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ARTICLE

Multivariate Logistic Regression Analysis of Risk Factors and Clinical Countermeasures of Neurogenic Bladder After Spinal Cord Injury

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Abstract

Aims/Background Neurogenic bladder (NB) is a common complication after spinal cord injury (SCI), significantly impacting patients' social functioning and quality of life. Urinary tract infections and neurological prognosis following SCI have been thoroughly investigated; however, studies assessing NB risk factors are limited, hindering its effective prevention. This study developed and validated a high-accuracy predictive model based on multivariate logistic regression analysis to identify key risk factors for NB after SCI and provide a basis for early intervention.
Methods This study included 115 SCI patients hospitalised between January 2022 and July 2024. Patients were divided into the NB and non-NB groups. General data were collected and analysed using univariate and multivariate logistic regression methods. A prediction model for NB post-SCI was developed and validated using the Hosmer-Lemeshow test and receiver operating characteristic (ROC) curve analysis with the bootstrap resampling method. Furthermore, NB patients underwent routine rehabilitation, and improvements in urinary incontinence, single voiding volume, and micturition frequency were recorded before and after treatment.
Results In this study, the incidence of NB in patients with SCI was 30.43%. Significant differences in NB incidence were observed based on age, American Spinal Cord Injury Association (ASIA) grade, urine culture results, C-reactive protein (CRP) levels, urination mode, pain scores, and sexual dysfunction ($p < 0.05$). Multivariate logistic regression identified old age, ASIA grade A, increased CRP levels, urinary incontinence/indwelling catheter, and higher pain scores as significant risk factors ($p < 0.05$). The formula is expressed as: NB prediction index after SCI = 0.058 × age + 0.045 × ASIA grade + 0.394 × CRP + 2.132 × urinary incontinence/indwelling catheter + 0.608 × pain score + 5.032. The prediction model had an overall accuracy rate of 97.14%, with a Hosmer-Lemeshow chi-square value of χ^2 =10.904 (p = 0.207), indicating a good fit. ROC curve analysis showed an area under the curve (AUC) of 0.904 (95% CI: 0.832–0.976, $p < 0.05$), with sensitivity of 88.60% and specificity of 82.50%. Post-treatment, daily urinary incontinence, and urination frequency decreased, while single voiding volume increased ($p < 0.05$).
Conclusion The occurrence of NB post-SCI is affected by various factors, such as age, ASIA grade, CRP levels, urination modes, and pain severity. The risk prediction model showed strong predictive value, offering a promising early risk management and clinical decision-making method.

Key words: spinal cord injury; neurogenic bladder; risk factors; clinical strategy

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Introduction

Spinal cord injury (SCI) is a traumatic disease caused directly or indirectly by external forces. The common causes include falls, traffic accidents, and sportsrelated injuries (Anjum et al, 2020). The annual incidence of SCI in China is approximately 1/100,000. SCI often results in lifelong neurological dysfunctions, severely affecting patients' ability to return to work and routine life, and imposing a significant public health burden on families and society. Neurogenic bladder (NB) is a prevalent lower urinary tract dysfunction following SCI, affecting over 70% of patients (Leslie et al, 2025). Persistent NB can result in serious complications such as urinary retention, urinary tract infections, and renal failure (Eli et al, 2021; Russo et al, 2020). As a result, long-term lower urinary tract dysfunction substantially affects the social functioning and quality of life of affected individuals.

Currently, the diagnosis and treatment of NB include various approaches, such as urinary catheterization, pharmacological management, surgical interventions, pelvic floor muscle training, electrical stimulation, and functional magnetic stimulation (Panicker, 2020). However, prolonged use of urethral catheters carries a high risk of urethral injury. In a recent study, Ikeda and colleagues administered targeted neurotrophic factor and nitric oxide signaling drugs to SCI mice to improve recovery and enhance NB function (Ikeda et al, 2022). However, pharmacological therapies often result in adverse reactions and are poorly tolerated by many patients. Surgical interventions are associated with complications such as gastrointestinal dysfunction, dyspepsia, and urinary incontinence (DeWitt-Foy and Elliott, 2022). Furthermore, electrical stimulation and other approaches have the risk of injury to the motor roots, potentially leading to lifelong urinary incontinence, thereby alleviating their widespread application (Lee, 2021). Therefore, reducing the risk of NB is crucial for improving quality of life, enhancing social functioning, and lowering disability rates. Another study identified lower visceral fat mass, advanced age, and prolonged surgical duration as independent risk factors for the development of postoperative NB in rectal cancer patients (Matsui et al, 2024).

However, there remains a scarcity of comprehensive research specifically identifying the risk factors associated with NB. While some studies have investigated predictors of SCI-related NB, their small sample sizes and the lack of systematic predictive modeling have made it challenging to effectively address these factors (Chen and Kuo, 2024; Ferreira et al, 2023). Given this, the present study employs multifactorial logistic regression analysis to assess the risk factors contributing to the development of NB after SCI. This study aims to identify potential predictors and provide a basis for the prevention of NB in clinical practice, as well as to optimize NB rehabilitation strategies for affected individuals.

Methods

Research Participants

This retrospective study analysed 115 SCI patients hospitalised at Affiliated Dongyang Hospital of Wenzhou Medical University between January 2022 and July 2024. Patient recruitment followed a convenience sampling approach. This study followed the ethical principles of the Declaration of Helsinki (2024) and was approved by the Ethics Committee of Affiliated Dongyang Hospital of Wenzhou

Medical University (approval number DRY2024-YX-234). Informed consent was obtained from all participants.

Inclusion criteria for patient selection were as follows: (1) SCI diagnosis following the "International Standards for Neurological Classification of SCI: revised 2019" (Rupp et al, 2021), confirmed by computer tomography/magnetic resonance imaging (CT/MRI) examination, and having completed the spinal cord shock stage; (2) survival throughout the hospitalisation period; (3) evaluation of SCI using the American Spinal Cord Injury Association (ASIA) classification upon admission; (4) disease duration of less than 3 months with a stable clinical condition; (5) patients aged 18 years or older; (6) no history of cardio-cerebrovascular disease or other conditions affecting brain structure and cognitive function.

