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Incidence of and risk factors for hyponatremia and diabetes insipidus in acute spinal cord injury: a retrospective cohort study

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Abstract

Background: Diabetes insipidus (DI) usually coexists with hyponatremia in patients with acute spinal cord injury (SCI). However, the incidence of DI after acute SCI has rarely been reported. In this study, we aimed to determine the incidence rates and risk factors for these conditions and explore early detection and intervention strategies.

Methods: Patients with acute SCI who were sequentially admitted to our center between January 2010 and November 2021 were included. Clinical information was extracted from the medical records. Univariate analyses were performed for each potential risk factor. Variables with a $P < 0.1$ in univariate analysis were included in the multivariate logistic regression analysis, and those with a $P < 0.05$ were defined as independent risk factors.

Results: The cohort included 317 patients. One hundred ten (34.7%) of the 317 patients with acute SCI developed hyponatremia, and 60 (18.9%) developed DI. The median time to onset of hyponatremia was 5 days (interquartile range [IQR]: 4–6), and the median time to onset of DI was 7 days (IQR: 6–8). Multivariate logistic regression analysis identified a cervical level of injury and a more severe injury (ASIA A) as strong independent risk factors for hyponatremia (both $P < 0.001$). Among fracture types, only Type C (compared to Type I) was individually associated with hyponatremia ($P = 0.038$), although the overall fracture-type variable was not significant ($P = 0.156$). In contrast, for DI, in addition to cervical level and ASIA A injury (both $P < 0.001$), the fracture-type variable was a significant predictor overall ($P < 0.001$), with both Type B ($P = 0.027$) and Type C ($P < 0.001$) fractures (vs. Type I) being independent risk factors.

Conclusion: We found a high incidence of hyponatremia (34.7%) and DI (18.9%) in patients with acute SCI. Hyponatremia was mainly associated with higher-level and more severe SCI, with an added risk observed in fracture type C, whereas DI was associated with higher-level SCI, more severe injuries, and fracture types B and C. Our study highlights the interconnected nature of hyponatremia and DI as manifestations of acute SCI. Future research should adopt a unified pathophysiological framework that integrates these findings to better understand the underlying mechanisms.

Keywords: Diabetes insipidus, Hyponatremia, Risk factor, Spinal cord injury

Introduction

Severe spinal cord injury (SCI) is a life-threatening condition requiring prompt and effective management. Early intervention is crucial, as it can significantly mitigate the degree of disability resulting from injury.[1] The incidence of hyponatremia in patients with acute SCI ranges from 25% to 80%.[2–4] Clinical manifestations of diabetes insipidus (DI) include excessive diuresis with hypotonic urine, intense thirst, polydipsia, and related symptoms.[5] Clinical reports have frequently highlighted the coexistence of DI and hyponatremia in patients with acute SCI. Both conditions can exacerbate secondary SCI and are significant risk factors for mortality in these patients.[6] Without timely and effective management, these complications may worsen, posing a critical threat to patient survival and reducing opportunities for successful rehabilitation.[7]

Given the severity of these complications, it is essential to understand their incidence and identify the associated risk factors. In this study, we analyzed clinical data from a historical cohort of patients with acute SCI to investigate the incidence of and risk factors for hyponatremia and DI. We aimed to determine the incidence rates and risk factors for these conditions and explore strategies for their early detection and intervention.

Materials and methods

Study design and participants

This retrospective study included patients with acute SCI who were sequentially admitted to our center between January 2010 and November 2021. The inclusion criteria were confirmed diagnosis of acute SCI based on clinical data, age between 18 and 60 years, and availability of complete clinical data. The exclusion criteria were death within 24 hours of admission, chronic SCI (injury >3 weeks old), open SCI, SCI caused by tumors, infections, or other factors,

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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cauda equina injuries, and acute or chronic renal insufficiency. This study was approved by the Ethical Research Committee of the Chinese People's Liberation Army General Hospital (2024KY053-KS001, May 31, 2024).

