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Spinal Cord Injury: A Critical Neurological Emergency

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ABSTRACT

Background: Spinal cord injury (SCI) is a major neurological emergency that can lead to profound and permanent disability. It poses significant clinical and socioeconomic burdens due to its high morbidity, mortality, and long-term impact on patient functionality and quality of life. Most cases occur in young adult males, with the leading causes being traffic accidents, falls, and sports-related trauma. This literature review aims to provide a comprehensive overview of the anatomy of the vertebral column and spinal cord, the pathophysiological mechanisms of SCI, clinical syndromes, diagnostic strategies, and both conservative and surgical management approaches.
Methods: This study uses a narrative literature review method, synthesizing data from textbooks, scientific articles, and clinical guidelines related to spinal cord injury. Sources were selected based on relevance, scientific validity, and recent updates in SCI management.
Results: SCI involves both primary and secondary injury mechanisms that affect the central and peripheral nervous systems. Clinical manifestations vary depending on the level and completeness of the injury and include motor, sensory, and autonomic dysfunctions. Diagnosis is supported by neurological examination using the ASIA classification, imaging studies (X-ray, CT, MRI), and specific reflex testing. Management involves acute stabilization, prevention of secondary injury, and long-term rehabilitation. Surgical interventions are considered in cases of instability or compression.
Conclusion: Comprehensive understanding of spinal cord anatomy, clinical syndromes, and multidisciplinary management is essential for optimizing outcomes in patients with SCI. Early diagnosis and prompt intervention can reduce complications and improve neurological recovery.

***Keywords*:** Spinal cord injury, trauma, pathophysiology, ASIA classification, neurogenic shock, spinal syndromes, literature review

INTRODUCTION

Spinal cord injury (SCI) is a devastating condition that results from trauma to the vertebral column, causing variable degrees of damage to the spinal cord and often leading to significant neurological impairment. SCI is associated with high morbidity and mortality, as well as long-term disability that profoundly impacts a patient's ability to perform daily activities, sustain employment, and maintain independence. Moreover, it imposes substantial psychological and

economic burdens on patients, families, and the healthcare system at large [1].

In the United States, the annual incidence of SCI is approximately 40 new cases per million population, with an estimated 12,000 new cases each year. Young adult males between the ages of 16 and 30 are disproportionately affected, with a male-to-female ratio of approximately 4:1 [2]. The most common causes of SCI include motor vehicle accidents (50.4%), falls (23.8%), and sports-related injuries (9%), followed by violence such as gunshot wounds and occupational injuries [2,3]. Mortality is highest in the acute phase of injury, with up to 50% of deaths occurring at the scene, and about 16% among those who survive to hospital admission [3].

SCI affects multiple physiological systems, resulting in complex impairments including motor and sensory deficits, autonomic dysfunction (e.g., urinary retention, bowel incontinence), respiratory compromise, pressure ulcers, and sexual dysfunction [1,4]. These consequences necessitate a multidisciplinary approach to management that spans acute stabilization, prevention of secondary injury, long-term rehabilitation, and social reintegration.

Historically, the management of acute SCI was limited to conservative therapy. However, advances in both pharmacological treatments—such as high-dose methylprednisolone—and surgical interventions, including decompression and spinal stabilization, have significantly improved outcomes in selected patients [5]. A comprehensive understanding of spinal cord anatomy, injury mechanisms, clinical manifestations, and evidence-based therapeutic strategies is essential for optimizing the care of patients with SCI.

MATERIALS & METHODS

This study employed a narrative literature review approach to explore the clinical, anatomical, and therapeutic aspects of spinal cord injury (SCI). The sources were selected from a range of peer-reviewed scientific journals, clinical guidelines, and authoritative textbooks focusing on neuroanatomy, spinal trauma, and rehabilitation medicine. The inclusion criteria consisted of articles published in English and Indonesian within the last 20 years, with an emphasis on up-to-date findings regarding the pathophysiology, diagnosis, and management of SCI.

