

Clean Intermittent Catheterization Before Initial Urodynamics Reduces Urinary Tract Infection and Improves Bladder Storage Function in Acute/Subacute Spinal Cord Injury: A Prospective cohort study

Mengyang Zhang

zhangmengyang@t.jh.tjmu.edu.cn

Tongji Hospital Affiliated to Tongji Medical College of Huazhong University of Science and Technology

Ye Chen

Lida Ren

Dongxu Lin

Kang Li

Lina Li

Jiang Chen

Zhong Chen

Ling Meng

Tao Xu

Department of Rehabilitation, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology

Article

Keywords: spinal cord injuries, neurogenic bladder/neurogenic lower urinary tract dysfunction, urinary tract infections, urodynamics, clean intermittent catheterization, indwelling urethral catheterization, prospective cohort study

Posted Date: July 3rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10031022/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: There is no duality of interest

Abstract

Study Design: Prospective observational cohort study.

Objectives: To compare the incidence of symptomatic urinary tract infection (UTI) following the first urodynamic study (UDS) between acute/subacute spinal cord injury (SCI) patients managed with clean intermittent catheterization (CIC) versus indwelling urethral catheter (IUC) prior to UDS.

Setting: Tertiary referral rehabilitation center in Wuhan, Hubei Province, China.

Methods: This prospective cohort study enrolled 271 SCI inpatients with neurogenic lower urinary tract dysfunction (NLUTD) within 6 months of injury between January 2025 and April 2026. Patients scheduled for UDS were classified into IUC (n=107) or CIC (n=164) groups based on pre-UDS bladder management. The primary outcome was symptomatic UTI within 72 hours post-UDS, defined by physician diagnosis, antibiotic initiation, and supporting clinical/laboratory evidence. Logistic regression was used to identify risk factors.

Results: The incidence of UTI was significantly higher in the IUC group than in the CIC group (16.8% vs. 2.4%; adjusted OR=5.149, 95%CI:1.426-18.594, P=0.012). Urodynamic storage parameters (bladder stability, compliance, maximum cystometric capacity) were better in the CIC group.

Conclusion: In acute/subacute SCI, a CIC-first pathway prior to initial UDS reduces post-procedural symptomatic UTI risk and is associated with better bladder storage function. Early CIC should be considered when UDS access is delayed.

Sponsorship: This work was supported by the Tongji Hospital Scientific Research Fund (Grant No. AI2024B08) and the National Natural Science Foundation of China (Grant No. 72504099).

Introduction

Neurogenic lower urinary tract dysfunction (NLUTD) is a significant complication of spinal cord injury (SCI), disrupting bladder storage and voiding, and increasing the risk of urinary tract infection (UTI)[1–3]. UTI is a leading cause of repeated medical visits and diminished quality of life in this population. Severe UTIs may also lead to upper urinary tract (UUT) damage and renal function deterioration. Therefore, effective bladder management is crucial for both urological health and overall patient well-being.

Clean intermittent catheterization (CIC) is widely recommended as the cornerstone of bladder management after acute SCI. By simulating a physiological filling-voiding cycle, CIC reduces the risk of bacterial biofilm formation compared to indwelling urethral catheterization (IUC) and aids in protecting UUT function[4–7]. To guide individualized management, urodynamic study (UDS) is essential for characterizing the specific NLUTD pattern, guiding decisions on pharmacotherapy and catheterization method[7, 8].

Current guidelines recommend completing the initial UDS within the first 3 months post-SCI and considering CIC as early as possible once the patient is medically stable and fluid intake is manageable, without stipulating a specific sequence between the two recommendations[7, 9]. However, in real-world clinical practice, particularly in resource-limited healthcare settings, the first UDS is often significantly delayed, and some patients may either decline the procedure entirely or lack access to it. This common delay creates a frequent clinical dilemma: which bladder management method should be employed while awaiting this often postponed definitive assessment? In practice, two divergent pathways emerge. The first is a conservative strategy where clinicians, concerned about undetected high intravesical pressure, maintain IUC continuously until the initial UDS is completed, using its results to guide any transition. The alternative pathway proactively establishes CIC (combined with empirical pharmacotherapy when necessary) as soon as clinically feasible, with subsequent UDS serving to optimize the management plan (Fig. 1).