A total of 488 patients with acute SCI were treated between January 2010 and December 2021, comprising 387 men and 101 women aged 18–90 years (mean age: 53.10 ± 14.69 years). After applying the exclusion criteria, 138 patients aged <18 or >60 years, 12 with open SCI, 13 with SCI due to metastases, and 8 with renal insufficiency, were excluded. Consequently, the data from 317 patients were included in the analysis (Fig. 1).

Clinical information was collected regarding sex, age, body mass index (BMI), mechanism of injury, type of fracture, SCI segment and grade, American Society of Anesthesiologists (ASA) grade, presence of head injury, presence of surgery, and length of hospital stay. The diagnostic criterion for hyponatremia was a serum sodium concentration of <135 mmol/L, whereas DI was defined as a hypoosmolar urine output exceeding 3000 mL/d.[7]

Fracture types were classified A, B, and C using the new AO (Arbeitsgemeinschaftfür Osteosynthesefragen) classification system for cervical fractures and the AO classification system for the thoracolumbar spine, with injuries without fracture dislocation recorded as type I.[8] The level of injury refers to the specific region of the affected spinal cord, including the cervical, thoracic, lumbar, sacral, and conus regions. The degree of injury indicates the severity of spinal cord damage, which is assessed using the American Spinal Injury Association (ASIA) scoring system. SCI levels and grades were determined based on the latest International Standards for Neurological Classification of SCI (ISNCSCI)-2019 checklist provided by the ASIA International Standards Committee.[9] This checklist evaluates neurological impairment severity and motor-sensory function, with the ASIA grade reflecting the extent of injury. The ASA grade was used to assess the preoperative physical status of the patients. Deaths occurring during hospitalization were also recorded for statistical analysis.

Statistical analysis

Categorical data are presented as frequencies and percentages, n (%), Comparisons between groups were performed using the chi-square test. Fisher's exact test was applied for 2×2 tables when the expected frequency in any cell was <5, and for larger contingency tables when more than 20% of the cells had an expected frequency <5. The Kolmogorov-Smirnov test was applied to continuous variables to assess normality. For normally distributed continuous variables, data are presented as mean ± standard deviation and compared using the *t* test. Non-normally distributed continuous variables are presented as median (interquartile range, IQR) and were analyzed using nonparametric methods, specifically the Mann-Whitney *U* test.

Univariate analysis was performed to evaluate potential risk factors. Variables with a $P < 0.1$ in the univariate analysis were included in the multivariate logistic regression model. Independent risk factors were identified as those with a $P < 0.05$ in the multivariate analysis. Statistical significance was defined as a $P < 0.05$. All statistical analyses were conducted using the SPSS software (version 22.0; IBM Corp., Armonk, NY).

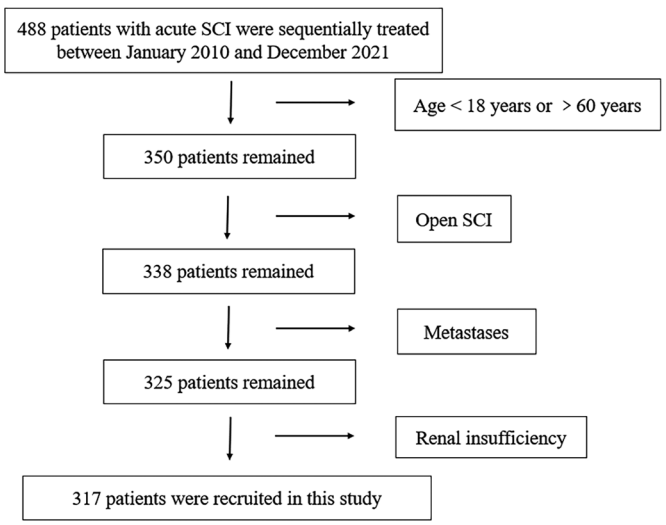

Figure 1. Flowchart of patient recruitment. SCI, spinal cord injury.