The literature search was conducted using academic databases such as PubMed, ScienceDirect, and Google Scholar. Keywords used included: “spinal cord injury”, “traumatic SCI”, “neurogenic shock”, “ASIA classification”, “spinal syndromes”, and “spinal trauma management”. Additional sources were obtained through manual searches of reference lists and institutional libraries.

Data from the selected sources were synthesized descriptively, focusing on key themes: (1) spinal cord anatomy, (2) mechanisms and pathophysiology of injury, (3) clinical syndromes and diagnostic classifications, and (4) conservative and operative management strategies. The analysis aimed to integrate theoretical knowledge with clinical applications relevant to SCI patients, as guided by standard references used in the Department of Orthopaedics and Traumatology, Faculty of Medicine, Udayana University.

No ethical approval was required, as this study did not involve human participants or original patient data.

RESULT

Anatomy of the Vertebral Column and Spinal Cord

The vertebral column consists of 33 vertebrae divided into cervical, thoracic, lumbar, sacral, and coccygeal regions, providing structural support and protection for the spinal cord. The spinal cord extends from the foramen magnum to the lower margin of the first lumbar vertebra in adults and is composed of 31 segments. It is encased by meninges and surrounded by cerebrospinal fluid, ensuring mechanical and immunological protection. The spinal cord is divided into gray matter, containing neuronal

cell bodies, and white matter, composed of ascending (sensory) and descending (motor) tracts that mediate reflexes and voluntary functions.

Epidemiology and Etiology

Spinal cord injuries primarily affect males aged 16 to 30, with a male-to-female ratio of 4:1. The most common causes are motor vehicle accidents (approximately 39–50%), falls (23–28%), and sports injuries such as diving (about 8–9%). Violent trauma, including gunshot wounds, accounts for up to 14% of cases. Non-traumatic causes include vascular, infectious, autoimmune, degenerative, neoplastic, and iatrogenic factors.

Pathophysiology of SCI

The pathophysiology of SCI involves both primary and secondary injury mechanisms. Primary injury results from mechanical trauma such as persistent compression, hyperflexion, hyperextension, distraction, or laceration. These mechanisms damage blood vessels, disrupt axons, and trigger immediate neurological dysfunction. Secondary injury develops minutes to hours later, involving ischemia, edema, excitotoxic neurotransmitter release, oxidative stress, and apoptosis. This cascade further damages neurons and glial cells, worsening functional outcomes.

Clinical Syndromes and Neurological Classification

SCI is classified using the ASIA Impairment Scale, ranging from grade A (complete injury) to E (normal function). Complete injury is defined by total loss of motor and sensory function below the lesion, including the sacral segments S4–S5. Incomplete injuries retain some motor or sensory function in these segments. Distinct incomplete syndromes include:

Central Cord Syndrome: greater motor impairment in upper limbs than lower limbs.

Anterior Cord Syndrome: loss of motor and pain/temperature sensation, with preserved proprioception.

Brown-Séquard Syndrome: ipsilateral motor and proprioceptive loss with contralateral pain/temperature loss.

Posterior Cord Syndrome: rare, characterized by loss of proprioception and vibration sense.

Conus Medullaris and Cauda Equina Syndromes: flaccid paralysis and early bladder/bowel dysfunction.

Diagnostic Approach

Clinical assessment involves a detailed neurological examination to evaluate sensory, motor, and autonomic function. Key components include motor strength grading, dermatome testing, sacral sparing, and reflex evaluation such as the bulbocavernosus reflex (BCR), which helps identify the end of spinal shock. Imaging studies include plain radiographs, CT scans, and MRI. MRI is especially valuable for identifying ligamentous injury, cord edema, and disc herniation, and is often used to guide decisions on immobilization or surgical intervention.

Management Strategies

SCI management encompasses pre-hospital and in-hospital phases. Pre-hospital care prioritizes spinal immobilization and airway management using a rigid collar and spinal board. Hospital-based treatment addresses multisystem complications—respiratory insufficiency, neurogenic shock, bladder dysfunction, gastrointestinal issues, and pressure ulcers. Methylprednisolone has been investigated for neuroprotection, but its routine use remains controversial. Surgical intervention is indicated for unstable fractures, persistent compression, or worsening neurological function. Skeletal traction and internal fixation techniques are used depending on injury location and stability.

