Understanding Spinal Injuries in Sports and Factors Affecting Recovery

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ABSTRACT

Spinal cord injuries in sports are significant and often result from forces that exceed the ability of the spine to absorb impact. The cervical and lumbar regions are particularly vulnerable due to their mobility and exposure to high forces. This paper reviews the anatomy of the spine and spinal cord and examines mechanisms of sports-related spinal injuries, including injuries involving the spinal cord, vertebrae, discs, nerves, and surrounding structures. It also investigates clinical assessment, treatment, and early diagnosis, including the use of imaging when appropriate. Prevention strategies, including proper care, equipment, and technique, are explored to reduce the risk of spinal injuries. Recovery depends on the structures affected and severity of the injury as well as physical, psychological, and social factors such as mental health, motivation, sleep, and nutrition. Understanding the complex interactions between the mechanisms of injury, spinal anatomy, and factors mediating recovery may facilitate injury prevention and improve treatment options for athletes at risk of a spinal cord injury.

INTRODUCTION

Spinal injuries are some of the most serious injuries occurring due to physical activity and sports (1). The spine provides structure to the body and protects the spinal cord, which serves as the primary route of communication between the brain and the rest of the body. Athletes can experience high-impact forces, repetitive loading, and rapid movements that increase the risk of a spinal injury, particularly in contact sports such as football, rugby, and soccer, as well as in activities involving heavy lifting, diving, and collisions (2). About 10%-15% of all athletes experience lower back pain (3). Understanding how these injuries occur is crucial for the prevention, recognition, and effective management of spinal injuries.

The design of the spinal cord and vertebral column directly influences the risk and impact of spinal injuries. Although the vertebrae protect the spinal cord, intervertebral discs and spinal nerves and their surrounding structures are vulnerable to compression and trauma. The cervical and lumbar regions of the vertebrae are particularly vulnerable due to their greater mobility, exposure to high-impact forces, and frequent loading compared to the more structurally stable thoracic and sacral regions. Since different spinal regions are associated with specific spinal nerves and spinal cord segments, the level and structure affected by an injury can influence the functional outcomes in different parts of the body.

This paper examines sport-related spinal injuries, including injuries involving the spinal cord, vertebrae, discs, nerves, and surrounding musculoskeletal structures, through the lenses of anatomy and physiology, injury mechanisms, pathophysiology, and factors impacting recovery. It also highlights the importance of prevention, early assessment, imaging, and physical, psychological, and social factors that may influence rehabilitation and recovery.

METHODS

A literature review was conducted to explore sports-related spinal injuries and the factors that can affect recovery. PubMed and Google Scholar were used to find research articles, while StatPearls and Cleveland Clinic provided additional medical information. These resources were recommended by a research mentor, and relevant sources were independently searched for and selected.

The search focused mainly on sources published from 2000 onward. Search terms included "spinal injuries in sports," "sport-related spinal cord injury," "lumbar spine injuries in sports," "spinal cord injury rehabilitation," and "psychological recovery after spinal cord injury." Sources were selected based on their relevance to the main topics of the paper, including spinal anatomy, injury mechanisms, diagnosis, treatment, rehabilitation, and physical and psychological factors that may affect recovery. Sources that were unrelated to these topics were excluded.

Research articles were used to examine how spinal injuries occur in sports and how they affect the body. Medical references provided information about diagnosis and treatment, while studies on rehabilitation and psychological recovery helped explain the roles of motivation, mental health, and social support. The findings were organized by topic to support the discussion of injury mechanisms, treatment, and recovery. This paper presents a narrative review of selected literature rather than a formal systematic review or meta-analysis.

