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VIEWPOINT

CLINICAL ANATOMY WILEY

Post-traumatic cauda equina concussion: Definition and description of the injury mechanism

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Abstract

Despite being a prevalent clinical condition, cauda equina concussion has not been thoroughly elucidated in the literature. The aim of this study is to delineate the etiology and pathogenesis of cauda equina concussion and its associated clinical manifestations. Patients exhibiting clinical manifestations indicative of spinal cord injury and transient neurological deficits after spinal trauma were evaluated retrospectively. The pathogenesis was elucidated through correlating clinical presentations with radiological findings. Neurological deficits were categorized into two principal groups, symmetrical and asymmetrical. Non-penetrating fractures were classified to ascertain the relationship between the type of trauma and the ensuing neurological deficits. A cohort of 82 patients was diagnosed with cauda equina concussion. Among these, 58 had experienced vertical trauma resulting from falls, while 24 had encountered axial trauma in vehicular accidents. Stable spinal fractures were identified in 52 patients across multiple levels, whereas single-level fractures were observed in 30. Asymmetrical neurological deficits were detected in 51 (62.19%) patients, with a notably higher incidence among those subjected to vertical trauma ($p < 0.014$). The mean recovery time was 14.25 ± 15.16 h for sensory deficits and 11.25 ± 13.36 h for motor deficits in those patients. Notably, motor deficits resolved more expeditiously than sensory deficits in all cases presenting with both. Cauda equina concussion emerges as a frequently encountered clinical phenomenon attributable to the impact of high-energy vertical forces. Neurological deficits commonly manifest asymmetrically. The rapid resolution of neurological deficits presents challenges for the diagnostic process.

KEYWORDS
cauda equina concussion, SCIWORA, spinal cord concussion, spinal cord injury, spinal fracture, spinal trauma

1 | INTRODUCTION

Cauda equina concussion is a spinal injury characterized by transient neurological dysfunction in the lower limbs during the early post-traumatic period. Distinguished by its pathogenesis, etiological factors, and clinical presentation, it differs from cauda equina syndrome (Orendácová et al., 2001; Quaile, 2019). Diagnosis proves challenging owing to the absence of radiological evidence of spinal injury, the rapid resolution of clinical symptoms, and the frequent occurrence of multi-trauma scenarios among patients. Sensory deficits in the lower limbs predominate, but motor deficits and incontinence are also common. The cauda equina, extending in the form of fibers, distributes

TABLE 1 Demographic data of the patients and distribution according to trauma types.

	Axial trauma ($n = 24$)	Vertical trauma ($n = 58$)	p Value
Sex	8 F/16 M	19 F/39 M	
Mean age	47.00 ± 18.81	40.43 ± 13.95	
Single-segment fracture	13	10	0.532
Two or more segmentary fractures	20	39	0.013
Segmentary asymmetrical deficit ($n = 57$)	18	39	0.005
Unilateral deficit ($n = 25$)	10	15	0.317

the energy of the trauma among those fibers, resulting in less severe impact than spinal cord injuries, thereby leading to milder and shorter-term clinical manifestations.

The fibrous structure of the cauda equina delineates mechanisms of trauma exposure distinct from non-penetrating spinal cord injuries. Clinical manifestations following exposure of the spine to high-energy vertical forces are often asymmetrical.

Cauda equina syndrome is a clinical condition typically resulting from injury or compression of the cauda equina. Recovery from the resulting neurological injury necessitates the removal of the compressive structure (Hazelwood et al., 2019; Hazelwood et al., 2021; Woodfield et al., 2022). In contrast, cauda equina concussion can be explained by the temporary nature of the injury to the cauda equina, suggesting that the injury is physiological rather than anatomical.

The aim of this study is to elucidate the clinical manifestations of cauda equina concussion, along with associated radiological findings, and to discuss the injury mechanism underlying this condition.