Results

Demographics and clinical characteristics

This study included 317 patients (266 males and 51 females) with a median age of 48 years (IQR: 40–55). The causes of injury were traffic accidents (119 cases), falls (91 cases), high-altitude falls (53 cases), crush injuries (36 cases), and other (18 cases). SCI was observed in the cervical, thoracic, lumbar, and conus regions in 184, 61, 47, and 25 cases, respectively.

The ASIA grades were distributed as follows: 128 cases (40.38%) were grade A, 80 cases (25.24%) were grade B, 55 cases (17.35%) were grade C, and 54 cases (17.04%) were grade D. Sixty-one patients (19.24%) had brain injuries. The fracture types of the participants included 84 (26.50%) type I, 97 (30.60%) type A, 89 (28.10%) type B, and 47 (14.80%) type C fractures.

The ASA grade was I in 45 patients (14.20%), II in 252 (79.50%), and III in 20 (6.30%). A total of 228 patients (71.90%) underwent surgery. There were 11 deaths, accounting for 3.5% of the total study population. The median length of hospital stay was 14 days (IQR: 10–23 days), and the median BMI was 22 (IQR: 19–25) (Table 1).

Incidence of hyponatremia and DI

Among the 317 patients with acute SCI, 110 (34.70%) developed hyponatremia, and 60 (18.93%) developed DI. The study period spanned 12 years, from January 2010 to December 2021. Therefore, the annual incidence rates for hyponatremia and DI were calculated as 9.17 and 5 cases per year, respectively.

Of the 184 patients with cervical SCI, 97 (52.71%) experienced hyponatremia, and 57 (30.97%) developed DI. Among the 61 patients with thoracic SCI, 13 (21.31%) developed hyponatremia, and 3 (4.92%) developed DI, all of which occurred in patients with injuries at T5 or above. Neither hyponatremia nor DI was observed in patients with SCI at lower levels. The median time to the onset of hyponatremia was 5 days (IQR: 4–6 days), whereas the median time to the onset of DI was 7 days (IQR: 6–8 days).

Univariate and multivariate logistic regression analyses for hyponatremia

Some variables in this cohort, including age, BMI, and length of hospital stay, did not follow a normal distribution and were analyzed using the Mann–Whitney *U* test. Univariate analysis for hyponatremia showed no significant differences in sex, age, BMI, mechanism of injury, presence of brain injury, or presence of surgery ($P > 0.05$) between patients with and without hyponatremia. However, significant between-group differences were observed in the

Table 1

Demographics and Clinical Characteristics in the Cohort

	Demographics and Clinical Characteristics
Gender	
Female	51 (16.1%)
Age (IQR)	48 (40–55)
Mechanism of injury	
Traffic accident	119 (37.5%)
High-altitude fall	53 (16.7%)
Fall	91 (28.7%)
Crush injury	36 (18.4%)
Others	18 (5.7%)
Level of injury	
Cervical	184 (59.0%)
Thoracic	61 (19.2%)
Lumbar	47 (14.8%)
Conus	25 (7.9%)
ASIA grade	
Grade A	128 (40.4%)
Grade B	80 (25.2%)
Grade C	55 (17.4%)
Grade D	54 (17.0%)
Type of fracture	
Type I	84 (26.5%)
Type A	77 (24.29%)
Type B	89 (28.1%)
Type C	67 (21.13%)
ASA grade	
Grade 1	45 (14.2%)
Grade 2	252 (79.5%)
Grade 3	20 (6.3%)
Hyponatremia	110 (34.7%)
Hyponatremia onset time	5 (4,6)
DI	60 (18.9%)
DI onset time	7 (6,8)
Brain injury	61 (19.2%)
BMI	22 (19–25)
Hospital stay	14 (10–23)

Continuous data are shown as the median (interquartile range) due to non-normal distribution. Categorical data are summarized as the number of cases and rate. Deaths occurring during hospitalization were recorded for statistical analysis.