This divergence in practice raises an important unresolved question. Since UDS itself is an invasive procedure and a known risk factor for symptomatic UTI (reported incidence: 16%-30%)[10–12], whether the choice of pre-UDS bladder management affects post-procedural infection risk remains unclear. We postulate that the answer may lie in the distinct microbial and functional bladder conditions shaped by each pathway. Prolonged IUC promotes bacterial colonization and biofilm[13]. Furthermore, the continuously drained IUC bladder may be functionally unprepared for the large-volume filling during UDS, potentially leading to adverse pressure responses linked to UTI susceptibility[14]. In contrast, pre-UDS CIC may reduce bacterial burden and maintain a more physiological cycle. Therefore, we hypothesize that a period of CIC prior to the initial UDS reduces the risk of post-procedural symptomatic UTI compared to maintaining persistent IUC. This study aims to explore the incidence and possible risk factors of symptomatic UTI following the first UDS, specifically in relation to pre-UDS bladder management (CIC versus IUC) in patients within 6 months of SCI.

Methods

Study Design and Participants

This prospective observational cohort study enrolled patients with NLUTD within 6 months of SCI. This study was approved by the Institutional Review Board of Tongji Hospital (IRB ID: TJ-IRB202512194). All participants provided written informed consent prior to enrollment. Although guidelines recommend initial UDS within 3 months post-SCI[9], disparities in regional healthcare resources and the limited availability of UDS equipment often delay the first examination. Given that a disease duration of 6 months is widely used as the cutoff between acute/subacute and chronic SCI[15, 16], this study included patients within 6 months of injury to reflect the real-world clinical practice.

SCI inpatients with NLUTD scheduled for UDS at our rehabilitation department were screened for eligibility. Inclusion criteria were: (1) SCI onset within 6 months prior to enrollment; (2) NLUTD with post-void residual > 100 ml requiring catheterization; (3) use of either IUC or CIC as the bladder emptying

method at enrollment; (4) no prior UDS since the onset of SCI; (5) informed consent and voluntary participation in the study. Exclusion criteria were: (1) severe systemic comorbidities or complications (e.g., significant cardiovascular disease, pulmonary infection, respiratory failure); (2) history of malignancy, immunocompromised status, urolithiasis, urinary tract malformation, or other conditions that may significantly increase UTI risk; (3) UUT complications (e.g., hydronephrosis, vesicoureteral reflux) requiring continuous bladder drainage; (4) symptomatic UTI or use of antibiotics for any reason within 7 days prior to enrollment. Patients who expressed a wish to discontinue participation during follow-up were excluded from the final analysis.

Based on a previous study[11], the anticipated event rate was 16%. Sample size calculation indicated that 207 participants were required to achieve 95% confidence that the observed incidence of symptomatic UTI would be within 5% of the true incidence. Considering a 10% non-response rate, the final sample size was set at 230. This study was conducted at our hospital between January 2025 and April 2026. Of the 412 patients initially screened, 271 met the eligibility criteria and were enrolled in the final cohort. Patients were assigned to two groups according to the bladder management strategy at enrollment.

IUC Group (n = 107): Patients who had received an IUC continuously from the time of injury until UDS.

CIC Group (n = 164): Patients who had been established on a planned CIC regimen for for at least 3 days prior to the UDS.

UDS Procedures

UDS was performed standardizedly using an air-charged cystometry system (Aquarius LT, Laborie, USA), following established guidelines and the standard methods recommended by the International Continence Society[17, 18]. No alterations were made to the schedule or dosage of medications used to manage neurogenic bladder, such as anticholinergics or beta-agonists, before or during urodynamic evaluation. The examination was conducted with the patient in the supine position.

Outcome Measures

The primary outcome was the incidence of symptomatic UTI occurring within 72 hours after the UDS. The diagnostic criteria for symptomatic UTI are as follows: supporting clinical evidence, which included documented symptoms (e.g., fever without other cause, new or worsened incontinence) together with at least one corroborating laboratory finding (positive leukocyte esterase, positive nitrite, or a positive urine culture with $\geq 10^5$ CFU/mL bacterial species)[19].

Risk Factors

Baseline demographic, neurological and clinical data were collected at enrollment using a standardized case report form. Catheterization data and urodynamic parameters were recorded at the time of the procedure. The following specific data were collected:

- Demographic data: age and sex.
- Neurological and clinical data: level of injury, ASIA Impairment Scale grade, type of SCI (traumatic vs. non-traumatic), time from SCI to UDS, number of general complications/comorbidities (see Supplementary Material 1 for detailed information), Activities of Daily Living (ADL) score, use of anticholinergics or β 3-agonists, serum creatinine, estimated glomerular filtration rate (eGFR), and results from urinalysis (leukocyte esterase and nitrite).
- Catheterization data: total duration of IUC (for the IUC group) and duration of CIC prior to UDS (for the CIC group).
- Urodynamic parameters: neurogenic detrusor overactivity, urgency urinary incontinence, maximum detrusor pressure during storage, bladder compliance, and maximum cystometric capacity.

