Narrative Review Article

Spine Injuries in Youth Athletes: A Review of Epidemiology, Diagnosis, Treatment, and Prevention

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ABSTRACT

Participation in organized sports provides substantial physical, psychological, and social benefits for children and adolescents; however, increasing training demands, year-round competition, and early specialization have contributed to growing concerns about sports-related injuries. Spinal injuries are particularly important because they may lead to persistent pain, neurological impairment, prolonged absence from sports, and long-term functional limitations. This narrative review summarizes the current evidence on epidemiology, developmental anatomy, biomechanics, injury patterns, risk factors, diagnosis, management, return-to-sport considerations, and prevention strategies for spinal injuries in youth athletes. A targeted, non-systematic review of the pediatric and adolescent spine injury literature was conducted using PubMed and Google Scholar. Relevant systematic reviews and consensus statements were also included. When pediatric-specific evidence was limited, findings from adult athletes, biomechanical studies, and broader sports medicine literature were included and clearly identified as extrapolated. The developing spine differs from the adult spine because of ongoing ossification, greater ligamentous flexibility, and immature neuromuscular control, resulting in unique injury patterns. Spondylolysis is the most common structural cause of persistent low back pain in adolescent athletes. In contrast, cervical spine trauma is the most serious spinal injury because of its potential for neurological injury. Diagnosis requires the integration of clinical evaluation, appropriate imaging modalities, and consideration of skeletal maturity. Most injuries can be managed conservatively with activity modification, rehabilitation, and an individualized, diagnosis-specific return-to-sport progression. Surgical intervention is reserved for selected cases involving instability, neurological compromise, or failure of nonoperative treatment. Overall, the prevention and management of spinal injuries in youth athletes require a multidisciplinary, developmentally informed approach.

Keywords: Youth athletes; Pediatric spine injuries; Low back pain; Spondylolysis; Cervical spine injury; Imaging; Injury prevention

INTRODUCTION

Participation in organized sports is a fundamental component of childhood and adolescent development. In the United States, an estimated 30–45 million children and adolescents participate in organized athletic activities annually, gaining important physical, psychological, and social benefits (1). However, increasing training intensity, year-round competition, and early sport specialization have been accompanied by a rising incidence of sports-

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related injuries. Spinal injuries are of particular concern because they may result in chronic pain, neurological impairment, prolonged absence from sports, and long-term functional limitations.

Low back pain is one of the most common musculoskeletal complaints in young athletes, affecting up to one-third of adolescents during their athletic careers. Structural abnormalities account for many of these cases (2). Spondylolysis is the leading identifiable structural cause of persistent low back pain in this population (3), whereas cervical spine injuries, although less common, represent the most serious type of injury because of their potential to cause catastrophic neurological damage.

The pediatric spine differs substantially from the adult spine in anatomy, biomechanics, and skeletal maturity. These differences result in distinct injury patterns, clinical presentations, and management considerations. Early recognition of these differences is essential for guiding appropriate imaging, treatment, and safe return-to-sport decisions while minimizing the risk of recurrent injury or long-term disability.

Throughout this review, the term youth athlete refers to competitors younger than 18 years; pediatric refers to skeletally immature athletes regardless of chronological age; adolescent refers to the approximate 10–19-year age range during which most sports-related spinal injuries occur; and skeletally mature refers to athletes who have completed growth-plate fusion. This review is based on a targeted, non-systematic evaluation of the available literature. Where pediatric-specific evidence was limited, findings from adult athletes or biomechanical studies are presented and clearly identified as extrapolated.

AGE GROUPS AND SKELETAL MATURITY

Youth athletes vary considerably in skeletal development and spinal biomechanics; consequently, injury mechanisms, diagnostic approaches, and treatment considerations differ across developmental stages. These stages overlap and vary according to sex, growth rate, skeletal maturity, and sport participation. In early childhood, generally before 10 years of age, sports-related overuse spinal injuries are relatively uncommon, and injuries are more often associated with falls or trauma. Younger children are also more susceptible to upper cervical injuries because the primary center of cervical motion is located higher in the spine.

During early adolescence, approximately 10–13 years of age, growth cartilage and secondary ossification centers remain mechanically weaker than mature bone. As sport-specific training intensifies, apophyseal injuries and early pars stress reactions become more common. Rapid growth may also temporarily reduce flexibility and core stability, altering lumbopelvic mechanics. In later adolescence, approximately 14–16 years of age, the incidence of spondylolysis is highest and disc-related disorders become more common as training demands increase while skeletal maturation is still incomplete.