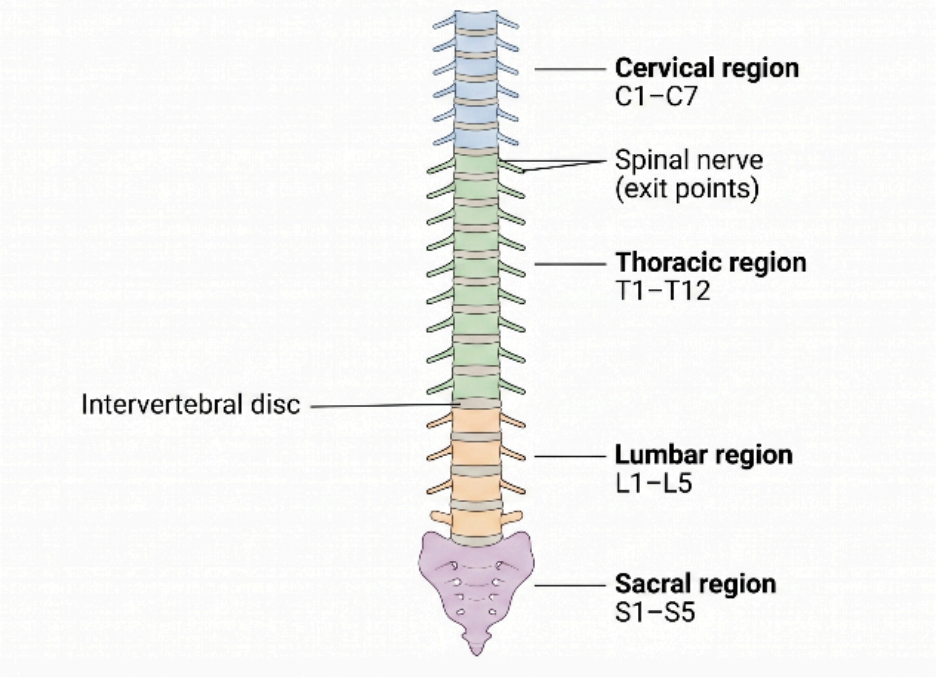
ANATOMY AND PHYSIOLOGY OF THE SPINE

The anatomy and physiology of the spinal cord demonstrate how specific injuries can occur during physical activity. The vertebral column protects the spinal cord, which is part of the central nervous system. The spinal cord is a cylindrical structure that extends from the brain caudally through the vertebral column (4). The vertebrae protect the spinal cord while allowing flexibility. Between each pair of vertebrae are intervertebral discs and openings through which spinal nerves exit. As a result, forces that relate to the body moving beyond its limit (e.g., axial load, hyperflexion or hyperextension, and collisions) can pinch or compress these nerves, potentially damaging the vertebrae, discs, or spinal cord (3).

The vertebral column consists of four regions: cervical, thoracic, lumbar, and sacral (see Figure 1). The cervical vertebral column contains seven vertebrae (C1-C7), while there are eight cervical spinal nerves (5). Therefore, the cervical spinal nerves should not be confused with the number of cervical vertebrae.

The cervical region is the most cranial portion of the cord, innervating the neck, diaphragm, arms, and hands. The C5-C6 spinal nerve roots are often strained or compressed in neck injuries, causing numbness or weakness. The thoracic region contains twelve vertebrae (T1-T12) and innervates the chest and abdominal muscles. These segments are relatively stable due to the ribcage, making spinal injuries less common, but they are still possible in the thoracic region. The lumbar region contains five vertebrae (L1-L5) occupying the lower back, hips, thighs, and parts of the lower legs. This region is prone to injury from heavy lifting and axial loading, which can lead to compression, a slipped disc, or lower back pain. The sacral region contains five vertebrae (S1-S5) and forms the base of the vertebral column and controls the pelvic organs and lower limbs. Injuries in this area can affect the bladder and the lower limbs (5). The effects of a spinal injury depend on the specific structure affected, the location of the injury, and its severity.