Statistical Analysis

Statistical analyses were performed using SPSS Statistics (Version 27, IBM Corp). Continuous variables were presented as mean $\pm$ standard deviation or median with an inter-quartile range (IQR), and comparisons between the IUC and CIC groups were performed using the t-test or Wilcoxon rank-sum test as appropriate. Categorical variables were presented as counts (percentages) and compared using the Chi-square test or Fisher's exact test. Univariate and multivariate logistic regression models were used to identify potential predictors of UTI. Variables that differed significantly at baseline were entered into the multivariate logistic regression model. Model performance was evaluated using the area under receiver operating characteristic curve (AUROC), accuracy, sensitivity, and specificity. The optimal cutoff point was determined using the Youden index. Odds ratios (OR) with 95% confidence intervals (CI) were calculated. A two-tailed p -value < 0.05 was considered statistically significant.

Results

A total of 271 patients were enrolled and categorized into an IUC group ($n = 107$, 39.5%) and a CIC group ($n = 164$, 60.5%). The mean age of all patients was 45.53 ± 16.45 years, and 194 patients (71.3%) were male. Significant differences were observed between the two groups in terms of sex, time from SCI to UDS, and use of anticholinergics or β 3-agonists (Table 1). Table 2 presented the differences in urodynamic parameters between the IUC and CIC groups, and significant differences were observed in neurogenic detrusor overactivity, bladder compliance, and maximum cystometric capacity.

Table 1

Comparison of baseline characteristics between the two groups prior to urodynamic study (n = 271)

Variable	IUC Group (n = 107)	CIC Group (n = 164)	Test Statistic	P- value
Demographics data				
Age (years), mean $\pm$ SD	47.24 $\pm$ 15.94	44.41 $\pm$ 16.73	1.383	0.168
Sex, n (%)			4.160	0.041
Female	23(21.5)	54(32.9)		
Male	84(78.5)	110(67.1)		
Neurological and clinical data				
Level of injury, n (%)			0.323	0.851
Cervical	32(29.9)	47(28.7)		
Thoracic	42(39.3)	70(42.7)		
Lumbar and below	33(30.8)	47(28.7)		
ASIA Impairment Scale, n (%)			5.079	0.079
A (Complete)	31(29.0)	54(32.9)		
B (Sensory Incomplete)	18(16.8)	13(7.9)		
C/D (Motor Incomplete)	58(54.2)	97(59.1)		
Type of SCI, n (%)			0.243	0.622
Traumatic SCI	72(67.3)	115(70.1)		
Non-traumatic SCI	35(32.7)	49(29.9)		
number of general complications/comorbidities, median (IQR)	7(5,9)	7(5,9)	-0.248	0.805
ADL			3.611	0.164
Mild Dependence (mBI score: 65–95)	5(4.7)	18(11.0)		
Moderate Dependence (mBI score: 45–60)	18(16.8)	22(13.4)		
^a: eGFR was not routinely calculated for pediatric patients per hospital protocol. Data on eGFR are missing for 17 patients (7 from the IUC group and 10 from the CIC group). Comparisons for eGFR were performed using available data.				

Variable	IUC Group (n = 107)	CIC Group (n = 164)	Test Statistic	P- value
Demographics data				
Severe to Complete Dependence (mBI score: 0–40)	84(78.5)	124(75.6)		
Time from SCI to UDS (days), median (IQR)	47.50(28.25,97.75)	103.50(51.00,167.00)	-6.200	<0.001
Use of anticholinergics or β 3- agonists, n (%)			15.159	<0.001
No	96(89.7)	114(69.5)		
Yes	11(10.3)	50(30.5)		
Serum creatinine (μ mol/L), mean $\pm$ SD	56.17 $\pm$ 19.11	55.32 $\pm$ 16.24	0.393	0.695
eGFR ^a (mL/min/1.73m ²), mean $\pm$ SD	113.66 $\pm$ 18.48	114.65 $\pm$ 16.41	-0.444	0.657
Leukocyte esterase			4.728	0.193
-:0	26(24.3)	31(18.9)		
+:1	13(12.1)	22(13.4)		
++:2	28(26.2)	62(37.8)		
+++:3	40(37.4)	49(29.9)		
Nitrite positive, n (%)			1.630	0.202
No	69(64.5)	93(56.7)		
Yes	38(35.5)	71(43.3)		
^a a: eGFR was not routinely calculated for pediatric patients per hospital protocol. Data on eGFR are missing for 17 patients (7 from the IUC group and 10 from the CIC group). Comparisons for eGFR were performed using available data.				