ASA, American Society of Anesthesiologists; ASIA, American Spinal Injury Association; BMI, body mass index; DI, diabetes insipidus; IQR, interquartile range.

level of injury ($P < 0.001$), degree of injury ($P < 0.001$), ASA grade ($P < 0.01$), length of hospital stay ($P < 0.001$), presence of DI ($P < 0.001$), hypotension ($P < 0.001$), and type of fracture ($P < 0.01$) (Table 2).

In the univariate analysis, potential risk factors for hyponatremia ($P < 0.1$) included injury level, injury severity, length of hospital stay, fracture type, and ASA grade. However, when diabetes insipidus (DI) and hypotension were included—either simultaneously or separately—in the multivariate logistic regression model, significant convergence problems occurred, preventing reliable estimation of coefficients. Even the use of stepwise regression failed to resolve these issues, suggesting instability arising from multicollinearity or quasi-complete separation. After excluding DI and hypotension, the multivariate logistic regression analysis proceeded without difficulty. The final model showed that hyponatremia following acute spinal cord injury (SCI) was independently associated with higher injury level (OR = 29.29, 95% CI: 11.18–76.78, $P < 0.001$) and greater injury severity (OR = 46.03, 95% CI: 17.95–118.06, $P < 0.001$). Among fracture subtypes, only fracture type C demonstrated a significant association compared to type I (OR = 3.18, 95% CI: 1.07–9.46, $P = 0.038$) (Table 3).

Univariate analysis and multivariate logistic regression analyses for DI

Univariate analysis revealed no significant differences in sex, age, BMI, mechanism of injury, presence of brain injury, or presence of surgery between patients with and without DI ($P > 0.05$). However, significant between-group differences were observed in the level of injury ($P < 0.001$), degree of injury ($P < 0.001$), length of hospital stay ($P = 0.001$), ASA grade ($P < 0.05$), hypotension ($P < 0.001$), hyponatremia ($P < 0.001$), and type of fracture ($P = 0.001$) (Table 4).

Univariate analysis identified injury level, injury severity, length of hospital stay, ASA grade, fracture type, hypotension, and hyponatremia as potential predictors of DI ($P < 0.1$). However, the inclusion of hyponatremia and hypotension in the multivariate model—either together or separately—resulted in convergence failure, as observed in the hyponatremia analysis. After excluding these

Table 2

Univariate Analysis for Hyponatremia in the Cohort

Variables	Hyponatremia	Non-Hyponatremia	Statistical Value	*P*
Gender			0.750	0.426
Female/male	15/95	36/171		
Age	49 (41.75–56)	47 (38–55)	−1.368	0.171
Mechanism of injury			3.044	0.561
Traffic accident	43	76		
High-altitude fall	12	24		
Fall	27	64		
Crush injury	19	34		
Others	9	9		
Level of injury			67.814	<0.001
Cervical	97	87		
Thoracic	12	49		
Lumbar	0	47		
Conus	1	24		
Degree of injury			125.246	<0.001
ASIA A	88	40		
ASIA B	22	58		
ASIA C	0	55		
ASIA D	0	54		
Type of fracture			11.825	0.008
Type I	19	65		
Type A	45	52		
Type B	32	57		
Type C	14	33		
ASA grade			11.984	0.002
Grade 1	16	29		
Grade 2	80	172		
Grade 3	14	6		
Brain injury	20/90	41/166	0.122	0.727
Hypotension	62/48	0/207	78.315	<0.001
DI	60/50	0/207	74.764	<0.001
Presence of surgery	85/25	143/64	2.386	0.122
BMI	22 (19–25)	22 (20–25)	−0.487	0.626
Hospital stay	18 (13–32)	13 (8–18)	−6.195	0.001

Values of continuous variables with a normal distribution are described as mean ± SD, and variables with a non-normally distributed continuous data are shown as the median (interquartile range). Categorical data are summarized as the number of cases.

