal missed time from sport. Young, high performing athletes may simply deny any past medical history when asked broadly, but detailed inquiry about missed games or practices may reveal a variety of injuries that were not mentioned in the first response. For example, asking if they have ever missed any games for any reason will be higher yield than simply asking if they have ever had any injuries. Additionally, direct questioning such as, *"Have you ever had or been diagnosed with a concussion?"* will provide better information than asking if they have any general medical problems. It is important to assess patient understanding of medications that they may take. For example, if a patient takes an antiseizure medication, it is important to ask if they understand why they take that medication.

Baseline Testing

In addition to a complete history and exam, athletes often require baseline cognitive assessment, balance assessment, visual assessment, and baseline symptom inventory. With respect to SRC, many school systems obtain annual or biannual baseline neurologic screening – a battery of neurologic and/or neurocognitive tests – prior to initiation of competition, in order for athletes who suffer a SRC to be compared to their own performance, rather than normative values. The most commonly used cognitive assessment is the computerized ImPACT battery, which provides objective measures of memory, attention, visual, and verbal problem solving [20]. Balance is typically tested using the modified Balance Error Scoring System (mBESS), which measures balance loss during 3 different poses [21]. The Sport Concussion Assessment Tool (SCAT) combines a neurologic screening, cognitive assessment, balance evaluation and the Post-Concussion Symptom Scale (PCSS) into a single efficient and comprehensive evaluation either on the field or in the clinic [22]. Baseline measures are often obtained by a neuropsychologist or AT, and though the neurosurgeon is not the one performing these tests, every sports neurosurgeon should be familiar with all baseline tests given their relevance in the post-concussion testing. These tests may be administered in an office individually or in a team/group setting at the beginning of the season.

Screening for Specific Cranial and Spinal Conditions

While there are many factors that determine the safety of an athlete's participation in sport, studies looking at various cranial or spinal conditions and their safety profile for participation have been published in an attempt to guide providers. Unfortunately, much of the prior literature consists of summative reviews rather than primary data. Some of the most relevant studies on cranial and spinal conditions are summarized for in Tables 1.3 and 1.4, respectively. Though neurosurgeons involved in these complex decisions would appreciate all-encompassing guidelines, most studies suggest that each athlete must be considered on a case-to-case basis given the complexity of a neurological patient, the athlete's desired long-term goals, level of competition, and type of sport (contact, limited-contact, non-contact). Below, we aim to provide guidance for individual conditions based on the available literature. While each one of these conditions could be the subject of a single chapter, we briefly summarize some of the relevant studies and present the most up-to-date recommendations regarding commonly encountered neurologic conditions.

Table 1.3 Cranial conditions

Condition	Author, year	Synopsis
Arachnoid cyst	Zaben et al. 2020 [19]	Survey of pediatric neurosurgeons in the UK All respondents allow participation in soccer 91.2%, 55.9%, and 53% allow participation in skiing, rugby, and taekwondo respectively
	Strahle et al. 2016 [23]	112 patients who played a variety of sports No patients with permanent neurological injury or injury requiring treatment by surgical intervention Two patients with subdural hygroma Safe to participate
	Miele et al. 2006 [12]	Expert commentary Possible increased risk of bleeding but not proven Recommend risk-benefit discussions with patient/family Not an absolute contraindication to play
Brain tumor	Stanuszek et al. 2020 [26]	42 patients 6–18 years with brain tumors 71.4% safely returned to contact sports, but not collision sports Predictors of not returning to play included worse WHO grade, tumor location, neurological deficit, hydrocephalus, and additional oncological treatment
	Davis et al. 2009 [25]	Expert commentary on an athlete with a tectal glioma and an athlete with a frontal meningioma Cleared to compete in contact sports if no neurological deficit and complete bony fusion after craniotomy One expert felt presence of a cyst should restrict athlete

Table 1.3 (continued)