2 | MATERIALS AND METHODS

Patients who presented to a tertiary healthcare institution were retrospectively evaluated. Neurosurgery and emergency department records were reviewed retrospectively, commencing from 2014, to identify patients diagnosed with post-traumatic cauda equina concussion. Patients presenting with post-traumatic spinal cord injury symptoms who had undergone diagnostic evaluations were assessed. After the clinical and radiological findings were examined, cases who showed no radiological evidence of spinal cord or cauda equina injury and exhibited complete neurological recovery were included in the study. Cases without specific spinal cord imaging, such as MRI or CT scans, and those with extremity injuries, were excluded. Data pertaining to the cases were obtained from patient medical records at the institution. Patients exhibiting sensory deficits below the L1 level, motor deficits, and incontinence, all of which spontaneously resolved within two days, met the inclusion criteria. Patients lacking vertebral fractures on radiological examination were excluded to delineate the pathogenesis of the condition.

An Excel database was established to document the patients' demographic characteristics, type of trauma (axial/vertical), sensory and motor deficits, incontinence findings, and duration of neurological symptoms in hours. Symmetrical and asymmetrical types of neurological deficits were also documented and summarized (Table 1).

The Picture Archiving and Communication Systems (PACS) were used for radiological assessments, and pathological findings related to spinal trauma were noted. Radiological findings, including transverse process fractures, endplate and anterior vertebral body fractures, and spinous process fractures, were recorded alongside the associated levels. The spine was evaluated in the coronal plane across three columns to determine the orientation of the trauma axis. Transverse processes were categorized as elements of the lateral columns, while the vertebral body, endplate, and spinous processes were designated as elements of the middle column. Patients presenting with fragments displaced into the spinal canal, unstable spinal fractures, and radiological findings suggesting compression or penetration along the cauda equina were excluded. Patients exhibiting neurological symptoms and findings indicating spinal cord injury above the L1 level were also excluded, warranting differential diagnosis from spinal concussion, SCIWORA, and Real SCIWORA.

The criteria for clinical findings encompassed patients with sensory and motor deficits below the L1 segment, along with urinary and fecal incontinence, all of which demonstrated complete spontaneous recovery within two days.

2.1 | Statistical analyses

Following the compilation of patients' data into an Excel file to establish a database, the requisite mathematical data for statistical analyses were exported to SPSS 22 software for comprehensive statistical examination. The chi-square test was employed to compare groups. The significance level was set at $p < 0.05$.

The Winautomatization tool was used to streamline data entry into the database, facilitate the transfer of data into SPSS files, and expedite repetitive computer operations. This software facilitated data entry automation by generating macro files, with concurrent verification of data entry accuracy.

2.2 | Ethics committee approval

Ethics committee approval for this study was obtained from the Kirsehir Ahi Evran University Clinical Research Ethics Committee. The Ethics Committee Approval number is 20-21-11/122.

3 | RESULTS

A total of 82 patients meeting the inclusion criteria were identified. Eleven patients with radiological assessments revealing no fractures were excluded from the study. The mean age of the cohort was 42.35 ± 15.70, comprising 56 males and 26 females. Among these, 51 agricultural workers were reported to have fallen from trees, while seven patients had fallen from high buildings, constituting cases exposed to vertical forces. In contrast, 24 patients involved in traffic accidents were evaluated for axial trauma exposure (Table 1).

All 82 patients presented stable spinal fractures that did not necessitate surgical intervention. There were transverse process fractures in 73 patients, and 43 exhibited endplate, vertebral body, or spinous process fractures. A total of 52 patients (63.41%) displayed fractures across multiple levels, and 56 (68.29%) presented multiple fractures involving different bone structures, indicating the potential association between force direction and asymmetrical deficits. The most prevalent fracture pattern, observed in 34 patients (41.46%), involved transverse process fractures combined with vertebral body or endplate fractures across various levels. Additionally, 22 patients (26.82%) exhibited transverse process fractures across different segments on distinct sides. Fracture distribution is detailed in Table 2.