ASA, American Society of Anesthesiologists; ASIA, American Spinal Injury Association; BMI, body mass index; DI, diabetes insipidus.

Table 3

Multivariate Logistic Regression Analysis for Hyponatremia

Selecting Variables	*B*	SE	Walds	*P*	OR	95% CI
Level of injury						
Thoracic, lumbar, and conus				Reference		
Cervical	3.377	0.492	47.196	<0.001	29.294	11.177–76.780
Degree of injury						
ASIA B-D				Reference		
ASIA A	3.829	0.481	63.493	<0.001	46.030	17.946–118.059
Type of fracture			5.232	0.156		
Type I				Reference		
Type A	0.992	0.525	3.568	0.059	2.697	0.963–7.549
Type B	0.884	0.516	2.932	0.087	2.421	0.880–6.658
Type C	1.157	0.556	4.322	0.038	3.180	1.068–9.462
ASA grade						
Grade 1				Reference		
Grade 2	−0.231	0.499	0.217	0.643	0.794	0.298–2.112
Grade 3	0.242	0.865	0.078	0.780	1.273	0.234–6.941
Hospital stay	−0.006	0.010	0.373	0.542	0.994	0.974–1.014

The multivariate logistic regression model for hyponatremia included the level of injury, the degree of injury, the type of fracture, hospital stay, and ASA grade. The inclusion of both hyponatremia and hypotension led to model instability, likely due to multicollinearity or perfect separation. Removing these factors allowed the analysis to proceed successfully. In the regression analysis for hyponatremia, categories with very few or zero cases were merged to improve model stability. Specifically, lumbar and conus injuries were combined with thoracic injuries for analysis, while ASIA C/D cases, both of which had zero counts, were merged into the ASIA B group.

ASA, American Society of Anesthesiologists; *B*, beta (coefficient); CI, confidence interval; DI, diabetes insipidus; OR, odds ratio; S.E., standard error.

two variables, the final multivariate logistic regression identified injury level, injury severity, and fracture type as independent predictors of DI (all $P < 0.001$) (Table 5). Specifically, higher injury level (OR = 30.41, 95% CI: 7.56–122.43, $P < 0.001$) and greater injury severity (OR = 30.30, 95% CI: 10.09–90.96, $P < 0.001$) were strong independent risk factors. Fracture type was also independently associated with DI (overall $P < 0.001$), with fracture type B (OR = 4.17, 95% CI: 1.18–14.82, $P = 0.027$) and fracture type C (OR = 36.31, 95% CI: 8.99–146.59, $P < 0.001$) conferring markedly increased risks compared to the reference type I (Table 5).

Discussion

This study demonstrated that hyponatremia occurs primarily in patients with severe SCI at or above the T5 level. Among the 317 patients with acute SCI in our cohort, the overall incidence of hyponatremia was 34.70%, and 18.93% developed DI. Notably, 52.71% of patients with cervical SCI experienced hyponatremia, and 30.97% developed DI. In contrast, for patients with thoracic SCI, the incidence of hyponatremia was 21.31%, and the incidence of DI was 4.92%, with both conditions occurring exclusively in injuries at or above T5. No cases of either condition were observed in patients with lower-level SCI. The median time to the onset of hyponatremia was 5 days (IQR: 4–6 days), whereas DI developed at a median of 7 days (IQR: 6–8 days). Independent risk factors differed between the two conditions. Hyponatremia was independently associated with higher injury level and greater injury severity (both $P < 0.001$), while only fracture type C showed a significant association ($P = 0.038$). In contrast, DI was independently associated with higher injury level and greater injury severity (both $P < 0.001$), and was further linked to fracture type B ($P = 0.027$) and fracture type C ($P < 0.001$).