As adolescents approach skeletal maturity, spinal biomechanics increasingly resemble those of adults, making adult-derived biomechanical and treatment evidence more applicable. However, developmental differences remain important, and findings based primarily on adult athletes, cadaveric specimens, or biomechanical models should still be identified as extrapolated rather than pediatric-specific evidence.

ANATOMY AND BIOMECHANICS OF THE PEDIATRIC SPINE

The developing spine

The pediatric spine undergoes continuous structural and biomechanical changes throughout childhood and adolescence. Ongoing skeletal growth, incomplete ossification, greater ligamentous flexibility, and immature neuromuscular control make the pediatric spine both adaptable and vulnerable to mechanical stress.

At birth, the vertebral column is predominantly cartilaginous. Primary ossification centers are present in the vertebral bodies and neural arches. Secondary ossification centers develop during adolescence and may not fully fuse until the late teenage years or early adulthood (6). During skeletal maturation, weaker growth cartilage increases susceptibility to repetitive loading and acute trauma, particularly during early and mid-adolescence.

Pediatric intervertebral discs are more hydrated and elastic than adult discs, providing greater flexibility and shock absorption. However, the cartilaginous vertebral endplates and disc–vertebral junctions are structurally weaker in young athletes. As a result, injuries may involve endplate avulsion or pediatric-specific patterns of disc herniation rather than the degenerative annular tears more typical of adults (7).

Age-related differences are particularly evident in the cervical spine. Compared with adults, children have greater ligamentous laxity, shallower and more horizontally oriented facet joints, proportionally larger heads, weaker cervical musculature, and less developed uncovertebral joints. In younger children, the primary center of cervical motion is located at C2–C3 rather than the adult C5–C6, increasing the risk of upper cervical injury following trauma. As skeletal maturity progresses, cervical biomechanics and injury patterns gradually become more similar to those of adults (4).

Biomechanics of the developing spine

Athletic participation exposes the spine to complex combinations of compressive, tensile, shear, bending, and torsional forces. Compared with adults, children have greater ligamentous laxity, shallower and more horizontally oriented facet joints, and proportionally larger heads. Repetitive lumbar extension combined with axial rotation places substantial stress on the pars interarticularis and is considered the primary mechanism of spondylolysis, the most common structural spinal injury in adolescent athletes. (8). Sports involving repetitive lumbar hyperextension, such as gymnastics, diving, figure skating, wrestling, baseball pitching, cricket fast bowling, and dance, have consistently been associated with an increased risk of spondylolysis. However, the reported incidence varies because of differences in study populations, diagnostic criteria, and levels of competition. Gymnastics has most consistently, though not universally, shown the highest reported rates, although direct comparisons across sports remain limited.

Lumbar spinal loading during athletic activity has been estimated primarily from adult biomechanical models. One model of more than 600 physical tasks estimated peak lumbar compressive forces exceeding 10 times body weight during ballistic jumping and landing. Lower, but still substantial, forces were estimated during running and resistance training (9). Comparable in vivo data in pediatric athletes are not available. The immature spine is also less mineralized and more compliant than the adult spine, which may result in different force distribution. Therefore, this adult-derived estimate should be considered illustrative rather than representative of the pediatric population.

The immature spine also exhibits greater coupling between rotation and lateral bending. Combined with incomplete neuromuscular development, reduced trunk stability, and delayed muscle activation, these characteristics may decrease the spine's ability to dissipate multidirectional forces generated during cutting, jumping, throwing, and contact sports (10).

During adolescence, rapid skeletal growth may outpace gains in muscle length and flexibility, temporarily reducing hamstring flexibility, hip mobility, and core stability. These changes alter lumbopelvic mechanics and increase lumbar loading, particularly around peak height velocity. As a result, early and mid-adolescence may be periods of increased vulnerability to overuse spinal injuries (5).

COMMON SPINE INJURIES

Injury patterns differ across the age groups described above; where relevant, the predominant age range associated with each condition is identified.

Spondylolysis

Spondylolysis is the most common structural cause of persistent low back pain in adolescent athletes and one of the best-studied overuse injuries of the pediatric spine (3). It is characterized by a stress reaction or fracture of the pars interarticularis, most commonly at L5, with L4 accounting for most remaining cases (2). The condition is uncommon before 8–10 years of age and becomes increasingly prevalent during the peri- and post-peak height velocity phases of adolescence as training intensity and volume increase.