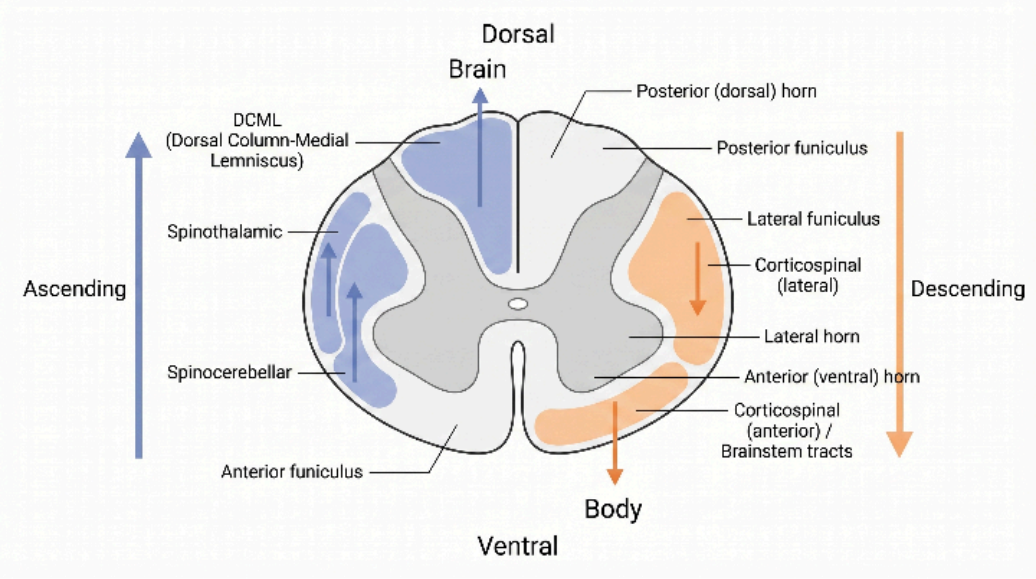
Figure 1. Anatomy of the vertebral column and its four regions, showing intervertebral discs and spinal nerves. This figure illustrates the cervical, thoracic, lumbar, and sacral regions of the vertebral column and their associated spinal nerves. Created by the author using BioRender.



The spinal cord serves as the main pathway for communication between the brain and the rest of the body, transmitting sensory signals from the body to the brain and motor signals from the brain to the body (4). The spinal cord has distinct functional regions that help transmit and process different types of signals; a cross-section of the spinal cord helps illustrate these regions and their functions (see Figure 2). When viewed in a cross-section, the spinal cord contains a central area of gray matter surrounded by white matter (6). The gray matter consists of three horns. The posterior (dorsal) horn receives sensory

information entering the spinal cord. Damage to this area can contribute to sensory loss. The anterior (ventral) horn contains motor neurons that send signals to the muscles for movement, so damage can contribute to loss of motor function. The lateral horn contains sympathetic neurons that help control automatic body functions. The white matter outside of the gray matter divides into three columns. The posterior column carries sensory information, the anterior column mainly carries the motor signals, and the lateral column carries both sensory and motor signals. Because an injury can affect multiple areas and pathways, spinal cord damage may result in a combination of motor and sensory impairments (6).

Figure 2. Cross-section of the spinal cord illustrating gray and white matter and functional regions. This cross-sectional diagram demonstrates the distribution of gray and white matter, including the anterior, posterior, and lateral horns. It also identifies major ascending and descending pathways to emphasize how signals travel between the brain and the body. Created by the author using BioRender.



When examining spinal injuries, it is also essential to consider the musculoskeletal system, which includes the muscles, bones, joints, and connective tissues such as tendons and ligaments that surround and support these structures (7). Not all sports-related spinal injuries involve the spinal cord. Injuries can also affect intervertebral discs, ligaments, muscles, or other surrounding tissues. Lower back pain is common among athletes and can be associated with stress on the vertebrae, discs, and surrounding tissues, particularly in sports that involve heavy weightlifting, contact collisions, or repetitive movement (3).