This aligns with previous studies that identified these factors as significant predictors.[10,11] In a study by Chavasiri et al.,[10] 54 out of 123 patients (43.9%) with cervical SCI developed hyponatremia, with an incidence of 65.8% among those with complete injuries. Logistic regression analysis identified complete SCI as the only significant risk factor for hyponatremia. Similarly, Nakao et al.[11] reported a 50% incidence of hyponatremia in a cohort of 172 patients with SCI, with injury severity being a key predictor of hyponatremia and hypotension. Ohbe et al.[12] identified similar risk factors for hyponatremia in patients with SCI, further reinforcing the importance of addressing these factors in clinical practice. Our findings are consistent with those of these studies, showing a 52.71% incidence of hyponatremia in patients with cervical SCI, with injury severity emerging as a significant risk factor. Furthermore, we observed a 21.31% incidence of hyponatremia in patients with thoracic SCI, all of which occurred in injuries at or above the T5 level.

However, the incidence of DI in patients with acute SCI has not been extensively studied. Farrell et al.[13] were among the first to report DI in a patient with an incomplete C7 SCI, in which the condition improved after arginine vasopressin (AVP) administration. Subsequent studies[14–16] reported sporadic cases of DI in SCI patients, but did not provide specific incidence rates. Iob et al.[17] documented 5 cases of DI among 85 patients with cervical SCI treated over a 5-year period, representing an incidence of 5.88%. In our study, the incidence of DI in patients with cervical SCI was 30.97%, which was notably high, likely because of the larger proportion of complete cervical injuries (45.11%).

The mechanisms underlying hyponatremia and DI after acute SCI are complex and multifactorial. Hyponatremia is primarily linked to central nervous system dysfunction and can be attributed to 2 distinct mechanisms: syndrome of inappropriate antidiuretic hormone secretion (SIADH) and cerebral salt-wasting syndrome (CSWS).[18,19] SIADH is characterized by hypervolemic hyponatremia resulting from excessive AVP secretion, leading to renal water retention and sodium loss. In contrast, CSWS causes hypovolemic hyponatremia, which arises from excessive renal sodium excretion owing to hypothalamic dysfunction. Differentiating between these 2 conditions can be clinically challenging, especially in patients with SCI, who often present with hypotension and bradycardia due to autonomic dysregulation.[20]

DI in patients with SCI is thought to result from disruptions to the hypothalamic-pituitary axis. Although traumatic brain injury (TBI) is a well-established cause of DI, it was not an exclusion criterion in our study because the primary aim was to investigate SCI-specific mechanisms. Moreover, no significant differences in the incidence of TBI were observed between patients with and without DI,

Table 4

Univariate Analysis for DI in the Cohort

Variables	DI	Non-DI	Statistical Value	*P*
Gender			1.072	0.337
Female/male	7/53	44/213		
Age	49 (42.25–55)	48 (38–55)	−0.600	0.549
Mechanism of injury			4.168	0.384
Traffic accident accident	25	94		
High-altitude fall	10	43		
Fall	13	78		
Crush injury	6	30		
Others	6	12		
Level of injury			65.014	<0.001
Cervical	57	127		
Thoracic	3	58		
Lumbar	0	47		
Conus	0	25		
Degree of injury			65.014	<0.001
ASIA A	51	77		
ASIA B	9	71		
ASIA C	0	55		
ASIA D	0	54		
Type of fracture			15.843	0.001
Type I	5	79		
Type A	25	72		
Type B	16	73		
Type C	14	33		
ASA grade			6.180	0.046
Grade 1	8	37		
Grade 2	44	208		
Grade 3	8	12		
Brain injury	10/50	51/206	0.316	0.716
Hypotension	60/0	2/255	197.616	<0.001
Hyponatremia	60/0	50/207	74.764	<0.001
Presence of surgery	48/12	180/77	2.390	0.122
BMI	22 (19–24.75)	22 (19–25)	−1.059	0.290
Hospital stay	18 (13–27.75)	13 (9–22)	−3.455	0.001

Values of continuous variables with a normal distribution are described as mean ± SD, and variables with a non-normally distributed continuous data are shown as the median (interquartile range). Categorical data are summarized as the number of cases.