Unlike acute fractures caused by a single traumatic event, spondylolysis develops gradually through repetitive mechanical loading. Recurrent lumbar hyperextension combined with axial rotation generates cumulative stress within the pars interarticularis. When repetitive loading exceeds the bone's ability to remodel, stress reactions may progress to incomplete or complete fractures. Bilateral defects can eventually lead to spondylolisthesis (8).

Patients typically present with gradual onset of localized low back pain that worsens with lumbar extension, rotation, or jumping and improves with rest. Neurological symptoms are uncommon unless significant vertebral slippage is present. Physical examination often reveals lower lumbar tenderness, painful or limited extension, hamstring tightness, and reduced core strength. Although the single-leg hyperextension (Stork) test is commonly performed, its diagnostic accuracy is limited, and it should not be used in isolation (11).

Lumbar intervertebral disc herniation

Lumbar disc herniation is considerably less common in children and adolescents than in adults and occurs most often in late adolescence, particularly among athletes nearing skeletal maturity. Unlike adult degenerative disc disease, pediatric disc injuries more often involve separation of the cartilaginous vertebral endplate or disruption of the disc–vertebral interface. This pattern reflects the greater hydration of the pediatric intervertebral discs (7).

Most pediatric lumbar disc herniations occur at the L4–L5 or L5–S1 levels. Repetitive lumbar flexion, rotation, heavy lifting, and axial loading in sports such as rowing, weightlifting, wrestling, football, and gymnastics may increase the risk. Clinical presentation typically includes low back pain with unilateral or bilateral leg pain, numbness, or paresthesia that worsens with sitting, coughing, sneezing, or forward flexion. Physical examination may demonstrate restricted lumbar motion, a positive straight-leg-raise test, dermatomal sensory loss, motor weakness, or diminished reflexes. Although uncommon, bowel or bladder dysfunction and saddle anesthesia require immediate evaluation for cauda equina syndrome, a surgical emergency (12).

Vertebral compression fractures

Thoracic and lumbar compression fractures usually result from acute axial loading during falls, awkward landings, high-energy collisions, or direct impact. The thoracolumbar junction (T12–L2) is the most frequently affected region, representing the transition between the relatively rigid thoracic spine and the more mobile lumbar spine (13).

Unlike osteoporotic compression fractures in older adults, pediatric compression fractures typically occur in otherwise healthy bone subjected to substantial force. Most are stable anterior vertebral body compression fractures without neurological injury, although burst fractures and unstable injuries may occur after high-energy trauma. Distinguishing stable from unstable injuries is critical because treatment and prognosis differ substantially.

A unique pediatric injury is the apophyseal ring fracture, in which the incompletely fused secondary ossification center separates from the vertebral body under shear loading. This injury occurs mainly in adolescents with unfused apophyses, most often at L4 or L5. It can mimic lumbar disc herniation when displaced fragments compress nearby nerve roots. Patients typically present with acute back pain after trauma. Common findings include localized tenderness, muscle spasm, and restricted motion. Neurological deficits may occur when the spinal canal is compromised.

Cervical spine trauma

Cervical spine injuries account for a relatively small proportion of sports-related spinal injuries but are the most serious because they can cause permanent neurological impairment or death. The highest risk occurs in contact and collision sports, including American football, rugby, wrestling, ice hockey, and gymnastics (4). Injury patterns vary with skeletal maturity. Younger children are more susceptible to upper cervical injuries, whereas adolescents nearing skeletal maturity increasingly sustain adult-type injuries of the subaxial cervical spine.

The most severe injuries typically result from axial loading of a slightly flexed cervical spine. This position reduces the normal cervical lordosis and directs compressive forces through the vertebral bodies and intervertebral discs. Classic mechanisms include head-first tackling, spear tackling, diving into shallow water, and being checked from behind.

The clinical spectrum ranges from muscle strains and ligamentous sprains to fractures, dislocations, and spinal cord injuries. Transient cervical cord neurapraxia (transient quadriplegia) may cause temporary bilateral sensory changes, weakness, or paralysis lasting from minutes to hours. Neurological recovery is usually complete. However, recurrent episodes warrant thorough evaluation because cervical stenosis or congenital abnormalities may increase the risk of permanent neurological injury (14). When cervical spine injury is suspected, immediate immobilization and evaluation using a standardized pediatric cervical spine clearance protocol are essential (15, 16).