The exclusion criteria were as follows: (1) presence of significant organ dysfunction, such as cerebral infarction and liver failure; (2) patients with kidney and urinary tract conditions, including hydronephrosis and urinary tract obstruction, recent surgery affecting bladder function, or use of medication that affects bladder function; (3) cognitive dysfunction or autonomic nervous system abnormalities preventing cooperation with urodynamic examination; (4) a history of somatic or neurological disorders either upon admission or in the past; (5) communication difficulties affecting listening, speaking, reading, or writing; and (6) incomplete clinical data.

Sample Size Calculation

Using a previously established sample size calculation method for factor analysis (Ritz et al, 2022), which recommends a minimum of 5 times the number of independent variables, given that this study involved 18 independent variables, the minimum required sample size was estimated to be 90 individuals. To account for a 10% rate of loss to follow-up or incomplete data, the sample size was adjusted to at least 99 participants. Ultimately, 115 participants were included in the study to ensure adequate statistical power and to account for any potential dropouts or missing data.

Observation Index

Baseline Characteristics

This retrospective study combined a review of relevant literature with clinical experience and collected comprehensive data from the hospital's electronic medical record system. The collected variables included gender, age, education level, marital status, occupation, medical expenses, location and cause of SCI, ASIA grade, disease duration, C-reactive protein (CRP) levels, white blood cell count (WBC), urine culture results, neutrophil percentage, muscle strength, mode of urination, pain intensity, and the presence of sexual dysfunction. Moreover, multiple interpolations were applied to deal with missing data.

Diagnostic Criteria of NB

Based on clinical signs of voiding dysfunction, different degrees of residual urine, and findings from NB ultrasonography (Panicker, 2020), urodynamic examinations revealed detrusor hyperactivity or detrusor-external sphincter dyssynergia. Patients were divided into either the neurogenic or non-NB groups based on the occurrence of NB following SCI.

ASIA Classification

Patients were classified as follows (Kirshblum et al, 2020):

(1) Grade A: complete injury, with no motor or sensory function preserved in the sacral segments S4–S5.

(2) Grade B: incomplete injury, with sensory function preserved below the neurological level, and no motor function.

(3) Grade C: incomplete injury, with motor function preserved below the neurological level and most key muscles exhibiting a muscle strength of ≤ 3.

(4) Grade D: incomplete injury, motor function preserved below the neurological level, and most key muscles demonstrating a muscle strength of ≥ 3.

(5) Grade E: normal sensory and motor functions with no neurological abnormalities.

Muscle Strength

Muscle strength is routinely evaluated during physical examinations, following previously reported criteria (Triki et al, 2023):

(1) Grade 0: complete paralysis with no observable muscle contraction.

(2) Grade 1: muscle contraction is observable, but no limb movement is achievable.

(3) Grade 2: limb movement is possible but cannot overcome gravity, and the limb cannot be lifted from the surface.

(4) Grade 3: ability to move against gravity but cannot withstand any additional resistance; however, the limb can be lifted only with difficulty.

(5) Grade 4: the limb can resist some external resistance, indicating moderate muscle strength.

(6) Grade 5: normal muscle strength with limbs able to resist full resistance without difficulty.

Visual Analogue Scale

The pain was assessed by experienced physicians using the Visual Analogue Scale (VAS) (Langley and Sheppeard, 1985). This scale comprised a 10-centimetre line marked from 0 to 10, where 0 denotes no discomfort and 10 extreme agony. Participants were asked to mark their pain level on the line, with higher scores indicating more severe pain.

Quality Control

During the research and design stage, a comprehensive review of domestic and international literature was conducted in phases. The research framework was further refined through expert consultations. Moreover, team members were assigned specific responsibilities for data collection and statistical analysis to reduce cross-contamination and minimise biases. The data collection process underwent rigorous review to prevent omissions and ensure the efficacy of the data. Additionally, dual data entry and double proofreading procedures were implemented to guarantee the accuracy and completeness of the statistical data.

Clinical Countermeasure

Patients with NB following SCI underwent a well-planned rehabilitation treatment that included:

(1) Fluid and urination management: a drinking schedule was developed, with daily fluid intake controlled between 1500–2000 mL. Patients were advised to avoid drinking water before bedtime.

(2) Clean intermittent catheterization (CIC): CIC was conducted under sterile conditions. This technique involved regular insertion of a catheter through the urethra or an alternative channel into the bladder to drain urine, typically performed 4 to 6 times daily.

(3) Therapeutic interventions: patients with bladder capacities less than 200 mL were administered with tolterodine tablets (National Medicinal Approval No. H20000609, Dikang Pharmaceutical Co., Ltd., Chengdu, China), at 2 mg twice daily.

(4) Neurofeedback therapy: this therapy was performed using a specialised apparatus (Model S470, Nanjing Weisi Medical Technology Co., LTD., Nanjing, China). Before use, the apparatus was disinfected and lubricated. For female patients, the probe was inserted into the vagina; for males, into the rectum and connected through a tail line. Patients then underwent anal contraction training under the supervision of medical staff, contracting for 7 seconds followed by a relaxation period. Each session lasted for 15 minutes, conducted once daily, five times a week, over a total duration of 8 weeks.

Survey Tool

(1) The incidence of NB after SCI was recorded, and patients were divided into the neurogenic and non-NB groups. Baseline demographic and clinical data were collected from both groups and subjected to univariate analyses (t-test or chi-square test). Variables demonstrating statistically significant differences between the two groups in the univariate analysis ($p < 0.05$) were included in multivariate logistic regression analyses.

(2) A predictive model for NB after SCI was developed, and its goodness-of-fit was assessed using the Hosmer-Lemeshow test.

(3) The predictive accuracy of the model was assessed using the area under the curve (AUC) of the receiver operating characteristic (ROC) curve. Bootstrapping with 1000 iterations was employed to evaluate sampling variability and the model's robustness.

(4) To assess the improvement in micturition function among patients with NB following SCI, the following parameters were recorded before and after treatment:

(a) Frequency of urinary incontinence episodes.

(b) Single micturition volume.

(c) Frequency of micturition (number of urinations).

These measurements were compared to evaluate the effectiveness of treatment in enhancing bladder control and urinary function. A flow chart of research design is shown in Fig. 1.