Bilateral motor deficits were detected in seven patients (8.53%), while bilateral sensory deficits were observed in 31 (37.80%). Notably, 51 patients (62.19%) exhibited asymmetrical deficits in both motor and sensory functions. Among all patients, three exhibited incontinence, all coinciding with motor deficits. The rates of asymmetrical neurological deficits were significantly higher among patients with vertical trauma ($p = 0.014$).

Most of the patients with sensory deficits ($n = 36$, 43.90%) recovered within 1–6 h ($p = 0.034$), whereas recovery was typically complete within the first hour for patients with motor deficits ($n = 12$; 14.63%). The group exhibiting the longest recovery period, involving 10 patients with sensory deficits and two with motor deficits, recovered completely in 24–48 h (Table 3). The mean duration of recovery was 14.25 ± 15.16 h for sensory deficits and 11.25 ± 13.36 h for motor deficits. Notably, motor deficits resolved more swiftly than sensory deficits in all cases presenting with both.

Early clinical prognosis indicated rapid improvement, with noticeable recovery between initial evaluation in the emergency department and subsequent clinical assessments following trauma. No patients were given corticosteroid treatment, as MRI examinations revealed no findings indicative of spinal cord injury.

4 | DISCUSSION

Cauda equina concussion is a clinical entity within the spectrum of spinal cord injuries characterized by transient neurological deficits and rapid neurological recovery. Below the level of the L1 vertebra, the spinal cord tapers and extends in the form of fibers, delineating a distinct anatomical configuration (Lavy et al., 2022; Rider & Marra, 2023). This anatomical feature distinguishes traumatic injuries in this region from those affecting the spinal cord elsewhere.

The concept of spinal cord neuropraxia was initially introduced by Torg in relation to American football players, elucidating non-penetrating trauma to the spinal cord resulting from axial trauma to the cervical region, which manifests as temporary neurological deficits with complete recovery (Boden et al., 2006; Jabola et al., 2021; Ladd & Scranton, 1986; Torg, 1995). Subsequent studies have elaborated this concept, demonstrating that spinal cord neuropraxia can also ensue from trauma with a vertical force axis. Such occurrences are particularly prevalent in the thoracic segment, the most extensive portion of the spinal cord (Asan, 2018a; Asan, 2018b). Consequently, neurological deficits stemming from falls from heights can be

TABLE 3 The duration of neurological deficits is shown in hours.

	Sensorial deficit	Motor deficit	Incontinence
	$n = 82$	$n = 32$	
<1 h	17 (20.73%)	12 (37.50%)	1 time
1–6 h	36 (43.90%)	10 (31.25%)	0
7–24 h	19 (23.17%)	8 (25.00%)	2 times
24–48 h	10 (12.19%)	2 (6.25%)	0
Mean	14.25 ± 15.16 h	11.25 ± 13.36 h	

TABLE 2 The distribution of sensory and motor deficits is depicted based on fracture types in the vertebrae. It is noteworthy that sensory deficits are observed in cases with motor deficits.

	Sensorial deficit ($n = 82$)			Motor deficit ($n = 32$)		
	Right SD	Left SD	Bilateral SD	Right MD	Left MD	Bilateral MD
Right TPF ($n = 10$)	6	1	3	1	0	0
Midline F ($n = 11$)	4	2	3	2	1	1
Left TPF ($n = 7$)	1	3	3	2	2	0
Right TPF + Midline F ($n = 16$)	9	2	5	4	1	2
Left TPF + Midline ($n = 18$)	2	6	10	1	4	1
Bilateral TPF ($n = 22$)	9	6	7	3	4	3

Abbreviations: F, fracture; MD, motor deficit; SD, sensory deficit; TPF, transverse processes fracture.

asymmetrical, given that the traumatic force applied to the spine is not always precisely vertical (i.e., 90°) (Asan, 2018b).