RISK FACTORS FOR SPINAL INJURY IN YOUTH ATHLETES

Sports-related spinal injuries in youth athletes arise from the interaction of biological, biomechanical, training, and psychosocial factors rather than a single cause. Many injuries develop gradually when repetitive loading exceeds the growing spine's capacity for adaptation and repair.

Training load and overtraining

Excessive training load is one of the most important modifiable risk factors for overuse spinal injuries. During skeletal maturation, repetitive mechanical stress may exceed the capacity of bones and soft tissues to recover, predisposing athletes to injury. Total workload includes organized sports, private coaching, strength training, and recreational activities. These combined demands may be underestimated by coaches, parents, and athletes. Rapid increases in weekly training volume have been associated with higher injury rates than more gradual progression (17). However, this evidence is derived primarily from general sports injury prevention research rather than from pediatric spine-specific studies, and its direct applicability to spinal overuse injuries remains uncertain.

Early sport specialization

Early sport specialization, defined as intensive year-round participation in a single sport before adolescence, has become increasingly common. Systematic reviews indicate that highly specialized youth athletes experience approximately two- to threefold higher rates of overuse injuries than peers who participate in multiple sports (18). Although these findings apply to overuse injuries in general rather than specifically to spinal injuries, they support limiting early specialization. The American Academy of Pediatrics recommends delaying single-sport specialization until approximately 15–16 years of age, except in sports requiring early technical skill development, such as gymnastics and figure skating (19).

Biomechanical technique

Faulty movement mechanics are another modifiable risk factor for spinal injury. In gymnastics, repetitive lumbar hyperextension during skills such as back walkovers, handsprings, and tumbling places substantial stress on the pars interarticularis. A small motion analysis study of elite rhythmic gymnasts found greater lumbar extension angles in athletes who later developed spondylolysis than in uninjured controls (20). Because this finding was based on a small sample of elite athletes from a single sport, it should be considered hypothesis generating rather than definitive.

Improper lifting techniques, particularly lumbar flexion under heavy axial loads, may increase the risk of disc injury, vertebral endplate damage, and pars stress reactions. In contact and collision sports, poor tackling technique remains the leading cause of catastrophic cervical spine injury. Head-first contact eliminates the normal cervical lordosis and concentrates impact forces through the cervical spine. Injury surveillance studies have shown that educational programs promoting heads-up tackling and proper body positioning are associated with lower rates of severe cervical spine injuries (21).

Growth and skeletal maturation

As described above, rapid growth near peak height velocity temporarily reduces flexibility, strength, and coordination as skeletal growth outpaces muscle-tendon adaptation (5), leaving immature spinal structures more susceptible to apophyseal, pars, and vertebral endplate injuries. Monitoring growth velocity, strength, and movement quality during this period may help identify athletes at increased risk, although this preventive approach has yet to be independently validated.

DIAGNOSIS IN YOUTH ATHLETES

Clinical evaluation

Evaluation of sports-related spinal injuries begins with a thorough history and physical examination. Key history includes the injury mechanism, whether symptoms developed acutely or gradually, pain characteristics, activity-related symptoms, neurological complaints, prior spinal injuries, recent growth spurts, training volume, and other risk factors for overuse. Gradual-onset low back pain aggravated by lumbar extension and rotation should raise suspicion for spondylolysis (8), whereas acute pain following a fall, collision, or axial loading is more suggestive of a vertebral fracture, disc herniation, or ligamentous injury. Clinicians should also screen for red flags, including persistent night pain, fever, unexplained weight loss, bowel or bladder dysfunction, saddle anesthesia, progressive neurological deficits, or severe, unremitting pain. These findings require prompt evaluation.

The physical examination should include assessment of posture, gait, spinal alignment, range of motion, strength, flexibility, and neurological function. Pain reproduced during lumbar extension is commonly associated with spondylolysis, whereas lumbar flexion more often provokes disc-related pathology. A complete neurological examination is recommended for all athletes with spinal pain, with straight-leg-raise testing or a focused cervical neurological examination performed when clinically indicated. Although the single-leg hyperextension (Stork) test is commonly used when spondylolysis is suspected, its diagnostic accuracy is limited. Results should therefore be interpreted alongside the overall clinical assessment (11). Functional testing, such as squatting, jumping, single-leg balance, and sport-specific movements, may identify biomechanical deficits and help guide rehabilitation. Examination findings should be interpreted in the context of skeletal maturity. Strength, coordination, and symptom reporting can differ considerably between younger children and skeletally mature adolescents.