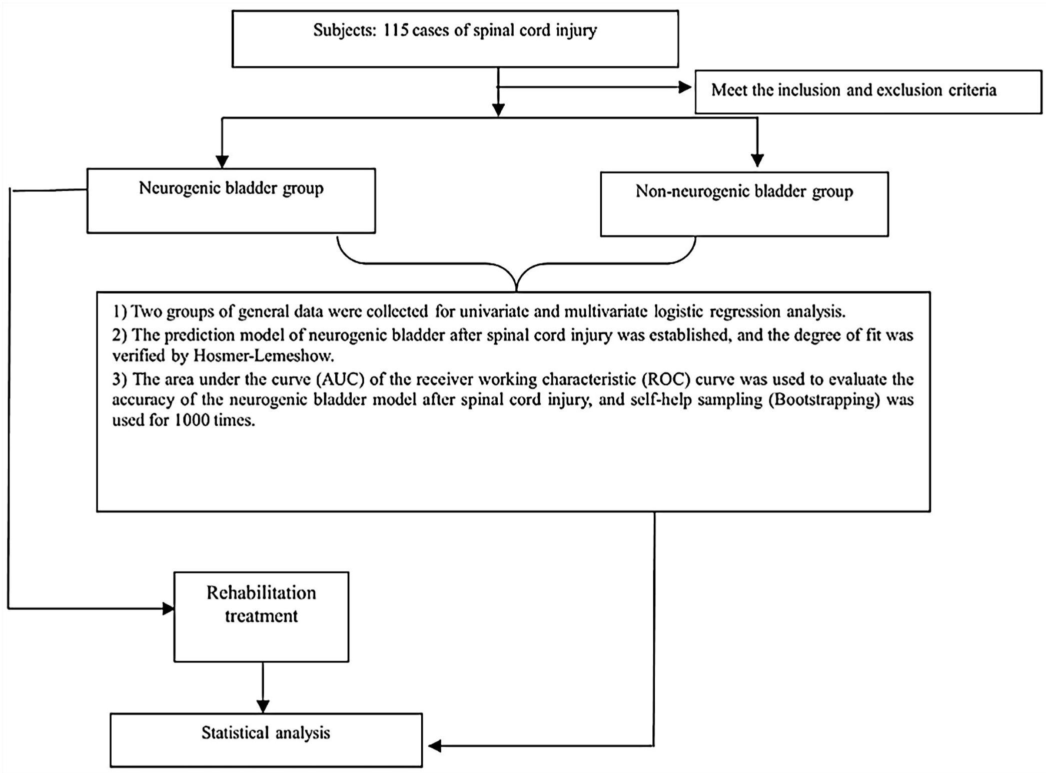

Fig. 1. A flow chart of the study design.

Statistical Analysis

Statistical analysis was conducted using SPSS (version 24.0, IBM Corp., Armonk, NY, USA). Categorical data were expressed as [n (%)], and comparisons between groups were performed employing the χ^2 test. When the expected frequencies (T) were $\geq$5, the chi-square test was used. The corrected chi-square test or Yates's corrected chi-square test was used for $1 \leq T < 5$, and the Fisher exact test was employed for T <1. Data normality was examined using the Shapiro-Wilk test. Measurement data following a normal distribution were represented as ($\bar{x} \pm s$). Comparison between groups was performed using an independent sample *t*-test, while within-group comparisons were conducted using a paired sample *t*-test. Furthermore, multivariate logistic regression was applied to identify the risk factors and establish a predictive model. The Hosmer-Lemeshow test was used to assess the model's goodness-of-fit and consistency. The predictive accuracy of the model was performed by calculating the area under the curve (AUC). Internal validation of the predictive models was determined using bootstrapping with 1000 resampling repetitions. A significant standard of α = 0.05 was applied to all tests.

Table 1. Univariate analysis of NB after SCI across study participants.

Variable	Experimental groups		t/χ^2	p-value
	Neurogenic bladder group (n = 35)	Non-neurogenic bladder group (n = 80)		
Gender [n (%)]			2.237	0.135
Male	24 (68.57)	65 (81.25)		
Female	11 (31.43)	15 (18.75)		
Age (years, $\bar{x} \pm s$)	57.40 ± 6.89	44.91 ± 5.57	10.275	<0.001
Education level [n (%)]			2.420	0.298
Primary school and below	10 (28.57)	35 (43.75)		
Junior high school/technical secondary school	19 (54.29)	33 (41.25)		
Senior high school/junior college or above	6 (17.14)	12 (15.00)		
Marital status [n (%)]			1.501	0.221
Married	29 (82.86)	74 (92.50)		
Divorced/unmarried	6 (17.14)	6 (7.50)		
Occupation [n (%)]			3.973	0.137
Farmers	19 (54.29)	59 (73.75)		
Workers	8 (22.86)	10 (12.50)		
Individual/unemployed/retired/student	2 (5.71)	11 (13.75)		
Medical expenses [n (%)]			0.732	0.392
Self-paying	17 (48.57)	32 (40.00)		
Medical insurance	18 (51.43)	48 (60.00)		
Location of spinal cord injury [n (%)]			5.241	0.073
Cervical vertebrae	22 (62.86)	66 (82.50)		
Thoracic vertebrae	3 (8.57)	3 (3.75)		
Lumbar vertebrae	10 (28.57)	11 (13.75)		
Etiology of spinal cord injury [n (%)]			6.139	0.105
High fall injury	18 (51.43)	24 (30.00)		
Car accident	9 (25.71)	22 (27.50)		
A fall/smash/trauma	5 (14.29)	26 (32.50)		
Postoperative/spontaneous bleeding	3 (8.57)	8 (10.00)		
ASIA grade [n (%)]				<0.001
A	18 (51.43)	11 (13.75)		
B	4 (11.43)	0 (0.00)		
D	1 (2.86)	12 (15.00)		
E	12 (34.29)	57 (71.25)		
Disease duration (Months, $\bar{x} \pm s$)	5.28 ± 1.44	5.40 ± 1.49	0.401	0.689
Urine culture [n (%)]			20.894	<0.001
Positive	24 (68.57)	19 (23.75)		
Negative	11 (31.43)	61 (76.25)		
WBC [$\times 10^9$/L, $\bar{x} \pm s$]	7.33 ± 2.56	7.32 ± 2.55	0.017	0.986
CRP levels [mg/L, $\bar{x} \pm s$]	10.01 ± 1.34	4.75 ± 0.79	26.264	<0.001
Neutrophil percentage [%, $\bar{x} \pm s$]	64.41 ± 14.86	64.17 ± 14.87	0.079	0.937
Muscle strength [n (%)]			2.199	0.138
≥3 stage	29 (82.86)	75 (93.75)		
<3 stage	6 (17.14)	5 (6.25)		

Table 1. Continued.