ASA, American Society of Anesthesiologists; ASIA, American Spinal Injury Association; BMI, body mass index; DI, diabetes insipidus.

reinforcing the hypothesis that DI in SCI is independent of head injury. Previous studies[14,17,21,22] have suggested that DI may stem from ischemic damage to the hypothalamic-pituitary axis, exacerbated by autonomic dysfunction and hypotension—findings that align with our observations.

Daia et al.,[16] Closson et al.,[21] and Johnson et al.[22] suggest that DI is associated with concurrent brain injury. However, in our study, no significant difference was found in the occurrence of brain injury among patients with DI, which does not support the hypothesis that brain injury is a direct cause of DI. Similarly, Prasad et al.[14] and Iob et al.[17] found no evidence linking head injury to DI. Instead, they proposed that the disruption of vasopressin (AVP) projection from the paraventricular nucleus to the spinal cord occurs after SCI, leading to degenerative changes in the hypothalamus. Kuzeyli et al.[23] suggested that DI may be secondary to hypothalamic-pituitary axis dysfunction, with hypotension as a key contributing factor. Under normal circumstances, neurohypophyseal blood flow is nearly 8 times faster than that in the cerebral cortex.[24] Our previous study found that 27% of patients with cervical SCI and 17% of those with thoracic SCI experienced autonomic reflex dysfunction-induced hypotension, which may result in ischemic injury to the hypothalamic-pituitary axis.[25]

In cases of hyponatremia with DI after acute SCI, regardless of whether the underlying mechanism of hyponatremia is attributed to CSWS or SIADH, treatment approaches for DI present conflicting principles.[20] The standard treatment for DI involves limiting fluid intake and administering AVP or its analogs to alleviate symptoms such as polyuria and excessive thirst.[26] If hyponatremia is diagnosed as CSWS, volume expansion is recommended, which directly contradicts the fluid restrictions required for DI. However, if hyponatremia is diagnosed as SIADH, an AVP receptor antagonist should be used to treat SIADH, whereas AVP is typically used for DI, leading to further contradictions in treatment strategies. This creates significant challenges for clinical management and highlights the urgent need to resolve this issue.[20]

The association among hypotension, hyponatremia, and DI after acute SCI is well recognized. Nakao et al.[11] proposed that hyponatremia and hypotension are related to the loss of central sympathetic nervous system control after SCI and that autonomic reflex hypotension potentially contributes to hyponatremia development. In our study, a clear association was observed between DI and hyponatremia in all patients who developed both conditions. However, when hyponatremia and hypotension were included as factors in the multivariate logistic regression analysis of DI, model convergence issues arose, suggesting potential multicollinearity or perfect separation between these 2 variables and the outcome. Even when stepwise regression was applied to select the most significant predictors, the inclusion of these 2 factors led to model instability and prevented the analysis from proceeding. The analysis could proceed only after removing hyponatremia and hypotension. This indicates that the presence of these highly correlated variables, together or separately, caused redundancy in the information provided by these predictors, thereby affecting the stability of the model. Given

Table 5

Multivariate Logistic Regression Analysis for DI

Selecting Variables	*B*	SE	Walds	*P*	OR	95% CI
Level of injury						
Thoracic, lumbar, and conus				Reference		
Cervical	3.415	0.711	23.097	<0.001	30.413	7.555–112.430
Degree of injury						
ASIA B-D				Reference		
ASIA A	3.411	0.561	36.993	<0.001	30.300	10.094–90.956
Type of fracture			34.078	<0.001		
Type I				Reference		
Type A	0.068	0.738	0.009	0.926	1.071	0.252–4.548
Type B	1.429	0.647	4.882	0.027	4.173	1.175–14.821
Type C	3.592	0.712	25.454	<0.001	36.312	8.995–146.588
ASA grade			0.254	0.881		
Grade 1				Reference		
Grade 2	−0.237	0.603	0.154	0.695	0.789	0.242–2.576
Grade 3	−0.480	1.008	0.227	0.634	0.619	0.086–4.458
Hospital stay	−0.010	0.010	0.935	0.334	0.990	0.971–1.010