Imaging

Imaging should be selected to maximize diagnostic accuracy while minimizing radiation exposure in children and adolescents.

Plain radiographs are often the initial imaging study for athletes with persistent spinal pain because they are widely available and cost-effective. They can detect fractures, alignment abnormalities, scoliosis, and advanced spondylolysis. However, radiographs have limited sensitivity for early pars stress injuries, which may develop before cortical disruption becomes visible. The classic "Scottie dog collar" sign on oblique lumbar radiographs is highly specific for spondylolysis but has limited sensitivity. Therefore, normal radiographs do not exclude the diagnosis when clinical suspicion remains high (22).

Magnetic resonance imaging (MRI), particularly with short tau inversion recovery (STIR) sequences, is preferred when spondylolysis is suspected. MRI avoids ionizing radiation and can detect early bone marrow edema in the pars interarticularis before a fracture develops. Reported sensitivity and specificity for pars stress reactions are approximately 80% and 85%, respectively (22).

Computed tomography (CT) provides excellent visualization of bone anatomy. It is most useful when MRI findings are inconclusive, for preoperative planning, or for detailed assessment of fractures such as apophyseal ring injuries.

Single-photon emission computed tomography (SPECT/CT) combines functional and anatomical imaging. It may help detect metabolically active pars lesions when MRI is nondiagnostic. However, because SPECT/CT and CT involve ionizing radiation, MRI remains the preferred first-line advanced imaging modality in pediatric patients (22). Table 1 summarizes the imaging modalities used to evaluate pediatric spinal injuries.

In athletes with suspected cervical spine trauma, imaging and clearance should follow a structured, age-appropriate protocol rather than routine CT. The 2019 Pediatric Cervical Spine Clearance Working Group developed a validated, multidisciplinary algorithm based on the Glasgow Coma Scale score and clinical findings. This approach helps minimize missed injuries while reducing unnecessary radiation exposure (15). A 2024 Cochrane systematic review found that commonly used adult clinical decision rules, including NEXUS and the Canadian C-spine Rule, are not sufficiently validated in children. These findings support the use of pediatric-specific, multidisciplinary clearance pathways rather than direct application of adult-based rules (16).

INJURY MANAGEMENT BY DIAGNOSIS

Management depends on the diagnosis, injury severity, spinal stability, and neurological involvement. The following sections address each injury type, with

Table 1. *Advantages and Limitations of Imaging Modalities for Pediatric Spinal Injuries.* [a]

Imaging Modality	Principal Advantages	Primary Limitations	Preferred Clinical Indications
Plain radiography	Low cost; widely available; detects fractures and spinal alignment	Limited sensitivity for early stress injuries	Initial evaluation of persistent back or neck pain
MRI (STIR)	No ionizing radiation; excellent soft-tissue and early bone stress assessment	Higher cost; longer scan time; sedation may be required in young children	First-line advanced imaging for suspected pediatric spinal injuries
CT	Excellent cortical bone detail	Ionizing radiation exposure	Complex fractures, chronic pars defects, or preoperative planning
SPECT/CT	Detects metabolically active stress lesions	Highest radiation dose among imaging modalities	Selected cases with inconclusive MRI findings

[a] Population: Children and adolescents (approximately 6–18 years) with suspected sports-related spinal injuries evaluated in outpatient or emergency sports medicine settings. Evidence basis: Imaging performance characteristics are derived from pediatric and adolescent spondylolysis studies and consensus recommendations (11, 12, 15, 21). Reported sensitivity and specificity estimates for STIR MRI are based on pooled findings from a single imaging classification study and may vary depending on scanner protocols and reader expertise. Abbreviations: MRI, magnetic resonance imaging; STIR, short tau inversion recovery; CT, computed tomography; SPECT, single-photon emission computed tomography.

emphasis on conservative treatment, surgical indications, and return-to-sport considerations.

Evidence quality varies across conditions. Spondylolysis has the strongest pediatric-specific evidence, including a recent randomized controlled trial and large cohort studies (23, 4, and 25). Evidence for pediatric disc herniation and vertebral fractures is more limited and relies mainly on case series and adult literature. Management of cervical spine trauma increasingly incorporates international expert consensus, although pediatric-specific validation remains limited (16, 26, 27).