Condition	Author, year	Synopsis
Cavum septum pellucidum	Gardner et al. 2016 [80]	Case matched study of 17 retired professional football players Increased prevalence and severity of cavum septum pellucidum No known clinical significance
	Miele et al. 2006 [12]	Expert summary Often result of trauma and not clinically relevant Isolated disease should not preclude participation
Chiari malformation	Zaben et al. 2020 [19]	Survey of pediatric neurosurgeons in the UK Paucity of evidence regarding Chiari and CSF obstruction Most decisions made based on personal experience of the physician
	Strahle et al. 2016 [28]	328 patients with a mean age of 10.7 with Chiari I malformation (CM-I) playing a variety of sports No increase catastrophic injuries Safe to participate in sports
	Meehan et al. 2015 [27]	147 patients ages 11–19 with diagnosed Chiari malformation playing a variety of sports No increase catastrophic injuries Case-by-case decision
	Harrell et al. 2010 [81]	Case report CM-I safe to participate in sport unless there is: Syringomyelia, obliteration of subarachnoid space, indention of anterior medulla, symptoms thought to be related to CSF flow
	Miele et al. 2006 [12]	Expert summary Syringomyelia, obliteration of the subarachnoid space, indentation of the anterior medulla, or symptomatic disease are contraindications for participation in sport Against participation if CM-I is diagnosed during concussion diagnosis/evaluation
	Callaway et al. 1996 [82]	Case report and expert consensus on CM-I causing functional spinal stenosis Syringomyelia, obliteration of the arachnoid space, or indentation of the anterior medulla are contraindications for contact sports
Previous craniotomy	Laker, 2011 [29]	Expert summary Precludes sport participation for 1 year Later participation should be evaluated by a multi-specialty team
	Miele et al. 2006 [12]	Expert summary Three concerns of previous craniotomy are bone flap weakness, fragility of underlying tissue, and possible CSF flow abnormalities None of these permanently preclude participation

(continued)

Table 1.3 (continued)

Condition	Author, year	Synopsis
Seizures	Capovilla et al. 2016 [32]	ILAE task force statement Benefit of seizure control in physical activity and sports participation exceeds the risk of participation Sports tiered by risk factors Consider seizure type, frequency, triggers, timing, and patient/family attitude towards possible risk
	Stanuszek et al. 2015 [83]	407 children hospitalized for seizure 3.4% associated with physical exertion or sport
	Pinikahana et al. 2009 [31]	225 patients with epilepsy 16.4% cited physical exercise as a provoking factor
	Miele et al. 2006 [12]	Expert summary Potential risks associated with participation are outweighed by the benefit of participation in other aspects of health No restriction to participation Caution should be taken with sports involving risk of fall especially from height
	Nakken et al. 2005 [30]	1677 pediatric patients in multiple cohorts 0.3–6.0& cite physical activity as a provoking factor
	Sahoo et al. 2004 [84]	Expert summary Risks of sports are outweighed by the seizure control benefits of exercise Case-by-case evaluation of athletes
	Frucht et al. 2000 [85]	400 epilepsy patients 0.5% cite physical activity as a provoking factor
Shunt	Zaben et al. 2020 [19]	Survey of pediatric neurosurgeons in the UK Paucity of evidence regarding CSF flow and sport participation Most decisions made based on personal experience
	Miele et al. 2006 [12]	Expert summary Low complication rate Most common are shunt dysfunction or fracture Most neurosurgeons do not prohibit noncontact sports, but most restrict contact sports
	Blount et al. 2004 [33]	Survey of 92 pediatric neurosurgeons >75% of physicians had not seen sport-related complication of shunt Shunt dysfunction or fracture were most common No evidence to suggest that restriction from sport is necessary
Vascular lesions	Sousa Nanji et al. 2015 [86]	738 cases of SAH 57.5% of cases were associated with physical activity 1.2% of cases were associated with sports, 1 sport related trauma Sport induced SAH is uncommon and has milder presentation
	Davis et al. 2009 [35]	Expert commentary on cavernoma No strong evidence for or against participation An incidental, asymptomatic cavernoma clear for participation