Because the spinal cord connects the brain to many parts of the body, spinal injuries can affect multiple body systems, including bladder, bowel, respiratory, and autonomic functions (6). Research shows that about 10%–15% of athletes experience lower back pain (3). These lower back injuries should be distinguished from spinal cord injuries because lower back pain can result from several musculoskeletal or spinal structures without involving the spinal cord.

PATHOPHYSIOLOGY OF SPINAL INJURIES

Sports-related spinal injuries occur when external forces exceed the ability of the spine to absorb or distribute a load, leading to tissue damage at both the structural and cellular levels (4). Without prompt recovery, the injury worsens, resulting in damage to the vertebrae, intervertebral discs, spinal cord, spinal nerves, or surrounding tissues (2). The type and severity of the injury depend on the force involved and the structures affected. Common mechanisms include axial load, hyperflexion or hyperextension, rotation, and other shear forces (2). Axial loading occurs along the spine's vertical axis, such as during head collisions, heavy weightlifting, or falls. This force is dangerous as it compresses the vertebrae and intervertebral discs, causing them to collapse or bulge and irritate the cord or nerves. During tackles, collisions, or whiplash, intense forces push the spine beyond its normal limits, resulting in hyperflexion and hyperextension. These forces can stretch or damage ligaments and intervertebral discs. Chronic lumbar spine injuries and lower back pain are associated with repetitive flexion and extension in sports like soccer and weight training (3). Rotation and shear forces occur when the spine twists while exposed to a high impact or load, which is common in sports that require agility and contact with other players. These forces increase stress on the discs and joints, leading to stress fractures, spondylolysis, and nerve pain. Certain regions of the spine are more vulnerable to sports injuries due to their location, mobility, and exposure to forces.

The cervical and lumbar regions are the most commonly injured areas because of their mobility and susceptibility to force, making them vulnerable during high-impact sports like football (2). However, an injury to these regions does not automatically mean that the spinal cord has been injured. A cervical spinal injury can result in major neurological consequences including loss of movement or sensation below the level of injury and, depending on the level and severity, impaired respiratory function. Thoracic injuries are less frequent in sports because the rib cage provides protection, making the region more stable. Injuries involving the lumbar spine primarily affect the vertebrae, disc, or nerve root and can cause lower back pain, numbness, or weakness (3). The effects of a lumbar region injury therefore depend on the specific structure involved and the severity of the damage. The sacral region controls bowel, bladder, and other lower limb functions (4). Injuries in this region can lead to significant complications such as loss of bladder control or sensory changes.

The outcome of a spinal injury depends on whether the injury is complete or incomplete, the level of the spinal cord that is affected, and the severity of the damage. Incomplete injuries can undergo partial recovery, which may include the gradual return of some movement strength, improved sensations below

the level of injury, or regained control over the bowel and bladder, whereas complete injuries often result in permanent motor and sensory deficits (4). These injuries have two phases: the primary stage, caused by mechanical force, triggers the second stage, which leads to inflammation, swelling, and further cellular disruption and damage over time (8). Early recognition and treatment are essential for improving outcomes following sport-related spinal injuries, as spending more time without recovery can worsen the injury.

TREATMENT AND RECOVERY

Recovery after a spinal injury is different for each person and depends on multiple physical, psychological, and social factors (9). Prevention can reduce the risk of spinal injuries through appropriate care, equipment, and technique (2). Adequate physical preparation and conditioning may also help athletes manage the physical demand of their sport, while insufficient recovery and excessive training can increase injury risk (10).