Spondylolysis

Conservative treatment: Most adolescent athletes with spondylolysis can be treated successfully without surgery. Treatment typically includes activity modification and structured physical therapy. Therapy focuses on lumbar stabilization, core strengthening, and correcting flexibility deficits.

A 2026 multicenter randomized trial of athletes aged 10–19 years with active spondylolysis found that starting physical therapy within seven days of diagnosis improved pain and function at one month. It also shortened return-to-sport by approximately 38 days and reduced 12-month recurrence compared with initial activity restriction followed by therapy (3% vs. 29%) (24).

Bracing remains controversial but may be considered in selected cases, particularly for acute unilateral stress reactions (23).

Return-to-sport decisions should be based on symptom resolution, pain-free range of motion, and restored functional performance rather than radiographic healing alone. In a cohort of 180 pediatric athletes, return-to-sport rates were similar between bony-union and symptom-guided treatment (98.9% vs. 97.6%). However, the bony-union approach required a longer treatment duration (4.7 vs. 1.8 months) (25).

Repeat imaging is not routinely needed in asymptomatic athletes. It should be reserved for suspected progression or surgical planning. Reported return-to-sport rates after conservative treatment range from approximately 73% to 99%, although differences among studies limit direct comparison (23, 25).

Surgical treatment: Surgery may be considered for persistent symptoms despite appropriate conservative treatment, progressive spondylolisthesis, or unstable bilateral pars defects. Direct pars repair, including pedicle screw–hook fixation, is generally preferred over spinal fusion because it preserves segmental motion and provides high healing rates (28). A 2022 systematic review and meta-analysis also found consistent improvements in pain and function across direct repair techniques (29).

Lumbar intervertebral disc herniation

Conservative treatment: Initial management includes activity modification, physical therapy, and analgesia when no progressive neurological deficits are present. Rehabilitation focuses on symptom control, mobility, trunk stabilization, and gradual return to sport-specific activities. Pediatric evidence remains limited. A systematic review found limited randomized trial evidence, with many studies having a high risk of bias. Supervised exercise improved pain compared with no treatment, whereas education alone did not clearly reduce pain prevalence (30). Many treatment recommendations are therefore extrapolated from adult disc herniation literature.

Surgical treatment: Surgery is reserved for persistent radiculopathy despite conservative treatment, progressive neurological deficits, or cauda equina syndrome. Discectomy or decompression may be performed based on the location and severity of neural compression. Outcomes are generally favorable, but evidence is limited to small case series. Return-to-sport timelines remain uncertain.

Vertebral compression fractures

Conservative treatment: Stable anterior compression fractures without neurological compromise are typically treated with temporary activity restriction, symptom management, and gradual rehabilitation. Bracing may be used selectively for pain control or to limit motion during early healing. Return to sport should occur only after resolution of pain, restoration of strength and range of motion, and confirmation of the absence of progressive deformity or instability.

Surgical treatment: Surgical evaluation is indicated for burst fractures, instability, progressive deformity, or neurological compromise. Apophyseal ring fractures causing spinal canal narrowing or nerve root compression may require decompression, fragment removal, or stabilization. Management should be guided by spinal stability, deformity, and neurological involvement rather than fracture type alone.

Cervical spine trauma and neurological injury

Conservative treatment: Suspected cervical spine injury requires immediate immobilization and evaluation using an age-appropriate clearance pathway (15, 16). Once instability and neurological injury are excluded, cervical strains and sprains can be managed with activity restriction, symptom control, and gradual rehabilitation. Athletes may return to sport after regaining full, pain-free range of motion, normal strength, and a normal neurological examination. Transient cervical cord neurapraxia management should be individualized. Athletes with a single episode and complete resolution may return after specialist evaluation. Recurrent episodes or underlying cervical stenosis warrant greater caution (14). A 2025 international modified Delphi consensus of sports spine surgeons found that selected athletes may return to high-impact, high-frequency sports after healed cervical fractures or ligamentous injuries. However, return to high-impact sports is not recommended after recurrent neurapraxia associated with cervical stenosis (26). These recommendations provide more specific guidance than earlier blanket restrictions. Pediatric-specific validation remains limited, and no universally validated pediatric return-to-sport protocol currently exists.

Surgical treatment: Cervical instability, spinal cord compression, persistent neurological deficits, or major structural disruption may require decompression, stabilization, or fusion. A 2025–2026 modified Delphi consensus similarly found agreement that athletes may return to high-impact, high-frequency sports after selected single-level cervical fusions and decompressions once healing is confirmed, indicating that postoperative restriction is not uniformly required and should be individualized rather than presumed (27).

