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Multilevel Spinal Cord Injuries in Children with SCIWORA Syndrome

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Background: The unique anatomical and physiological features of the pediatric spine predispose children to a distinct form of spinal cord trauma known as SCIWORA (Spinal Cord Injury Without Radiographic Abnormality). This condition occurs predominantly in children and is characterized by clinical evidence of spinal cord injury in the absence of detectable abnormalities on conventional imaging modalities, including plain radiography and MRI. Recent studies indicate that multilevel spinal cord involvement in pediatric SCIWORA cases may be more frequent than previously recognized, and some patients may ultimately require surgical management.

Methods: A retrospective analysis was performed on 80 children aged 4–18 years who were treated for SCIWORA at the Pediatric Neurosurgery Department in Omsk between 2008 and 2022. The mechanisms of injury were evaluated, and neurological status was assessed using the Frankel scale to determine the severity of neurological deficits. Injury severity was additionally classified according to the criteria proposed by Zwimpfer T.J. (1990). All patients underwent spinal radiography in two standard projections as well as MRI examination. In twenty-eight cases, electromyography (EMG) studies were performed.

Results: In two patients, clinical manifestations of L4–L5 radiculopathy were observed despite the absence of lumbar spinal trauma. All patients demonstrated favorable outcomes following conservative treatment.

Conclusions: Pediatric SCIWORA remains a relatively rare yet potentially severe form of spinal cord injury. In children with SCIWORA syndrome, multifocal spinal cord involvement is possible, and the degree of neurological recovery largely depends on the presence and severity of MRI-detected abnormalities.

Keywords: Spinal Cord Injuries; Child; Radiculopathy; Magnetic Resonance Imaging; Electromyography.

INTRODUCTION

Spinal injuries in children account for up to 2% of all fractures, while neurological complications involving the spinal cord are observed in approximately 27% of cases [5]. The distinct anatomical and physiological characteristics of the pediatric spine predispose children to a unique type of injury known as SCIWORA syndrome (Spinal Cord Injury Without Radiographic Abnormality). First described by Pang D. in 1982, this syndrome represents up to 75% of spinal cord injuries in children and is characterized by isolated spinal cord damage in the absence of vertebral column injury [7]. The pathophysiology of SCIWORA has been attributed to the discrepancy between the high elasticity of the spinal column and the relative vulnerability of the spinal cord. Currently, the mechanisms underlying these injuries are well established [3,8]. Such trauma is frequently associated

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with significant neurological deficits and, in certain cases, may require surgical management [9]. The treatment of patients with associated injuries presents additional clinical challenges. The introduction of MRI has enabled SCIWORA to be subdivided into two categories: cases with detectable spinal cord abnormalities on MRI and cases without radiological changes.

MATERIALS AND METHODS

The diagnostic characteristics and clinical manifestations of isolated spinal cord injuries in 80 pediatric patients diagnosed with SCIWORA syndrome who demonstrated no radiographic evidence of vertebral injury was analyzed. The patients, aged 4–18 years, were treated at the Department of Pediatric Neurosurgery in Omsk between 2008 and 2022. Mechanisms of injury were investigated, and neurological status was evaluated using the Frankel scale to determine the severity of neurological deficits. Injury severity was additionally classified according to the criteria proposed by Zwimpfer TJ (1990) [16]. All patients underwent spinal radiography in two standard projections as well as MRI examinations. A subgroup of patients (n=28) presenting with Frankel grades B, C, and D underwent electromyographic (EMG) evaluation in collaboration with a neurophysiologist using the four-channel “NeuroMVP-4” analyzer (Neurosoft, Russia) and the VikingQuest system (Nicolet, USA). Standard stimulation electromyography (SEMG), including both surface and needle EMG techniques, was applied. Statistical analysis was conducted using Statistica 6.0 software. Differences were considered statistically significant at p<0.05. The minimum required sample size was calculated according to N. Fox method.

RESULTS

Among the analyzed cases, domestic trauma accounted for 72 injuries, traffic-related trauma for 6 cases, while the remaining injuries were associated with sports activities. Boys were affected more frequently than girls, with a male-to-female ratio of 1:0.7. The predominant mechanisms of injury were compression-flexion (n=38) and distraction-extension (n=30), whereas in 12 cases the mechanism of injury could not be determined.

At admission, patients demonstrated neurological deficits corresponding to Frankel grades C, D, and E. Preschool-aged children presented with more severe neurological impairment at the time of hospitalization (Table 1).

Table 1. Evaluation of neurological deficit severity according to the Frankel scale across different pediatric age groups.