DISCUSSION

Spinal cord injury (SCI) remains one of the most debilitating forms of trauma, with long-lasting impacts on neurological function, quality of life, and healthcare resources. The high prevalence in young adult males

highlights the socio-economic burden of this condition, particularly due to its association with high-energy trauma such as motor vehicle accidents and falls. The data consistently show that the majority of patients experience significant physical limitations and require long-term rehabilitation and support, especially those with complete lesions [1,2].

The pathophysiological cascade of SCI involves a primary mechanical insult followed by complex secondary processes including vascular disruption, ischemia, excitotoxicity, and inflammation. These secondary injuries are especially critical as they are potentially modifiable through early medical intervention. For instance, the concept of administering high-dose methylprednisolone within 8 hours of injury, as suggested by the NASCIS II and III trials, has shown neurological benefits in some patients. However, its use remains controversial, with more recent guidelines cautioning against routine use due to potential complications such as infection and gastrointestinal bleeding [3,4].

Accurate classification of SCI using the ASIA Impairment Scale provides clinicians with a standardized method to assess injury severity and monitor progression. Importantly, the presence of sacral sparing and the return of bulbocavernosus reflex (BCR) are key indicators for distinguishing between complete and incomplete injuries. These findings guide prognosis and influence treatment decisions. For example, a positive BCR after spinal shock has resolved but with absent sensory or motor function indicates a complete lesion, limiting the expectation for neurological recovery [5].

The diagnosis of SCI relies heavily on imaging modalities. Plain radiographs are often the first step, but their sensitivity is limited. CT scans are superior for detecting bony injuries, while MRI is essential for evaluating soft tissue structures, spinal cord compression, and intramedullary damage. MRI findings can support decisions to discontinue spinal immobilization, particularly in cases with no evidence of ligamentous injury or cord compression [6]. Therefore, MRI is not only diagnostic but also essential for preventing unnecessary prolonged immobilization.

Management of SCI requires a multidisciplinary approach. In the pre-hospital setting, immobilization is critical to prevent secondary damage. In-hospital care focuses on airway protection, cardiovascular stabilization, bladder and bowel control, and prevention of complications such as pressure ulcers and thromboembolism. Respiratory compromise is especially concerning in high cervical injuries (above C5), necessitating mechanical ventilation. Cardiovascular instability due to neurogenic shock, particularly in lesions above T6, further complicates management and requires the use of vasopressors and strict hemodynamic monitoring [7].

Surgical intervention plays an essential role in selected cases, particularly those with unstable fractures, persistent neurological deficits, or evident cord compression on imaging. While surgery may not directly reverse the neural injury sustained at the moment of trauma, it serves to stabilize the spinal column, decompress the cord, and prevent further deterioration. Early surgical decompression has been associated with better functional outcomes, especially in incomplete SCI cases [8].

Ultimately, SCI management is not only about acute survival but also about long-term rehabilitation and reintegration. Multisystem care, early mobilization, and psychological support are critical to optimizing recovery and reducing secondary complications. The complexity of SCI underscores the need for continued research, particularly in areas such as neuroprotection, stem cell therapy, and functional electrical stimulation, which hold promise for future treatment paradigms.

CONCLUSION

Spinal cord injury (SCI) is a severe neurological condition, predominantly caused by trauma, that leads to significant motor, sensory, and autonomic dysfunction. Its complex pathophysiology involves both

primary mechanical damage and secondary processes such as ischemia and inflammation. Accurate classification using the ASIA Impairment Scale and prompt diagnostic imaging, particularly MRI, are essential for guiding treatment. Early interventions including spinal immobilization, respiratory and cardiovascular support, and surgical decompression when indicated are critical in reducing further injury and improving outcomes. Long-term management requires a multidisciplinary approach addressing systemic complications, functional rehabilitation, and social reintegration. While certain treatments like high-dose corticosteroids remain controversial, ongoing research into neuroprotective and regenerative therapies offers hope for improving recovery and quality of life in SCI patients.

Declaration by Authors

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