Variable	Experimental groups		t/χ^2	p-value
	Neurogenic bladder group (n = 35)	Non-neurogenic bladder group (n = 80)		
Micturition mode [n (%)]			63.087	<0.001
Self-solution	5 (14.29)	72 (90.00)		
Incontinence/indwelling catheterization	30 (85.71)	8 (10.00)		
Pain scores [points, $\bar{x} \pm s$]	3.89 ± 0.25	3.10 ± 0.22	16.989	<0.001
Sexual dysfunction [n (%)]			4.340	0.037
Yes	6 (17.14)	3 (3.75)		
No	29 (82.86)	77 (96.25)		

Note: NB, neurogenic bladder; SCI, spinal cord injury; ASIA, American Spinal Cord Injury Association; CRP, C-reactive protein; WBC, white blood cell count.

Results

Univariate Analysis of NB After SCI

Among the 115 SCI patients, the incidence of NB was 30.43% (35/115), and patients were divided into the neurogenic and non-NB groups. There were no significant differences between the two groups regarding sex, education level, marital status, occupation, medical expenses, location of SCI, cause of injury, disease duration, WBC, neutrophil percentage, and muscle strength ($p > 0.05$). However, the two groups showed significant differences in ages, ASIA grades, urine culture results, CRP levels, urination mode, pain scores, and presence of sexual dysfunction ($p < 0.05$, Table 1).

Multivariate Logistic Regression Analysis of Factors Affecting NB After SCI

Using the occurrence of NB after SCI as the dependent variable (NB = 1, non-NB = 0), variables with "$p < 0.05$" identified in the univariate analyses (Table 1) were selected as the independent variable, with the assignment's details shown in Table 2. Multivariate logistic regression analysis demonstrated that the independent risk factors for developing NB after SCI included age, ASIA grade A, increased CRP levels, incontinence of urination or the use of an indwelling catheter, and higher pain scores ($p < 0.05$, Table 3).

Accuracy of the Multivariate Logistic Regression Model in Predicting NB After SCI

A predictive model for NB after SCI was developed based on the identified factors, achieving an overall accuracy rate of 97.14%, as summarised in Table 4.

Validation of NB Prediction Model After SCI Through Bootstrap Sampling Approach

The model was validated through the bootstrap sampling method with 1000 repetitions. The prediction formula for NB after SCI was as follows: logistic (P)

Table 2. Assignment table.

Variable	Variable type	Assignment
Age	Continuous variable	Bring in the original value
ASIA grade	Multi-classification variable	A = 3, B = 2, D = 1, E = 0
CRP levels	Continuous variable	Bring in the original value
Urine culture	Binomial variable	Positive = 1, Negative = 0
Micturition mode	Binomial variable	Incontinence/indwelling catheter = 1, Self-solution = 0
Pain scores	Continuous variable	Bring in the original value
Sexual dysfunction	Binomial variable	Yes = 1, No = 0

Note: ASIA, American Spinal Cord Injury Association; CRP, C-reactive protein.

Table 3. Logistic regression analysis of factors influencing NB after SCI.

Variable	Regression coefficient	Standard error	Wald	*p*-value	OR	95% CI
Constant	5.032	1.192	17.795	<0.001	/	/
Age	0.058	0.024	5.639	0.018	1.059	1.011–1.111
ASIA grading						
Class A is better than grade E	0.045	0.018	6.250	0.012	1.046	1.010–1.084
Class B is better than grade E	0.056	0.045	1.549	0.213	1.058	0.968–1.155
Class D is better than grade E	0.048	0.037	1.683	0.195	1.049	0.976–1.128
Elevated CRP levels	0.394	0.147	7.187	0.007	1.483	1.112–1.979
Positive urine culture	2.076	1.485	1.955	0.162	7.972	0.434–146.438
Urinary incontinence/indwelling catheter	2.132	0.849	6.306	0.012	8.432	1.597–44.525
Increased pain score	0.608	0.251	5.781	0.015	1.837	1.123–3.004
Sexual dysfunction	0.678	0.970	0.489	0.485	1.970	0.294–13.174

Note: ASIA, American Spinal Cord Injury Association; CRP, C-reactive protein; OR, odds ratio; CI, confidence interval.

= 0.058 × age + 0.045 × ASIA grade + 0.394 × CRP + 2.132 × urinary incontinence/indwelling catheter + 0.608 × pain score + 5.032.

The predictive model's performance was evaluated using the ROC curve, yielding an AUC of 0.904 (95% confidence interval [CI]: 0.832–0.976, $p < 0.05$). The sensitivity of the model was 88.60%, and the specificity was 82.50%. The model's goodness of fit was assessed using the Hosmer-Lemeshow test, yielding a chi-square value of $\chi^2 = 10.904$ with a corresponding *p*-value of 0.207, indicating a good fit. Furthermore, the calibration curve revealed a strong agreement between the predicted and observed outcomes. These results suggest that the predictive model effectively predicts the risk of NB after SCI. Validation of the predictive model is detailed in Table 5, and the model's performance is shown in Figs. 2,3.

Clinical Rehabilitation Effect of Patients With NB After SCI

After treatment, a significant reduction was observed in the daily frequency of incontinence and frequency of urination, along with an increase in the single

Table 4. Accuracy of the multivariate logistic regression model in predicting NB after SCI.