Patient group	Degree of spinal cord injury by Frankel’s scale				Total
	Type B	Type C	Type D	Type E	
Children under 7 years	1	2	6	4	13
Children over 7 years	-	4	15	48	67
Total	1	6	21	52	80

Statistical analysis confirmed that the differences in the frequency of Frankel grades D and E were statistically significant and not attributable to random variation (p<0.05). In contrast, no statistically significant intergroup differences were identified for Frankel grades B and C.

Our findings differ slightly from those reported by other authors, who described more severe spinal cord injuries in pediatric patients [4,8]. This discrepancy may be explained by differences in patient populations, as some studies indicate that up to 50% of SCIWORA cases are associated with traffic-related trauma [9]. Cervical spinal injuries were the most frequently observed, likely due to the increased mobility of this spinal segment (Table 2). Neurological deficits generally developed within the first 24 hours following trauma. In the majority of patients, neurological symptoms regressed rapidly, except in two cases in which MRI demonstrated areas of spinal cord contusion. Statistical analysis showed no

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statistically significant association between the extent of spinal cord injury and the anatomical localization of the lesion.

Table 2. Localization of spinal cord lesions in patients with SCIWORA syndrome.

Localization	Spinal cord concussion	Spinal cord contusion
Cervical	24	12
Thoracic	23	9
Lumbar	4	2
Unspecified	4	2

Treatment was selected according to neurological status, MRI findings, and the presence or absence of spinal instability or compression. All patients received conservative treatment, including spinal immobilization, analgesic and anti-edema therapy, neuroprotective treatment, symptomatic therapy, and rehabilitation measures. No surgical intervention was required in patients without MRI evidence of compression or instability. External spinal immobilization for up to 12 weeks was the primary treatment strategy for patients with spinal cord injury. Additionally, patients are recommended to avoid high-risk physical activities for at least 6 months following diagnosis in order to minimize symptom exacerbation and reduce the likelihood of recurrent injury. In asymptomatic patients with confirmed spinal stability on flexion–extension dynamic radiographs, immobilization devices may be discontinued earlier.

The mean length of hospital stay was 7±0,22 days, ranging from 3 to 11 days. Patients with mild neurological deficits and no MRI-detected spinal cord lesions had shorter hospitalization periods, while children with spinal cord contusion or more severe neurological impairment required longer inpatient treatment and rehabilitation.

Follow-up was available for 56 patients, with a mean follow-up duration of 6 months. At discharge, neurological improvement was observed in most patients. Children with Frankel grade E remained neurologically intact, while the majority of patients with Frankel grade D demonstrated complete or near-complete recovery. Patients with Frankel grade C showed partial neurological improvement, although recovery was slower and less complete in those with MRI-confirmed spinal cord contusion.

However, in two children aged 10 and 12 years who sustained cervical trauma, positive Lasègue sign values of 45° and 70° were detected. MRI of the lumbar spine revealed no pathological changes that could explain the neurological deficits. No clinically significant motor or sensory disturbances in the extremities were identified. The abnormalities in these spinal segments appeared to be transient and reversible. Electromyographic examination in the patient with radicular syndrome demonstrated findings consistent with radiculopathy.

Electromyography was performed in 28 patients with Frankel grades B, C, and D. In two children with cervical and upper thoracic trauma, clinical signs of L4–L5 radiculopathy were identified despite the absence of lumbar spine trauma on MRI. EMG confirmed signs of radiculopathy, which were interpreted as clinical or subclinical manifestations of spinal root traction injury. Both patients improved with conservative treatment. Follow-up EMG demonstrated regression of conduction abnormalities.

Overall, neurological recovery depended mainly on the initial neurological status and the presence or absence of MRI-detected spinal cord changes. Children without MRI abnormalities generally had favorable outcomes, whereas patients with spinal cord contusion showed slower recovery and a higher risk of residual neurological symptoms.

Clinical Case

A 9-year-old male with a history of falling from a height of approximately two meters from a tree onto his back. Immediately after the injury, the patient experienced a transient sensation resembling an

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electric shock in both the upper and lower extremities lasting for about one minute, followed by lower limb weakness persisting for approximately one hour, as well as back pain.

On admission, the patient's general condition was assessed as moderate. The skin and mucous membranes were clean, hemodynamic parameters were stable, and urinary function was preserved. Neurological examination revealed positive Neri sign and bilateral positive Lasègue sign at 45°. The remaining neurological findings were unremarkable, with preserved muscle strength graded at 5/5 and no sensory disturbances detected.

Spinal radiography and MRI revealed no evidence of traumatic structural abnormalities (Figure 1). The patient was diagnosed with complicated vertebral-spinal trauma, thoracic spine contusion, and spinal cord concussion.