Table 1.4 Clearance and RTP in athletes with cervical spine pathology

Author, year	Synopsis
Richards et al. 2020 [87]	73 golf/tennis/swimming athletes with cervical spine surgery Median (range) age 69 (33–90); older athlete population ACDF 63%; 19% cervical laminectomy; 18% cervical laminectomy/fusion 81% returned to preoperative sport practice; 68% returned to golf; 31% returned to tennis; 82% returned to swimming
Schroeder et al. 2020 [44]	Modified Delphi consensus among cervical spine surgeons 1–2 level ACDF appropriate for RTP; not for 3-level ACDF Asymptomatic athletes with cervical stenosis OK for play (canal >10 mm 90.5%; resolved MRI findings >13 mm 81.3%)
Kang et al. 2016 [43]	Review concluding that 1-level ACDF can safely return to play No consensus regarding 2–3 level ACDF; most studies say contraindication to RTP Poor consensus on other cervical procedures
Molinari et al. 2016 [88]	Review of 9 studies, 175 patients 1-level ACDF appropriate for RTP; controversy over all else 6 months is appropriate time for RTP after fusion-procedure
Tempel et al. 2015 [89]	5 professional athletes with T2 hyperintensity on MRI after spinal cord contusion 4/5 underwent ACDF; 1 nonoperative Signal change was NOT a contraindication if no symptoms The 2 athletes that have RTP have had no sequelae
Maroon et al. 2013 [42]	15 pro athletes underwent 1-level ACDF (7 football; 8 wrestlers) Transient neuropraxia most common presentation 13/15 athletes RTP between 2–12 months

Cranial Conditions

Arachnoid Cyst

In a study of 112 athletes with arachnoid cyst, there were no subjects who suffered permanent neurological injury, and complication rates related to sports were very low [23]. In an expert commentary by Miele et al. the authors consider the theoretical increased risk of subdural or intra-cyst hemorrhage, but there is no clinical evidence to support these concerns presently as reasons to limit sport participation [12]. However, a survey of UK neurosurgeons showed that there are inconsistencies between providers and the sport in question [19]. The authors of this chapter feel that at this point in time, there are no absolute contraindications for patient with arachnoid cysts to participate in sport, unless there is history of a prior cyst-related hemorrhage. However, parents and athletes should be counseled appropriately [24].

Brain Tumor

While brain tumors encompass a wide variety of pathologies and symptomatic features, Davis et al. showed that some experts believe athletes should be allowed to play if they do not have any neurological deficit or high-risk feature for sudden decompensation as a result of their tumor [25]. Additionally, it has been shown that athletes with tumors have safely returned to play, but predictors of their ability to participate include WHO grade, tumor location, neurological deficit, adjuvant oncological treatment and the presence of hydrocephalus [26]. Other considerations such as clearance for participation after undergoing craniotomy for resection are discussed in subsequent sections.

Chiari Malformation

Studies by Meehan et al. and Strahle et al. have shown that the risk of catastrophic injury in athletes with Chiari malformation is quite low, and report 0 cases in their studies [27, 28]. Additionally, an expert consensus by Miele et al. and a survey amongst pediatric surgeons by Zaben et al. show that it is typically safe for these athletes to participate, as long as they don't have high risk features including syringomyelia, obliteration of subarachnoid space, indentation of the anterior medulla, or symptoms thought to be related to changes in CSF flow [12, 19]. The presence of a syrinx or brainstem/spinal cord compression are contraindications to participation in sports, as these patients likely require surgery. Anecdotally, many providers would allow return to sports participation after successful Chiari malformation decompression, after full recovery and resolution of pre-operative symptoms, syrinx, and brainstem compression. Our practice throughout the last decade reflects this management approach.