True value	Predictive value		Predictive accuracy (%)
	No neurogenic bladder occurred	Development of neurogenic bladder	
No neurogenic bladder occurred	74	6	74 (92.5)
Development of neurogenic bladder	7	28	28 (80.0)
Total	81	34	34 (97.14)

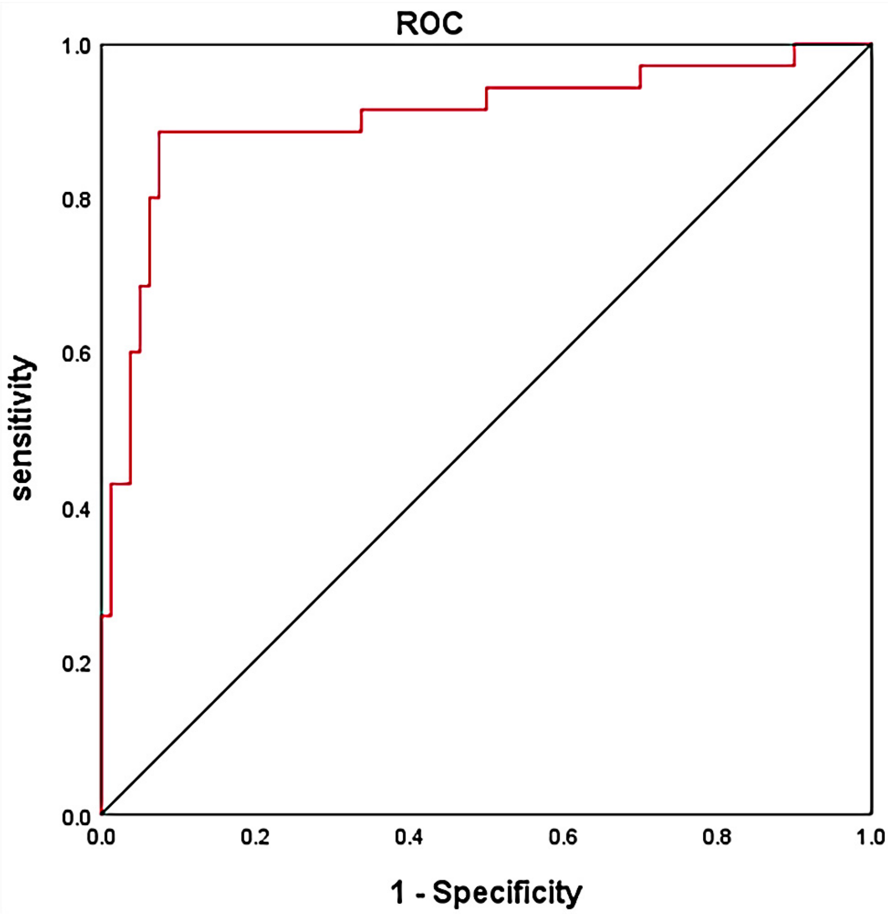

Fig. 2. ROC curve analysis of NB predictive model after SCI. Note: ROC, receiver operating characteristic; NB, neurogenic bladder; SCI, spinal cord injury.

volume of urination compared to before-treatment levels ($p < 0.05$, Table 6). These changes indicate a significant improvement in micturition function following the intervention.

Discussion

NB is a prevalent complication following SCI, characterised by difficulty in urinary expulsion and retention in the bladder, resulting in abnormal bladder and urethral function. This condition significantly impacts the overall health and quality of life of patients (Perez et al, 2022). Studies have revealed that within 12 months

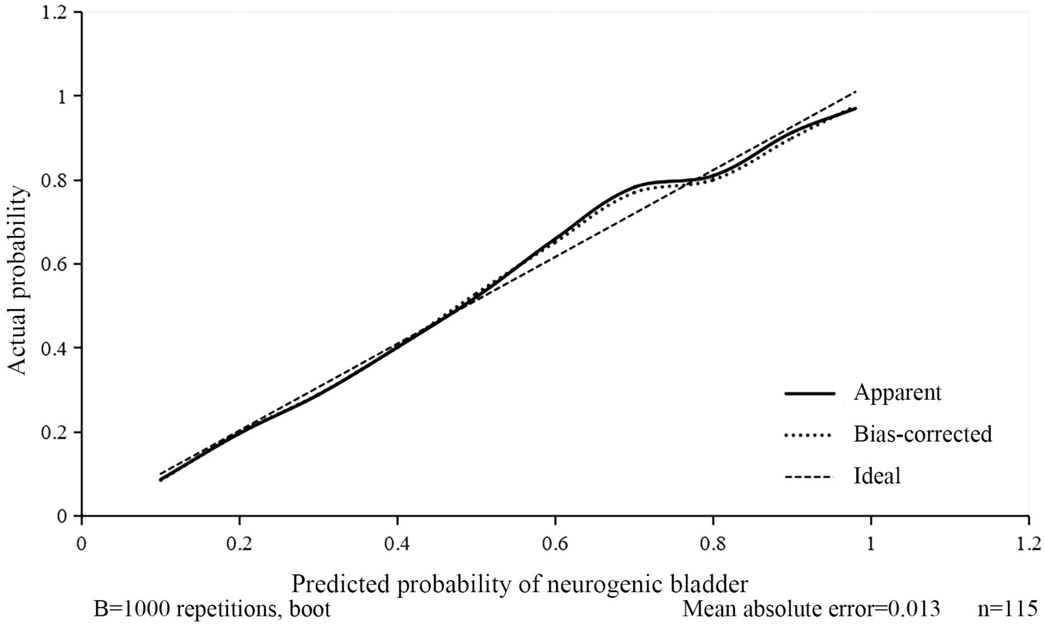

Fig. 3. Calibration curves for NB prediction model.

post-discharge, SCI patients experience an average of 4.7 complications, with NB being the most common (Hogg et al, 2021; Joshi et al, 2022). In this study, the incidence of NB among 115 SCI patients was 30.43% (35 out of 115), aligning with previous findings (Moghalu et al, 2022). These results highlight the high prevalence of NB following SCI and emphasise the need for effective clinical interventions. The primary cause of NB development in these cases is attributed to SCI itself.