Figure 1. MRI showing no signs of vertebral or spinal cord injury in patient with SCIWORA.

Electromyographic evaluation demonstrated signs of L4–L5 radiculopathy and peroneal neuropathy, more pronounced on the left side (S>D), predominantly of the axonal type. These findings were interpreted as subclinical manifestations of spinal nerve root injury.

During the 5-day course of treatment, the patient's condition improved significantly, with resolution of pain and normalization of reflex activity. Follow-up examination two weeks later revealed no neurological deficits. Repeat electromyography performed four weeks after the injury demonstrated no pathological abnormalities.

DISCUSSION

The higher prevalence of SCIWORA in pediatric patients has been attributed to the distinct anatomical and biomechanical characteristics of the cervical spine that differentiate children from adults [3,9].

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The pathophysiology remains incompletely understood. It is believed to result from multiple traumatic mechanisms, including hyperextension, traction forces, spinal cord edema, and vascular injury, all of which may contribute to spinal cord damage in the absence of radiographic abnormalities.

Several authors have reported isolated thoracic and lumbar spinal cord injuries associated with SCIWORA syndrome [2,6,14]. In our series, cervical spinal cord involvement was observed more frequently, which may be related to the predominant mechanisms of injury.

Recent studies have described multilevel spinal cord injuries in children with traction-type SCIWORA syndrome, including MRI-confirmed spinal cord abnormalities and, in certain cases, the necessity for surgical intervention [1,15]. However, reports describing radiculopathy in pediatric SCIWORA patients remain extremely limited.

Although the relatively small sample size prevents definitive conclusions, our findings suggest that traction-related mechanisms of injury — particularly compression-flexion and distraction-extension forces — may lead to transient displacement of the vertebrae without structural damage. Such displacement can produce traction on the spinal cord and nerve roots, potentially resulting in either clinical or subclinical manifestations of spinal root injury.

Traumatic injuries involving the upper thoracic spine may also be associated with traction of the spinal nerve roots. This phenomenon can be explained by the relatively large head size and increased mobility of the cervical spine in children, which predispose pediatric patients to traction-related injuries. In our cohort, nearly half of the patients sustained cervical spine trauma, while a considerable number had injuries with unspecified localization.

In cases involving thoracic and lumbar spinal injuries, the clinical manifestations are unlikely to be attributable solely to traction mechanisms. Vascular factors may also play a role in the development of neurological symptoms, as previously suggested by other investigators [4,12].

Radiculopathy was identified in only two patients with cervical and upper thoracic spinal trauma. Electromyographic findings support the possibility of subclinical spinal root injury and provide an effective method for monitoring the regression of conduction abnormalities over time.

Neurological recovery in patients with SCIWORA is influenced by several factors, including the mechanism of the initial injury, spinal canal diameter, patient age, extent of spinal cord damage, the presence of disc-ligamentous lesions, and the severity of neurological impairment [6,7]. For these reasons, surgical intervention is not considered the standard treatment approach. Surgical management should be reserved for patients with clear MRI evidence of extra-neural pathology, such as spinal cord compression, ligamentous injury, or spinal instability, particularly in cases of neurological deterioration or lack of clinical improvement.

CONCLUSION

Pediatric SCIWORA remains a relatively rare yet potentially severe form of spinal cord injury. In children with SCIWORA syndrome, multifocal spinal cord involvement is possible, and the degree of neurological recovery largely depends on the presence and severity of MRI-detected abnormalities.

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DISCLOSURES

Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. The institutional ethics committee waived off the need to obtain individual participant's consent.

Consent to participate

The patients gave consent to use their information and images for research purposes. *Consent for publication*

Conflict of interest

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper

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Artificial intelligence

In the preparation of this manuscript, the authors utilized generative AI and AI-assisted technologies to enhance the quality and precision of the content. Specifically, ChatGPT-4.0 was employed for the translation of certain phrases from Uzbek to English, ensuring accurate and fluent language conversion. Additionally, Grammarly was used to refine the grammar and overall readability of the text. The authors have thoroughly reviewed and edited all AI-assisted outputs, assuming full responsibility for the integrity and quality of the final manuscript.

CONTRIBUTIONS

-**Makhmud Akhmediev:** Formal analysis, Conceptualization
-**Igor Larkin:** Supervision, Methodology, Formal analysis
-**Valery Larkin:** Supervision, Resources
-**Tokhir Akhmediev:** Writing – original draft, Methodology, Resources, Formal analysis
-**Elena Kravchenko:** Methodology, Writing – original draft

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