It is challenging for the spinal canal and the cauda equina to sustain axial trauma to the lumbosacral region without penetrating injuries such as vertebral fractures (Attabib et al., 2021; Harrop et al., 2004; Kingwell et al., 2008; Torg et al., 1986; Torg et al., 1995; Torg et al., 1997; Torg et al., 2002). Similarly, falls from heights typically lead to vertebral compression fractures, penetrating bone fractures, or instability, making non-penetrating injuries within the spinal canal unlikely (Bradford & McBride, 1987; Brouwers et al., 2017; Dai et al., 2007; Hu et al., 1993; Meves & Avanzi, 2005; Thongtrangan et al., 2004). High-energy trauma is usually required to cause non-penetrating injuries to the spine and spinal cord.

The diagnosis of cauda equina concussion can easily be overlooked or delayed owing to the rapid and spontaneous recovery by affected patients. Complicating factors include the absence of pathological radiological findings of spinal cord or cauda equina involvement, the milder neurological symptoms than in other spinal cord injuries, and the swift resolution of those symptoms (Asan, 2018a; Asan, 2018b). Given the low likelihood of trauma affecting all cauda equina fibers, patients typically present with a less severe course than those with spinal concussion or cauda equina syndrome. Moreover, high-energy trauma is typically necessary to affect the cauda equina, given its fibrous extension.

Following exposure to vertical forces, the kyphotic and lordotic curvatures of the spinal canal serve as barriers, limiting the force's transmission to higher spinal canal segments (Asan, 2018a). In axial traumas, the spinal cord is usually affected by flexion and extension motions, limiting the number of affected segments and increasing the likelihood of symmetrical neurological deficits. In contrast, vertical forces necessitate a vertical transmission along the spinal cord if segmental involvement is to be symmetrical. However, a precise 90-degree angle of force transmission along the spinal canal is unusual, particularly in falls from

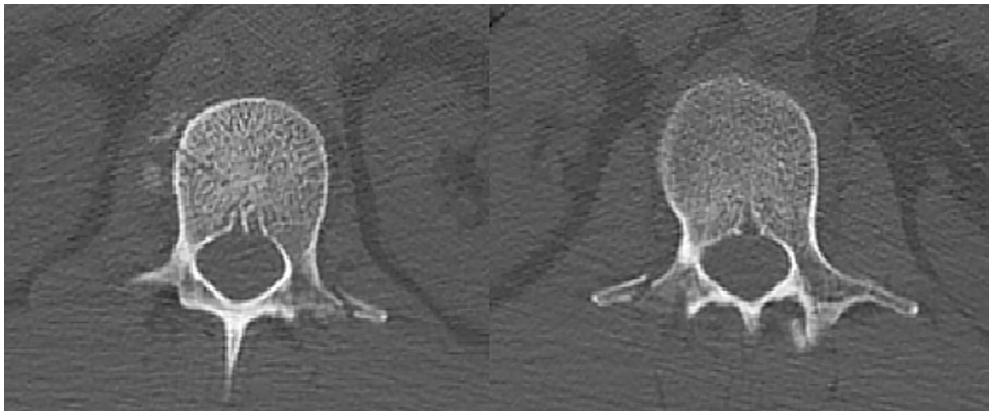

FIGURE 1 Example of transverse process fractures on different sides at different levels in a patient with asymmetrical neurological deficits, indicating that the force axis passes through the spinal canal.