Table 2 summarizes the age group, mechanisms, high-risk sports, clinical features, imaging findings, management, surgical indications, return-to-sport criteria, and evidence limitations for each injury.

Table 2. *Summary of common spinal injuries in youth athletes.* [a]

Feature	Spondylolysis	Lumbar disc herniation	Vertebral compression fracture	Cervical spine trauma
Typical age group	Adolescence; uncommon <8–10 years	Late adolescence	Any age after significant trauma	Younger children: upper cervical; adolescents: subaxial
Mechanism / high-risk sports	Extension/rotation/ gymnastics, diving, wrestling, dance	Flexion, rotation, loading/ wrestling, football, weightlifting	Falls, landings, collisions	Axial loading/ football, rugby, hockey, diving
Key symptoms and red flags	Extension-related low back pain	Back/leg pain, paresthesia	Acute pain, tenderness	Neck pain ± neurological deficits
Preferred imaging	Radiographs; MRI (STIR)	MRI	Radiographs ± MRI/CT	Structured clearance ± MRI/CT
First-line management	Activity restriction + PT; selective bracing	Activity modification + PT	Activity modification; selective bracing	Immobilization + clearance protocol
Surgical indications	Persistent symptoms, progressive spondylolisthesis, instability	Neurological deficit, cauda equina, refractory symptoms	Instability, deformity, neural compression	Instability, cord compression, persistent deficit
Return-to-sport criteria	Symptom- and function-based	Individualized; limited pediatric evidence	Symptom-guided; individualized	Individualized; consensus-informed
Evidence limitations	Strongest pediatric evidence; few RCTs	Limited pediatric evidence; adult extrapolation	Mostly case series	Limited pediatric validation

[a] *Population: Youth athletes (approximately 8–18 years). Evidence strength varies by injury type. This table provides a concise clinical reference and does not replace the diagnosis-specific discussion. Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging; PT, physical therapy; RCT, randomized controlled trial; STIR, short tau inversion recovery.*