When a spinal injury is suspected during physical activity, the initial priority is to assess the athlete, minimize unnecessary spinal movement, and arrange appropriate medical evaluation. Assessment should initially include a quick survey to evaluate airway, breathing, circulation, disability, and exposure (4). A focused neurological and musculoskeletal assessment may also be used to identify signs of neurological or structural injury. Earlier recognition and treatment of injury can support better outcomes and reduce complications. Prompt recognition and appropriate treatment may help reduce complications and support better outcomes. Further evaluation in a medical setting may include CT or MRI when clinically indicated to assess potential spinal, vertebral, or neurological damage (3, 4). The American Spinal Injury Association (ASIA) Impairment Scale (see Figure 3) can be used to classify the severity of a spinal cord injury by evaluating motor and sensory function, helping clinicians characterize the injury and inform rehabilitation planning (4, 11).

Figure 3. American Spinal Injury Association (ASIA) Impairment Scale (AIS). This table summarizes the five AIS grades (A–E), which classify spinal cord injury according to sensory and motor function. The scale helps clinicians characterize the extent of impairment and supports clinical assessment and rehabilitation planning. Created by the author based on Rupp et al. (2021) (11).

Grade	Classification	Description
A	Complete	No sensory or motor function is preserved in the sacral segments S4–S5.
B	Sensory Incomplete	Sensory function is preserved, including at the sacral segments S4–S5, but the criteria for motor-incomplete injury are not met.
C	Motor Incomplete	Motor function is preserved below the neurological level of injury, and more than half of the key muscle functions below that level have a muscle grade below 3.
D	Motor Incomplete	Motor-incomplete injury in which at least half of the key muscle functions below the neurological level have a muscle grade of 3 or higher.
E	Normal	Sensory and motor functions are normal on examination in a person who previously had a spinal cord injury.

A medical professional who plays a significant role in recovery is the physical therapist. Physical therapists can contribute to rehabilitation by addressing physical function and helping individuals work toward appropriate recovery goals. Communication between patients and healthcare professionals is also important because psychological factors can affect participation in rehabilitation (1). Safe transfer, appropriate precautions during transport, and surgery when required depend on the types and severity of the injury and should be managed by qualified healthcare professionals (4).

In addition, sleep, nutrition, communication, and patient-centered care are vital components of recovery. Adequate sleep supports growth, repair, regeneration, immune function, and physical performance, while insufficient sleep can contribute to fatigue and increased injury risk (12). Athletes and injured individuals often require adequate sleep to support recovery and regeneration. Proper nutrition is also important because inadequate nutrition intake can negatively affect recovery and performance (12).

Better motivation regulation may support better recovery, participation, and performance (13). Effective communication between healthcare providers, physical therapists, and patients can help build trust, allow patients to express their concerns and goals, and support participation in rehabilitation (1). Patient-centered care values the patient's perspective, goals, and preferences and can help address not only physical impairments but also psychological and social factors involved in recovery.

Social and psychological factors play a significant role in recovery from a spinal injury. A close and multifaceted relationship exists between mental health and physical performance. Individuals with spinal cord injuries may experience psychological distress and reduced life satisfaction, particularly following the injury (14). Mental health has a critical role in the recovery process. Linking to both physical

outcomes and the quality of life (10). Individuals with spinal cord injuries often experience increased psychological distress, such as anxiety, depression, fear, and reduced life satisfaction, usually in the early stages after being injured (9). These factors can influence how patients perceive pain, engage in rehabilitation, and adhere to treatment plans. While many individuals adapt to their condition over time, recovery experiences differ between individuals (9). Coping skills, social support, motivation, and communication can influence how individuals respond to their injury and participate in rehabilitation.