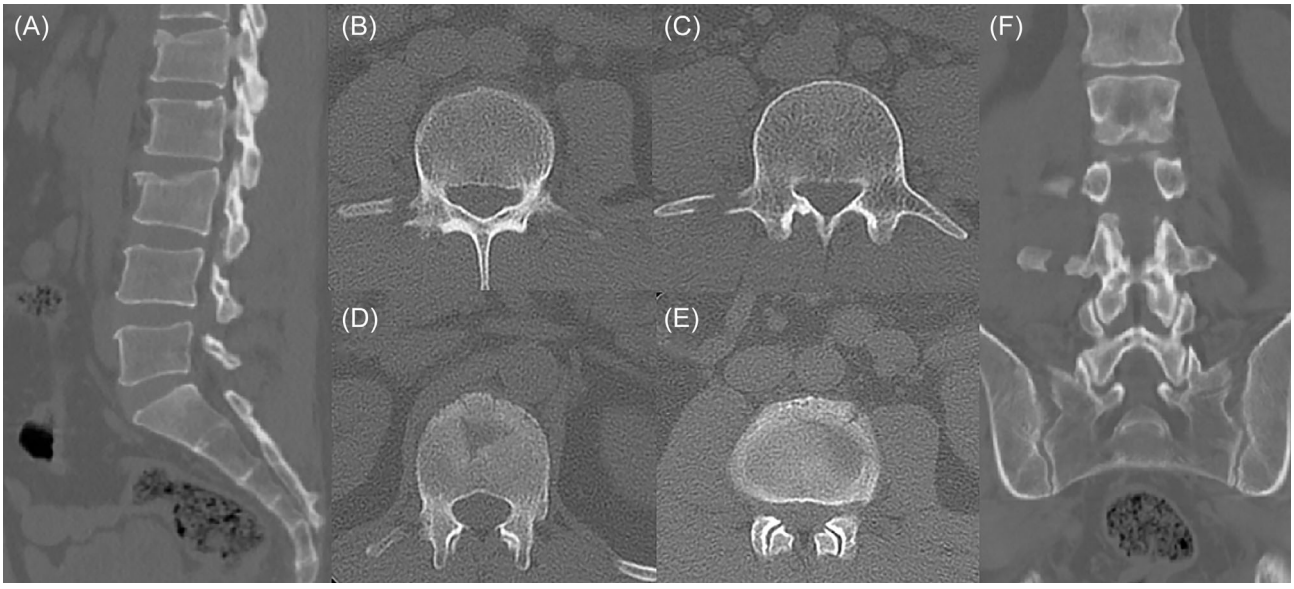

FIGURE 2 CT scans of various spine regions in a patient who experienced a fall from height, illustrating the direction of the force passing through the spinal canal. (A) L1 and L3 endplate fractures, (B, C) right transverse process fractures in the L3 and L4 vertebrae, (D, E) endplate and vertebral body fractures in L1 and L3, (F) transverse process fractures indicating the force direction in the coronal plane.

heights (Ladd & Scranton, 1986). In this study, 37.8% ($n = 31$) of patients subjected to vertical forces exhibited symmetrical clinical findings, while 24.39% ($n = 20$) displayed symmetrical or isolated midline fractures on radiological evaluation. Segmental asymmetry was prevalent, with 62.2% of patients demonstrating neurological findings and 75.61% exhibiting radiological findings consistent with segmental asymmetry. Transverse process fractures in different segments and sides were the most common finding (Figure 1), indicating that the force axis traversed the spinal canal and produced fractures in various spine structures across different segments (Figure 2).

In previous studies, clinical findings of spinal concussion patients were reported to resolve completely within a maximum of three days (Torg et al., 1986). Patients with axial trauma-related cervical neuropraxia, as described by Torg, and those experiencing vertical trauma, as described by Asan, achieved complete recovery within three days at the latest (Asan, 2018a; Asan, 2018b; Torg, 1995; Torg et al., 1985). In contrast, over 87.80% ($n = 72$) of patients diagnosed with cauda equina concussion demonstrated total neurological recovery within one day. Sensory deficits were consistently observed in all patients, with motor deficits in 39.02% ($n = 32$).