Previous Craniotomy

Experts have suggested that athletes who have had a craniotomy for any type of pathology should wait at least 1 year prior to returning to competition, to allow fusion of the bone flap, especially those participating in contact sports [12, 29]. Previous concerns included the possibility of flap weakness, fragility of underlying tissue, or changes in CSF flow after operation [12, 29]. While a craniotomy itself does not prohibit participation, it is important to assess the athlete in the setting of their underlying pathology as well. Previously treated and resolved pathology should not impede sport participation (benign brain tumor, resolved aneurysm with no rupture); however, unresolved conditions requiring further treatment should be considered cautiously (subtotal resection, etc.).

Seizure

While the rates of epileptic seizures being provoked by physical activity vary greatly, ranging from 0.3–16% of all seizures, the consensus is that the benefit of sport participation from a seizure control standpoint and other comorbidities strongly outweigh the risk of seizure provocation [30, 31]. In a task force statement by the International League Against Epilepsy (ILAE) on Sports and Epilepsy, the authors recommend that individuals should not be restricted from athletic competition due to seizures [32]. However, careful consideration should be given to seizure type, specifically drop-attacks and those involving loss of consciousness, especially for sports involving heights. A neurologist's input for these patients can also be very helpful.

Shunt

In three studies surveying pediatric neurosurgeons on their experience treating sport-related shunt complications, the overwhelming majority have seen very low rates of sport-related shunt complications [12, 19, 33]. In a survey of 92 pediatric neurosurgery providers, 77% had never observed a sport-related shunt complication, and the remaining 23% treated a total of 25–30 complications. The most common complications were broken shunt catheters or shunt dysfunction, with only one acute intracranial hematoma observed. The authors concluded that the incidence of sport-related shunt complications in children was significantly less than 1%. Moreover, 90% of pediatric neurosurgeons did not restrict their patients' participation in non-contact sports, and for contact sports, 33% recommend no participation, 33% decided on a case-by-case and sport basis, and 33% allowed contact sport play. Given the low frequency and severity of complications, we believe that patients with VP shunts should be allowed to participate in athletic competition, though counseling should be offered about high-contact and collision sports that may create hardware disruption [12, 19, 33].

Vascular Lesions

Vascular lesions include a variety of conditions such as aneurysms, arteriovenous malformations (AVMs), and cavernomas. Routine screening for vascular lesions in athletes is not done. Incidental aneurysms should be evaluated and treated accordingly. Our anecdotal approach to incidentally found aneurysms is that if the aneurysm does not need to be treated based on the surgeon's assessment or rupture risk (though this is rare in a young person), the athlete can play with the understanding that the athlete may be at an increased risk compared to an athlete without an aneurysm. If the aneurysm does require treatment, and is successfully treated, the athlete can play after full recovery. For large AVMs, we would likely recommend against intense physical activity, but for other, smaller lesions, we recommend treatment on a case-by-case method, depending no sport, location, and size of the AVM. Like aneurysms, if fully treated, RTP after a full recovery is allowed. An 18-year-old football player suffered an AVM rupture during exercise, received radiosurgery, and successfully returned to play [34]. For cavernomas, Davis et al. provided an expert commentary stating that if a patient has an asymptomatic, incidentally found cavernoma, they should be able to participate in athletic competition [35].

Spinal Conditions

Spine pathology requiring screening includes congenital conditions, previous trauma, and postoperative clearance. Below we have broken down spine clearance by specific pathology, yet many reports focus on postoperative RTP. According to patient experiences from 98 neurosurgeons who operated on athletes, Saigal et al. [36] reported that 72% of patients with spinal instrumentation returned to sport, whereas 28% did not, and nearly all (97%) of patients that underwent uninstrumented spine procedures returned to sport. Football was the primary sport in 55% of cases. Similar percentages of pediatric (82%) and adult (92%) patients were allowed to RTP. The most controversial area regarding clearance of spinal conditions deals with the cervical spine, and relevant studies have been succinctly summarized in Table 1.4**.** Below we elaborate on specific preexisting and postoperative conditions.