Several factors contribute to NB after SCI, including the severity of the injury, urination mode, and other relevant factors. In this study, older age, ASIA grade A, increased CRP levels, urinary incontinence or the use of indwelling catheters, and increased pain scores were observed as significant risk factors. With increasing age, the functionality of various organs and systems decreases, and the repair and regeneration ability of the nervous system after SCI diminishes, resulting in a higher probability of developing NB (Böthig et al, 2021). Moreover, elderly patients with SCI are more susceptible to abnormal neuronal control of bladder function, resulting in urinary retention or incontinence and thereby increasing the incidence of NB (Mora-Boga et al, 2021). The ASIA grading is a commonly used method for evaluating the degree of neurological dysfunction in patients with SCI. Severe neurological injury, as evidenced by lower ASIA grades, especially grade A, leads to greater disruption of bladder control, thereby increasing the risk of NB (El Sammak et al, 2023). Given this, Wu and colleagues developed a predictive model for early bladder outcome after SCI, showing ASIA grade as a significant independent predictor of bladder emptying function (Wu et al, 2024).

Patients with severe SCI, as indicated by a lower ASIA grade, may often experience additional complications such as infections and compromised immune function. These co-occurring conditions can exacerbate the severity of the disease and substantially elevate the risk of developing NB. The cumulative effects of these complications underscore the complexities of managing SCI patients, particularly

Table 5. Validation of the predictive model using the bootstrap sampling method.

Variable	β	Bootstrap			
		Deviation	Standard error	Significant (double-tailed)	95% CI
Constant	5.032	2.799	57.404	0.001	2.409–11.739
Age	0.058	0.020	0.390	0.004	0.006–0.136
ASIA grade					
Class A is better than grade E	0.045	1.294	3.281	0.003	0.082–0.193
Class B is better than grade E	0.056	0.422	5.192	0.345	0.028–0.234
Class D is better than grade E	0.048	0.371	4.295	0.372	0.234–1.294
Elevated CRP levels	0.394	0.469	7.483	0.017	0.085–1.323
Positive urine culture	2.076	9.085	54.002	0.203	1.052–30.608
Urinary incontinence/indwelling catheter	2.132	9.415	50.800	0.005	1.259–31.308
Higher pain score	0.608	0.328	5.683	0.020	0.109–1.819
Sexual dysfunction	0.678	1.060	4.832	0.538	2.666–20.528

Note: ASIA, American Spinal Cord Injury Association; CRP, C-reactive protein.

Table 6. Clinical rehabilitation effect of patients with NB after SCI (n = 35).

Variable	Before treatment	After treatment	t	p-value
Daily frequency of urinary incontinence	12.38 ± 3.92	5.29 ± 0.84	10.463	<0.001
Single urination volume (mL)	98.82 ± 12.38	231.91 ± 32.94	22.375	<0.001
Daily urination frequency	15.41 ± 3.29	5.39 ± 0.97	17.300	<0.001

regarding their overall health and urinary system functionality (Pelosi et al, 2023). CRP, an inflammatory marker produced in response to immune elicitation, is commonly elevated in SCI patients. Research indicates that CRP levels increase in proportion to the severity of SCI. The pathological and physiological mechanisms underlying SCI are complex, primarily involving immune system activation and inflammatory responses. Following SCI, immune activation triggers inflammation that not only exacerbates neuronal injury but also disrupts normal nervous system function, impairs bladder control, and elevates the risk of developing NB. These interconnected processes highlight the multifaceted impact of inflammation on the progression and complications associated with SCI (Banait et al, 2022; Park et al, 2022; Visagan et al, 2023).

The need for an indwelling catheter may arise due to the intervention of external factors, and long-term catheter use may lead to urethral injury or infection, ultimately impairing bladder function. In patients with SCI, urinary incontinence is commonly linked to abnormal neural regulation of the bladder, causing the inability to sense bladder filling or control urination, resulting in long-term excessive pressure, which damages both the bladder muscle and the associated neuronal pathways, thereby increasing the risk of developing NB (Dere et al, 2022; Erden et al, 2023). Similarly, an observational study reported that quadriplegic patients who discontinued CIC experienced improved bladder-related quality of life compared to paraplegic patients (Patel et al, 2020).

Patients with SCI commonly experience autonomic nerve dysfunction, which can lead to elevated sympathetic nerve activity in those suffering from pain. This heightened activity can disrupt the regulation of internal and external bladder sphincters, resulting in bladder dysfunction and increasing the risk of NB. The link between autonomic dysregulation and pain underscores the complexities involved in managing bladder function in SCI patients (Dudley-Javoroski et al, 2022; Mendes et al, 2022; Reyes-Campo et al, 2022). The multi-factor logistic regression model established for predicting NB after SCI showed an overall accuracy of 97.14%. Validation using the Bootstrap method confirmed the robustness and stability of the model. This predictive model allows for systematic assessment of various clinical characteristics post-SCI, enhancing prediction accuracy. It will enable medical professionals to effectively identify high-risk individuals and devise tailored prevention strategies, representing a significant advancement in the proactive management of SCI-related complications.

Recent laboratory and clinical studies, both domestically and internationally, have investigated various neuromodulation approaches, including surgical interventions, drug therapies, and rehabilitation strategies. Among these methods, rehabilitation treatment is crucial due to its ease of application, considerable therapeutic benefits, and minimal discomfort (Bapir et al, 2022; Krebs et al, 2022). However, due to the complex etiology of NB after SCI, a standardised consensus on rehabilitation programs has yet to be developed. In this study, patients with NB underwent well-managed rehabilitation training. The results indicate significant improvement after treatment, including a reduction in daily urinary incontinence episodes and urination frequency, alongside an increase in single urination volume. These observations underscore the critical role of rehabilitation treatment in improving urinary function in SCI patients. This improvement was primarily attributed to targeted urination plans, bladder function training regimens, and neurofeedback stimulation. Neurofeedback stimulation plays a crucial role by modulating neural signal transmission and enhancing bladder function, thereby ameliorating clinical symptoms. Collectively, these interventions substantially enhance urinary function and overall quality of life in individuals with NB post-SCI.

We acknowledge several limitations in this study. First, the relatively small sample size may not adequately capture the broader heterogeneity of the patient population. Secondly, the study was restricted to a single hospital, and the shared regional lifestyle and genetic background may limit the generalizability of the results and introduce potential bias. Furthermore, the lack of long-term follow-up data limited the ability to evaluate the temporal development of NB after SCI. Future studies should incorporate extended follow-up durations, such as 6 months, 1 year, and 5 years, to better observe NB progression at different time intervals post-SCI. Moreover, as retrospective studies rely on existing medical records, increasing the likelihood of missing data may affect the accuracy of the results. To overcome these limitations, future research should involve large-scale, multicenter, longitudinal studies across diverse geographic regions and healthcare settings. Such studies would provide more representative data and serve as an external validation for the predictive performance of the model across various populations.