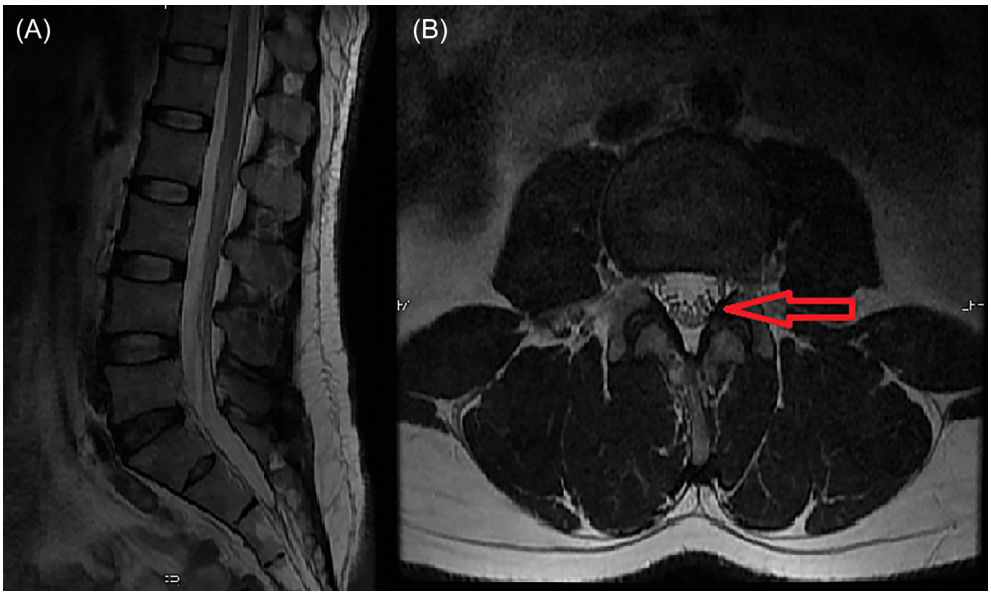

FIGURE 3 In sagittal (A) and axial (B) T2 sequences of lumbar MRI imaging, there is no pathology associated with the conus and cauda equina. Cauda equina fibers are visualized normally (red arrow).