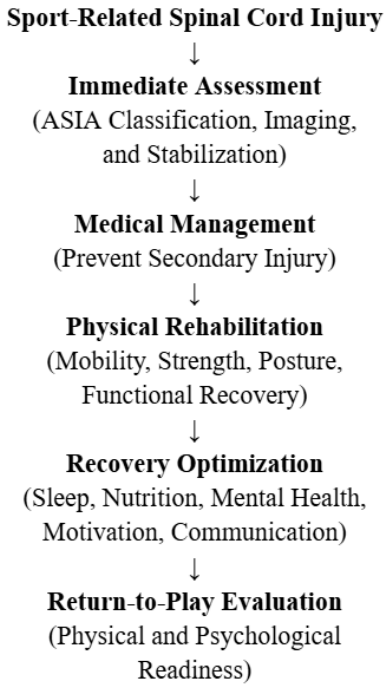
Psychological factors can act as either protective factors or risk factors during recovery. Protective factors include strong motivation, self-efficacy, positive coping skills, social support, and effective communication with healthcare providers (15). These factors may support participation in rehabilitation, adherence to recovery activities, coping, and quality of life. In contrast, psychological distress, fear, low motivation, and limited support can create barriers to rehabilitation and negatively affect participation and well-being (1).

It is important to distinguish these effects from biological neurological recovery. Physiological and social factors may influence rehabilitation participation, functional recovery, coping, and quality of life, but they should not be presented as direct causes of spinal recovery. The level and severity of the spinal injury remain important factors in determining neurological outcomes (4,8).

While physical, psychological, and social factors are often discussed separately, the literature reviewed in this paper suggests that these factors can interact during recovery. Based on the findings discussed throughout this review, Figure 4 presents an author-created conceptual framework that organizes these interconnected factors. The framework is intended to illustrate the major areas that may be considered during recovery from sport-related spinal injuries and is not a validated clinical pathway or treatment protocol.

The framework consists of five connected areas. First, immediate assessment includes initial stabilization, appropriate medical evaluation, imaging when clinically indicated, and classification of spinal cord injury severity when an SCI is present. Second, medical management focuses on the structures affected and the severity of the injury while addressing the risk of further complications. Third, physical rehabilitation focuses on restoring appropriate physical function based on the individual's injury and rehabilitation needs. Fourth, recovery optimization includes sleep, nutrition, motivation, psychological well-being, and communication. Finally, return-to-play decisions can consider both physical and psychological readiness. These areas are presented as interconnected components of a conceptual framework rather than a required sequence of treatment. Further research would be needed to determine whether this framework is useful for clinical decision-making or whether integrating these factors improves outcomes.

Figure 4. Conceptual Framework for Recovery Following Sport-Related Spinal Injury. This author-created framework organizes physical, medical, psychological, social, and lifestyle factors identified in the literature reviewed in this paper. The framework is conceptual and has not been independently validated as a clinical pathway or treatment protocol.



CONCLUSION

Spinal injuries in sports stem from interactions between anatomy, mechanics, and external forces. The cervical and lumbar regions are particularly exposed to injury because of their mobility and exposure to different loading and movement patterns. However, the effects of a spinal injury depend on the specific structures involved, which may include the vertebrae, discs, spinal nerves, spinal cord, or surrounding musculoskeletal tissues. The severity of a spinal cord injury also depends on the level and completeness of the injury and can result in different neurological outcomes.

Early recognition and appropriate management are important for reducing complications and supporting recovery. Assessment, imaging when clinically indicated, injury classification, and appropriate medical management can help guide treatment. Physical rehabilitation is an important part of recovery, but sleep, nutrition, communication, motivation, and psychological well-being can also influence rehabilitation participation, functional recovery, coping, and quality of life. Effective communication between healthcare providers, such as physicians and physical therapists, can help coordinate care and ensure that the patient's physical and psychological needs are considered throughout recovery (1).

Future research on spinal injuries should continue to focus on prevention strategies, training, and recovery approaches that include both physical and psychological factors. Further research is also needed to better understand how these factors interact during rehabilitation and how their effects may differ depending on the type and severity of spinal injury. The conceptual framework proposed in this review organizes medical, rehabilitative, psychological, and lifestyle factors identified in the literature. However, the framework has not been independently validated and should not be considered a clinical pathway. A comprehensive, patient-centered approach that considers physical, psychological, and social factors may provide a useful foundation for understanding recovery and improving quality of life following sport-related spinal injuries.

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