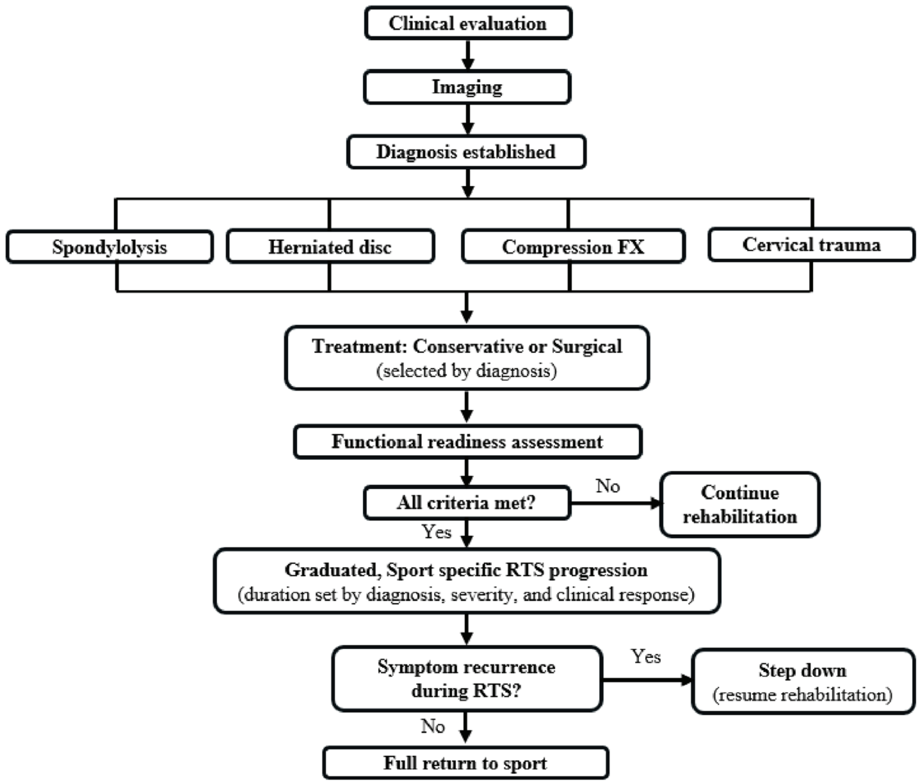

Figure 1. ***Return-to-sport clinical decision pathway for pediatric spinal injuries.*** *Population: adolescent athletes (approximately 10–18 years) with suspected or confirmed spinal injury evaluated in outpatient sports medicine or orthopedic settings. Intended use: support initial and follow-up decisions regarding activity restriction and return-to-sport clearance; not a substitute for individualized specialist assessment. Rather than a single fixed timeline, the duration of activity restriction and the pace of return-to-sport progression are determined by diagnosis, injury severity, and clinical response. Evidence basis: pathway elements are synthesized from diagnosis-specific recommendations and expert consensus (8, 15, 16, 23, 24, 25, 26, 27, 28) and have not been prospectively validated as a unified algorithm. Abbreviations: RTS, return to sport; ROM, range of motion; PT, physical therapy.*

Return-to-sport decision pathway

Decisions should consider diagnosis, spinal stability, neurological status, treatment response, and sport-specific demands. Athletes should be pain-free with full range of motion, normal neurological function, and restored strength and motor control. They should also complete sport-specific activities without symptom recurrence. Imaging may help guide decisions when instability, progression, or healing status is a concern. However, it should complement rather than replace clinical and functional assessment. Activity restriction and rehabilitation vary by diagnosis. Therefore, return-to-sport progression should follow the diagnosis-specific criteria in Table 2 rather than a fixed timeline. Figure 1 presents a diagnosis-specific decision pathway intended as an illustrative synthesis rather than a validated clinical instrument or prescriptive timeline.

PREVENTION STRATEGIES FOR SPINAL INJURIES IN YOUTH ATHLETES

Preventing spinal injuries in youth athletes requires a multifactorial approach that considers training load, biomechanics, neuromuscular control, sport-specific demands, and skeletal maturity. The level of evidence varies, ranging from pediatric spine-specific studies to findings extrapolated from broader youth sports and adult low back pain research.

Training load management

Evidence is largely extrapolated from general musculoskeletal injury-prevention research because pediatric spine-specific data are limited. Rapid increases in training workload are associated with greater injury risk. Structured training with gradual progression and adequate recovery is therefore recommended (17). Although pediatric spine-specific workload thresholds have not been established, avoiding sudden increases in training volume is reasonable. Cumulative demands across organized sports, private coaching, and recreational activities should also be monitored.

Neuromuscular training and core strengthening

Evidence combines limited pediatric studies with findings from general injury-prevention and adult low back pain research. Preventive programs emphasize neuromuscular control and strengthening the deep core muscles, including the multifidus, transversus abdominis, diaphragm, and pelvic floor. These exercises may improve spinal stability, although much of the supporting evidence comes from adults (31). A one-year controlled trial in adolescent athletes found that perturbation-based trunk training reduced three-month low back pain prevalence by approximately 49%. It also improved trunk strength and reduced muscle imbalance (32). However, the study was limited by its small sample size and non-randomized design. Supervised, age-appropriate resistance training with proper technique and gradual progression is considered safe for youth athletes and may reduce overall injury risk (19).

Education and sport culture

Evidence comes from pediatric studies, broader injury-prevention research, and sport-specific data. Education for athletes, coaches, parents, and administrators can improve recognition of spinal injuries and encourage timely symptom reporting (33). However, evidence that education alone reduces low back pain in youth athletes is limited (30). Education is therefore most effective when combined with other prevention strategies. Strict enforcement of safety rules in contact sports is more strongly supported for preventing acute cervical trauma. In particular, restricting illegal tackling techniques in football and rugby has reduced catastrophic cervical spine injuries (21).

CONCLUSION

Sports-related spinal injuries in youth athletes require an age- and developmentally appropriate approach. The growing spine differs from the adult spine in anatomy, biomechanics, and skeletal maturity. Spondylolysis is the most common structural cause of persistent low back pain. Other injuries, including disc herniation, vertebral fractures, and cervical spine trauma, also require careful evaluation because of their potential for neurological injury and long-term disability. Diagnosis should include a thorough clinical assessment, appropriate imaging, and consideration of skeletal maturity. Management should emphasize evidence-based conservative care, individualized rehabilitation, and diagnosis-specific return-to-sport criteria. Prevention should focus on appropriate training loads, neuromuscular control, proper technique, and education. However, pediatric spine-specific evidence remains limited. Recent systematic reviews and international expert consensus statements have improved guidance for cervical spine imaging, surgical treatment, and return to sport. Further research is needed to validate these recommendations specifically in pediatric athletes.

CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

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