Cervical Stenosis

Cervical stenosis, with or without an episode of neuropraxia, is perhaps the biggest controversy regarding spine clearance in athletes. The major decision point is stenosis with or without a symptomatic episode (most often transient quadriparesis), as symptoms usually unmask the previously unknown stenosis. Davis et al. [37] highlighted both these scenarios with expert commentary. For asymptomatic athletes, the experts acknowledged a lack of literature to guide the ultimate decision. Cantu and colleagues stated that effacement of CSF in an asymptomatic athlete represented functional stenosis, and players should not be allowed to participate in sport [38, 39]. However, others have argued for a more lenient approach, that after appropriate counseling with a neurosurgeon, athletes should be allowed to participate as long as they understand the inherent risk [37]. Moreover, the experts also agreed that previous Torg-Pavlov ratios may not be useful in athletes, as the ratio had a positive predictive value of 0.2% [37]. The experts also agreed that a transient episode of quadriparesis in an athlete, without radiographic stenosis, does not preclude RTP [37, 40]. Drawing from a systematic review of cervical contusions, Nagoshi et al. [41] describe two cases of spinal cord contusion without radiographic stenosis; one pediatric patient had no recurrent symptoms, and an adult experienced a recurrence after RTP. In the setting of stenosis, some returned successfully while others suffered permanent neurologic deficit, highlighting the heterogeneity of practices. Despite expert commentaries from spine surgeons involved in the care of professional athletes, no all-encompassing guidelines exist, and an individualized approach specific to athlete is recommended.

Cervical Surgery

The most literature exists surrounding clearance for play after anterior cervical discectomy and fusion (ACDF). Maroon et al. [42] reported 15 professional athletes after 1-level ACDF, and 13/15 athletes returned between 2–12 months. Overall, the consensus is that athletes who undergo 1 and 2-level ACDFs may return to play after fusion has been confirmed, whereas 3–4 level ACDF is likely a contraindication to participation in sport. Two reviews have provided similar conclusions regarding 1 and 2-level ACDF [43, 44]. However, there is no current consensus on sport participation after cervical disc replacement, posterior cervical decompression and/or fusion, and posterior cervical laminoplasty.

Down's Syndrome and Atlantoaxial Instability

Individuals with Down's Syndrome have high rates of atlantooccipital (AO) and atlantoaxial (AA) instability, affecting approximately 7% to 27% of patients with Down's syndrome [45]. One study of 80 patients with Down's syndrome reported 17.5% with atlantooccipital instability, and 11.2% had atlantoaxial instability [46]. Yet, only 3.8% of patients had symptoms referable to the documented instability. The authors defined AO instability as the basion-dens interval (BDI) or the basion-axial interval (BAI) >12 mm, and AA instability as ADI of >3 mm. The authors widely concluded that follow-up was appropriate, rather than any immediate surgical action. With regard to sport, special Olympics and other activities can be a major source of enjoyment, pride, and confidence for this population. Myslieiec and colleagues summarized the literature and concurred with the Special Olympics Rules, [45, 47] flexion-extension x-rays should be obtained for any Down's Syndrome patient participating in most organized sports, including: butterfly stroke, diving, pentathlon, high jump, equestrian sports, artistic gymnastics, soccer, alpine skiing and any warm-up exercise placing undue stress on the head and neck [45]. Tassone and colleagues [48] summarized the pathophysiology of AO/AA instability and treatment recommendations. For asymptomatic athletes with AO/AA instability, no reports exist of neurologic injuries incurred from sport in athletes with Down's Syndrome, yet follow-up is crucial. Any concern over canal narrowing on x-ray warrants an MRI scan. If symptomatic, surgery may be appropriate, though operative treatment still has challenges. Younger age and other spinal anomalies may contribute to non-union rates, [49] and fusion to the occiput may be required, though it adds additional morbidity.