Conclusion

The development of NB after SCI is influenced by several factors, such as age, ASIA grade, CRP levels, micturition patterns, and the severity of pain. The risk predictive model developed in this study demonstrates substantial predictive value, aiding in risk identification, and guiding clinical interventions. Furthermore, integrating targeted rehabilitation approaches can reduce symptoms and enhance voiding function, highlighting the significance of comprehensive management in NB patients after SCI.

Key Points

- The incidence of NB among SCI patients was found to be high, with a prevalence rate of 30.43%.
- Older age, ASIA grade A, increased CRP levels, urinary incontinence or use of the indwelling catheter, and elevated pain scores were identified as independent risk factors for NB after SCI.
- The NB risk predictive model developed in this study demonstrated a high accuracy of 97.14%.
- Rehabilitation therapy significantly improved patients' incontinence symptoms and bladder control through neurofeedback stimulation and bladder function training.

Availability of Data and Materials

All data included in this study are available from the corresponding author upon reasonable request.

Author Contributions

MY and TTT designed the research study. MY and XD performed the research. XD analysed the data. MY drafted the manuscript. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study followed the ethical principles of the Declaration of Helsinki (2024) and was approved by the Ethics Committee of Affiliated Dongyang Hospital of Wenzhou Medical University (approval number DRY2024-YX-234). Informed consent was obtained from all participants.

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Conflict of Interest

The authors declare no conflict of interest.

References

Anjum A, Yazid MD, Fauzi Daud M, Idris J, Ng AMH, Selvi Naicker A, et al. Spinal Cord Injury: Pathophysiology, Multimolecular Interactions, and Underlying Recovery Mechanisms. International Journal of Molecular Sciences. 2020; 21: 7533. https://doi.org/10.3390/ijms21207533

Banait T, Wanjari A, Danade V, Banait S, Jain J. Role of High-Sensitivity C-reactive Protein (Hs-CRP) in Non-communicable Diseases: A Review. Cureus. 2022; 14: e30225. https://doi.org/10.7759/cureus.30225

Bapir R, Bhatti KH, Eliwa A, García-Perdomo HA, Gherabi N, Hennessey D, et al. Efficacy of overactive neurogenic bladder treatment: A systematic review of randomized controlled trials. Archivio Italiano Di Urologia, Andrologia. 2022; 94: 492–506. https://doi.org/10.4081/aiua.2022.4.492

Böthig R, Tiburtius C, Schöps W, Zellner M, Balzer O, Kowald B, et al. Urinary bladder cancer as a late sequela of traumatic spinal cord injury. Military Medical Research. 2021; 8: 29. https://doi.org/10.1186/s40779-021-00322-7

Chen YC, Kuo HC. Risk factors of video urodynamics and bladder management for long-term complications in patients with chronic spinal cord injury. Scientific Reports. 2024; 14: 12632. https://doi.org/10.1038/s41598-024-63441-w

Dere Ç, Dere D, Paker N, Buğdaycı Soy D, Ersoy S. Urinary system complications and long-term treatment compliance in chronic traumatic spinal cord injury patients with neurogenic lower urinary tract dysfunction. Turkish Journal of Physical Medicine and Rehabilitation. 2022; 68: 278–285. https://doi.org/10.5606/tftrd.2022.7719

DeWitt-Foy ME, Elliott SP. Neurogenic Bladder: Assessment and Operative Management. The Urologic Clinics of North America. 2022; 49: 519–532. https://doi.org/10.1016/j.ucl.2022.04.010

Dudley-Javoroski S, Lee J, Shields RK. Cognitive function, quality of life, and aging: relationships in individuals with and without spinal cord injury. Physiotherapy Theory and Practice. 2022; 38: 36–45. https://doi.org/10.1080/09593985.2020.1712755

El Sammak S, Michalopoulos GD, Arya N, Bhandarkar AR, Moinuddin FM, Jarrah R, et al. Prediction Model for Neurogenic Bladder Recovery One Year After Traumatic Spinal Cord Injury. World Neurosurgery. 2023; 179: e222–e231. https://doi.org/10.1016/j.wneu.2023.08.054

Eli I, Lerner DP, Ghogawala Z. Acute Traumatic Spinal Cord Injury. Neurologic Clinics. 2021; 39: 471–488. https://doi.org/10.1016/j.ncl.2021.02.004

Erden E, Ersöz M, Erden E, Tiftik T. Urodynamic findings and therapeutic approaches for neurogenic lower urinary tract dysfunction in patients with thoracic spinal cord injury. Irish Journal of Medical Science. 2023; 192: 2513–2520. https://doi.org/10.1007/s11845-022-03239-9

Ferreira A, Nascimento D, Cruz CD. Molecular Mechanism Operating in Animal Models of Neurogenic Detrusor Overactivity: A Systematic Review Focusing on Bladder Dysfunction of Neurogenic Origin. International Journal of Molecular Sciences. 2023; 24: 3273. https://doi.org/10.3390/ijms24043273

Hogg FRA, Kearney S, Solomon E, Gallagher MJ, Zoumprouli A, Papadopoulos MC, et al. Acute, severe traumatic spinal cord injury: improving urinary bladder function by optimizing spinal cord perfusion.