The multivariate logistic regression model for diabetes insipidus (DI) included the level of injury, the degree of injury, the type of fracture, hospital stay, and ASA grade. The inclusion of both hyponatremia and hypotension led to model instability, likely due to multicollinearity or perfect separation. Removing these factors allowed the analysis to proceed successfully. In the regression analysis for hyponatremia, categories with very few or zero cases were merged to improve model stability. Specifically, lumbar and conus injuries were combined with thoracic injuries for analysis, while ASIA C/D cases, both of which had zero counts, were merged into the ASIA B group.

ASA, American Society of Anesthesiologists; *B*, beta (coefficient); CI, confidence interval; DI, diabetes insipidus; OR, odds ratio; S.E., standard error.

the close relationship among hyponatremia, DI, and autonomic dysfunction, we suggest that future research should treat these conditions as interconnected manifestations of acute SCI rather than as isolated phenomena. This approach will deepen our understanding of the pathophysiological mechanisms and improve clinical management strategies for patients with SCI.

Limitations

The limitations of this study include its retrospective design and inherent selection bias. Another limitation is the exclusion of hypotension from the data analysis. Given that hyponatremia and DI are closely related complications of SCI, we believe that hypotension should not be dismissed as an irrelevant risk factor. However, this study primarily focused on identifying risk factors associated with the concurrent occurrence of hyponatremia and DI in patients with acute SCI. Therefore, investigating the role of hypotension in this context may represent a valuable direction for future research.

Moreover, during the multivariate logistic regression analysis for DI, we encountered convergence issues when hyponatremia and hypotension were included in the model, simultaneously or separately. The model failed to converge despite applying stepwise regression, indicating potential multicollinearity or perfect separation between the variables. The analysis could proceed only once those 2 factors were removed. This statistical challenge presents a limitation of our analysis and suggests that further investigations using refined modeling techniques or larger sample sizes may be needed to more accurately assess the effects of these factors on DI in patients with SCI.

Additionally, owing to the relatively small sample size of our study, we did not apply propensity score matching (PSM) or inverse probability of treatment weighting (IPTW) to control for confounding variables and reduce selection bias. These methods are typically recommended for larger samples to ensure reliable matching and stable weight estimates. Given the limited sample size, using PSM or IPTW would have likely resulted in unstable and potentially unreliable treatment effect estimates.[27,28] Although these methods can offer valuable insights in a larger study with more robust data, we chose alternative statistical approaches that were better suited to the available sample size. Future research with a larger cohort can benefit from employing these methods to better assess the causal relationships and minimize bias.

Conclusion

Our findings indicate a high incidence of hyponatremia (34.7%) and DI (18.9%) in patients with acute SCI. For hyponatremia, the most significant independent risk factors were higher injury level and greater injury severity (both $P < 0.001$), with only fracture type C showing a significant association ($P = 0.038$). In contrast, DI was independently associated with higher injury level and greater injury severity (both $P < 0.001$), as well as fracture type B ($P = 0.027$) and fracture type C ($P < 0.001$). These results underscore both the shared and distinct risk profiles of hyponatremia and DI following acute SCI. Future research should aim to establish a unified pathophysiological framework to clarify the mechanisms underlying these electrolyte disturbances and guide targeted therapeutic strategies.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

The authors confirm that their contributions to the paper are as follows. Li L. designed the study and wrote the original draft. Lu H., Yu Q., Gao J., Li C., and Chen H. provided the research materials. Li L. performed statistical analysis and interpreted results. Liu Z. revised the manuscript. All authors read and approved the final manuscript.

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Ethical approval of studies and informed consent

This study was approved, and written informed consent was waived by the Institutional Ethics Board of the Chinese People's Liberation Army (PLA) General Hospital (2024KY053-KS001, May 31, 2024), owing to the anonymized retrospective nature of the analysis.

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