Os Odontoideum

Os ondotoideum is a congenital or acquired condition where the dens is separated from the body of C2. The tip of the dens, instead of connected to the inferior C2 body, is a separate, smooth ossicle, variable in shape and size, with an obvious gap from the shortened odontoid process. Little guidance exists regarding os odontoideum and sport participation. Similar to Down's syndrome patients, any evidence of cervical instability requires further workup, and surgery may be indicated if symptomatic, most often a C1/2 fusion. Any sign of instability, such as a pathologic increase in the atlanto-dens interval (ADI) requires further workup, and the athlete should not play until the workup is resolved. Also, evidence of stenosis should be evaluated and treated accordingly.

Stingers

Stingers, also known as “burners”, are characterized by an intense, electric-like pain occurring unilaterally down one arm, associated with numbness and/or weakness in the arm and hand. Stingers typically last for 10 seconds or less, but can last for hours or even days, and are caused by transient compression or irritation of proximal nerve roots or more distal peripheral nerves, most often in the brachial plexus. Stingers are very common, especially in American football players due to the tackling technique of hitting between the neck and shoulder area. In a study of 57 NCAA football programs from 2009–2015, 229 stingers were reported with a rate of 2.04 per 10,000 athletic events [50]. One in five stingers (19%) were recurrent, and most injuries occurred during player contact (93%) during tackling (37%) and blocking (26%). First time stingers, once symptoms are resolved, can return to competition the same day after pain resolves and full range of motion and strength resume [51]. In many cases, the athlete may be out of the game for only minutes. Athletes with second-time stingers are withheld from the remainder of play that day, but can return once the pain resolves, assuming they remain with full strength. Third- and fourth-time stingers require cervical imaging, including flexion-extension x-rays and an MRI, as these recurrent injuries may be a sign of existing foraminal or central stenosis.

Lumbar Spine

For lumbar spine conditions, if the spinal cord is not involved, disc herniations and stenosis can be treated nonoperatively, and the athlete may return to play as long as they can tolerate the pain and no neurologic compromise is identified, such as a foot drop. Fractures and traumatic injuries require a workup for stability, and the athlete should not be cleared until this is completed. Several reports exist on clearance and return to play in athletes after lumbar spine surgery. Importantly, the risk is significantly less than cervical lesions, yet still worthy of discussion. Clearance for return to sport after lumbar decompressive surgery is fairly straightforward, most often occurring in the 6–12 week time period, yet more controversy exists over fusion. Hsu et al. [52] evaluated 342 North American professional athletes with lumbar disc herniations, and 226 (66.1%) required surgery. Professional baseball players had a higher return to play rate than other sports, whereas American football players had a lower rate than other sports; however, no specific return to play times were reported. In 87 NHL players with lumbar disc herniations, 31 treated nonoperatively, 48 undergoing discectomy, and 8 undergoing a single-level fusion, return to play was high for all athletes at 85% [53]. The lumbar fusion group did not show a decrease in games played per season or performance after surgery [53]. Moreover, return to play after lumbar fusion in golfers, a low contact sport, is high, with 50% returning to on-course play within 1 year of lumbar fusion surgery [54]. Larger fusions for spondylolisthesis or scoliosis correction should be counseled on an individual patient basis, and likely require a longer recovery period before return to play [55].

Conclusions

In an athlete with an existing neurologic condition or prior neurologic injury, clearance for participation is rarely straightforward, with many academic, sport, and personal factors to consider. Neurosurgeons are often asked to provide informed counseling for parents and athletes in these situations. Given the absence of accepted, all-encompassing guidelines, obtaining a full neurologic history and exam in each individual athlete is crucial, as each athlete is truly unique. Though neurosurgeons are charged with leading these complex decisions, in most cases, parents and athletes ultimately make the final decision to return or not after understanding the potential associated risks. Sports neurosurgeons should understand the factors important in pre-participation screening, lead the multi-disciplinary discussions involved in sport participation, and continue to improve the process of pre-participation screening.

Conflicts of Interest/Financial Disclosures None.

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