Journal of Neurosurgery. Spine. 2021; 36: 145–152. https://doi.org/10.3171/2021.3.SPINE202056

Ikeda Y, Zabbarova I, Tyagi P, Hitchens TK, Wolf-Johnston A, Wipf P, et al. Targeting neurotrophin and nitric oxide signaling to treat spinal cord injury and associated neurogenic bladder overactivity. Continence. 2022; 1: 100014. https://doi.org/10.1016/j.cont.2022.100014

Joshi AD, Shukla A, Chawathe V, Gaur AK. Clean intermittent catheterization in long-term management of neurogenic bladder in spinal cord injury: Patient perspective and experiences. International Journal of Urology. 2022; 29: 317–323. https://doi.org/10.1111/iju.14776

Kirshblum S, Snider B, Rupp R, Read MS, International Standards Committee of ASIA and ISCoS. Updates of the International Standards for Neurologic Classification of Spinal Cord Injury: 2015 and 2019. Physical Medicine and Rehabilitation Clinics of North America. 2020; 31: 319–330. https://doi.org/10.1016/j.pmr.2020.03.005

Krebs J, Wöllner J, Rademacher F, Pannek J. Bladder management in individuals with spinal cord injury or disease during and after primary rehabilitation: a retrospective cohort study. World Journal of Urology. 2022; 40: 1737–1742. https://doi.org/10.1007/s00345-022-04027-x

Langley GB, Sheppeard H. The visual analogue scale: its use in pain measurement. Rheumatology International. 1985; 5: 145–148. https://doi.org/10.1007/BF00541514

Lee JK. Neurogenic Bladder Management. Radiologic Technology. 2021; 92: 281–295.

Leslie SW, Tadi P, Tayyeb M. Neurogenic Bladder and Neurogenic Lower Urinary Tract Dysfunction. StatPearls: Treasure Island (FL). 2025.

Matsui T, Kiuchi J, Kuriu Y, Arita T, Shimizu H, Nanishi K, et al. Deep pelvis and low visceral fat mass as risk factors for neurogenic bladder after rectal cancer surgery. BMC Gastroenterology. 2024; 24: 323. https://doi.org/10.1186/s12876-024-03433-2

Mendes PA, Dias N, Simaes J, Dinis P, Cruz F, Pinto R. Daily low dose of tadalafil improves pain and frequency in bladder pain syndrome/interstitial cystitis patients. Turkish Journal of Urology. 2022; 48: 82–87. https://doi.org/10.5152/tud.2022.21292

Moghalu O, Stoffel JT, Elliott SP, Welk B, Zhang C, Presson A, et al. Time-Related Changes in Patient Reported Bladder Symptoms and Satisfaction after Spinal Cord Injury. The Journal of Urology. 2022; 207: 392–399. https://doi.org/10.1097/JU.0000000000002228

Mora-Boga R, Canosa-Hermida E, Toral-Guisasola I, Balboa-Barreiro V, Salvador-de la Barrera S, Ferreiro-Velasco ME, et al. Clinical characteristics and prognosis of spinal cord injury in individuals over 75 years old. Neurocirugia. 2021; 32: 209–216. https://doi.org/10.1016/j.neucie.2020.06.001

Panicker JN. Neurogenic Bladder: Epidemiology, Diagnosis, and Management. Seminars in Neurology. 2020; 40: 569–579. https://doi.org/10.1055/s-0040-1713876

Park A, Anderson D, Battaglino RA, Nguyen N, Morse LR. Ibuprofen use is associated with reduced C-reactive protein and interleukin-6 levels in chronic spinal cord injury. The Journal of Spinal Cord Medicine. 2022; 45: 117–125. https://doi.org/10.1080/10790268.2020.1773029

Patel DP, Herrick JS, Stoffel JT, Elliott SP, Lenherr SM, Presson AP, et al. Reasons for cessation of clean intermittent catheterization after spinal cord injury: Results from the Neurogenic Bladder Research Group spinal cord injury registry. Neurourology and Urodynamics. 2020; 39: 211–219. https://doi.org/10.1002/nau.24172

Pelosi G, Faleiros F, Pereira MRC, Bimbatti KDF, Tholl AD. Study on the prevalence of neurogenic bladder in Brazilians with traumatic and non-traumatic spinal cord injury. The Journal of Spinal Cord Medicine. 2023; 46: 677–681. https://doi.org/10.1080/10790268.2021.1981715

Perez NE, Godbole NP, Amin K, Syan R, Gater DR, Jr. Neurogenic Bladder Physiology, Pathogenesis, and Management after Spinal Cord Injury. Journal of Personalized Medicine. 2022; 12: 968. https://doi.org/10.3390/jpm12060968

Reyes-Campo A, Pacichana-Quinayás SG, Kumar AA, Leiva-Pemberthy LM, Tovar-Sánchez MA, Bonilla-Escobar FJ. Factors associated with neuropathic pain in Colombian patients with spinal cord injury of traumatic origin: case-control study. Spinal Cord Series and Cases. 2022; 8: 27. https://doi.org/10.1038/s41394-022-00494-x

Ritz C, Olsen MF, Grenov B, Friis H. Sample size calculations for continuous outcomes in clinical nutrition. European Journal of Clinical Nutrition. 2022; 76: 1682–1689. https://doi.org/10.1038/s41430-022-01169-4

Rupp R, Biering-Sørensen F, Burns SP, Graves DE, Guest J, Jones L, et al. International Standards for Neurological Classification of Spinal Cord Injury: Revised 2019. Topics in Spinal Cord Injury Rehabilitation. 2021; 27: 1–22. https://doi.org/10.46292/sci2702-1

Russo GS, Mangan JJ, Galetta MS, Boody B, Bronson W, Segar A, et al. Update on Spinal Cord Injury Management. Clinical Spine Surgery. 2020; 33: 258–264. https://doi.org/10.1097/BSD.0000000000000956

Triki R, Zouhal H, Chtourou H, Salhi I, Jebabli N, Saeidi A, et al. Timing of Resistance Training During Ramadan Fasting and Its Effects on Muscle Strength and Hypertrophy. International Journal of Sports Physiology and Performance. 2023; 18: 579–589. https://doi.org/10.1123/ijspp.2022-0268

Visagan R, Kearney S, Blex C, Serdani-Neuhaus L, Kopp MA, Schwab JM, et al. Adverse Effect of Neurogenic, Infective, and Inflammatory Fever on Acutely Injured Human Spinal Cord. Journal of Neurotrauma. 2023; 40: 2680–2693. https://doi.org/10.1089/neu.2023.0026

Wu X, Xi X, Xu M, Gao M, Liang Y, Sun M, et al. Prediction of early bladder outcomes after spinal cord injury: The HALT score. CNS Neuroscience & Therapeutics. 2024; 30: e14628. https://doi.org/10.1111/cns.14628