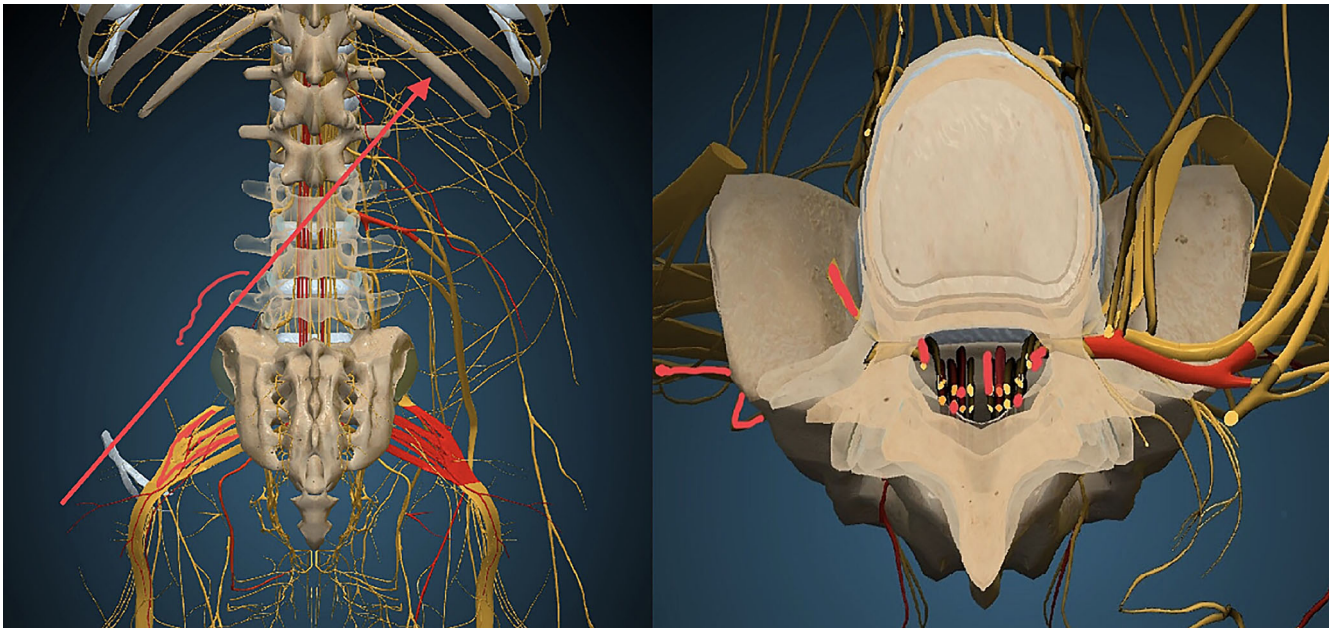

FIGURE 4 Cauda equina fibers are asymmetrically affected owing to their anatomical characteristics, resulting in the emergence of asymmetric deficits.

The mean duration of total recovery was 14.25 ± 15.16 h for patients with sensory deficits, and 11.25 ± 13.36 h for those with motor deficits. Remarkably, 68.75% ($n = 22$) of patients with motor deficits experienced complete resolution within the first 6 h. None of the patients presented with plegia at the time of diagnosis and frust paresthesia was noted in 28.12% ($n = 9$). It is evident that clinical findings resolve much more rapidly in cauda equina concussion than spinal concussion cohorts, with patients presenting relatively less severe symptoms. Incontinence was reported in three patients (3.66%), with only one experiencing recurrent episodes. Fecal incontinence was observed in one patient.

In contrast to the spinal cord, the cauda equina lacks a single relatively thick medullary structure, resulting in incomplete absorption of incoming force. Consequently, cauda equina injuries tend to be milder and of shorter duration than those suffered by spinal concussion patients.

Cauda equina concussion arises from exposure of the spine to high-energy, primarily vertical forces. Diagnosis is complicated by the rapid resolution of symptoms and the absence of pathological radiological findings in the cauda equina (Figure 3), and the less prominent clinical presentation than in spinal concussion. Diagnosis can be further obscured, particularly in cases presenting solely with sensory deficits or non-recurring incontinence without motor deficits. In such instances, asymmetrical sensory deficits warrant careful evaluation as they can go unnoticed. Diagnosis of cauda equina concussion should be considered in patients exhibiting mild clinical symptoms alongside asymmetrical pathological findings on radiological examination (Figure 4). Notably, patients with post-traumatic clinical presentations resembling cauda equina syndrome can require aggressive treatment approaches, as relatively mild or moderate pathologies detected on radiological assessment can underlie their clinical symptoms. Common presentations in such cases can include traumatic disc herniations that do not culminate in cauda equina syndrome.

In treating cases diagnosed with spinal cord injury, the approach focuses on eliminating the etiological cause of the injury. Although controversial, methylprednisolone therapy remains the most commonly applied medical treatment. In cases diagnosed with cauda equina concussion, neurological deficits are temporary, and no anatomical structure causing the cauda equina injury can be identified. Therefore, it is inferred that the neural injury is physiological rather than anatomical. In cases of post-traumatic spinal cord injury with rapid neurological recovery, it is not always urgent to initiate high-risk treatments such as methylprednisolone therapy. Until a definitive diagnosis is made, methylprednisolone therapy can be anticipated in cases showing rapid clinical improvement during the early stages.

When patients' clinical courses are evaluated alongside radiological findings, it is crucial to recognize that post-traumatic cauda equina concussion can be more common than anticipated among spinal trauma patients, potentially evading diagnosis.

5 | CONCLUSION

Cauda equina concussion is a clinical entity frequently encountered following exposure to high-energy vertical forces. Neurological deficits associated with this condition commonly manifest asymmetrically. The swift resolution of neurological symptoms further complicates diagnosis.

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