Table 2
Comparison of urodynamic parameters between the two groups (n = 271)

Variable	IUC Group (n = 107)	CIC Group (n = 164)	Test Statistic	P- value
Neurogenic detrusor overactivity, n (%)			5.086	0.024
No	49(45.8)	98(59.8)		
Yes	58(54.2)	66(40.2)		
Urgency urinary incontinence, n (%)			0.685	0.408
No	74(69.2)	121(73.8)		
Yes	33(30.8)	43(26.2)		
Maximum detrusor pressure during storage (cmH ₂ O), median (IQR)	26 (18,43)	24 (12,54.25)	-0.915	0.360
Low bladder compliance (< 30 ml/cmH ₂ O), n (%)			35.446	<0.001
No	51(47.7)	134(81.7)		
Yes	44(41.1)	26(15.9)		
Non-measurable ^b	12(11.2)	4(2.4)		
Maximum cystometric capacity (ml), median (IQR)	319 (202,400)	368.5 (301,400)	-3.954	<0.001
^a b: "Non-measurable" indicates that the patient's effective bladder filling volume is too low to accurately calculate bladder compliance.				

During follow-up, 22 cases of UTI were observed: 18 cases (16.8%) in the IUC group and 4 cases (2.4%) in the CIC group. Table 3 showed a comparison between patients who developed a UTI and those who did not. Patients who developed an infection had a shorter time from SCI to UDS (49 vs. 78 days, $P = 0.028$) and a lower proportion of CIC use (18.2% vs. 64.3%, $P < 0.001$). No other variables showed significant differences between the two groups.

Table 3
Comparison of patients who developed a UTI (n = 271)

Variable	Without UTI (n = 249)	With UTI (n = 22)	Test Statistic	P-value
Demographics data				
Age (years), mean ± SD	45.13 ± 16.40	50.05 ± 16.70	-1.346	0.179
Sex, n (%)			2.570	0.109
Female	74(29.7)	3(13.6)		
Male	175(70.3)	19(86.4)		
Neurological and clinical data				
Level of injury, n (%)			4.914	0.086
Cervical	75(30.1)	4(18.2)		
Thoracic	105(42.2)	7(31.8)		
Lumbar and below	69(27.7)	11(50.0)		
ASIA Impairment Scale, n (%)			5.599	0.061
A (Complete)	77(30.9)	8(36.4)		
B (Sensory Incomplete)	31(12.4)	0(0.0)		
C/D (Motor Incomplete)	141(56.6)	14(63.6)		
Type of SCI, n (%)			1.100	0.294
Traumatic SCI	174(69.9)	13(59.1)		
Non-traumatic SCI	75(30.1)	9(40.9)		
number of general complications/comorbidities, median (IQR)	7(5,9)	6(4,8)	-1.058	0.290
ADL			1.468	0.480
Mild Dependence (mBI score: 65–95)	22(8.8)	1(4.5)		
^a a: eGFR was not routinely calculated for pediatric patients per hospital protocol. Data on eGFR are missing for 17 patients (7 from the IUC group and 10 from the CIC group). Comparisons for eGFR were performed using available data.				
^b b: “Non-measurable” indicates that the patient’s effective bladder filling volume is too low to accurately calculate bladder compliance.				

Variable	Without UTI (n = 249)	With UTI (n = 22)	Test Statistic	P-value
Demographics data				
Moderate Dependence (mBI score: 45–60)	35(14.1)	5(22.7)		
Severe to Complete Dependence (mBI score: 0–40)	192(77.1)	16(72.7)		
Time from SCI to UDS (days), median (IQR)	78.00 (39.00,161.50)	49.00 (30.50,93.00)	-2.198	0.028
Use of anticholinergics or β 3- agonists, n (%)			1.705	0.192
No	190(76.3)	20(90.9)		
Yes	59(23.7)	2(9.1)		
Serum creatinine (μ mol/L), median (IQR)	54 (47,65)	55 (42.5,59.5)	-0.114	0.910
eGFR ^a (mL/min/1.73m ²), mean $\pm$ SD	114.49 $\pm$ 16.81	111.68 $\pm$ 21.62	0.716	0.474
Leukocyte esterase			0.434	0.933
-:0	52(20.9)	5(22.7)		
+:1	33(13.3)	2(9.1)		
++:2	83(33.3)	7(31.8)		
+++:3	81(32.5)	8(36.4)		
Nitrite positive, n (%)			0.273	0.602
No	150(60.2)	12(54.5)		
Yes	99(39.8)	10(45.5)		
urodynamic parameters				
Neurogenic detrusor overactivity, n (%)			1.715	0.190
^a a: eGFR was not routinely calculated for pediatric patients per hospital protocol. Data on eGFR are missing for 17 patients (7 from the IUC group and 10 from the CIC group). Comparisons for eGFR were performed using available data.				
b: “Non-measurable” indicates that the patient’s effective bladder filling volume is too low to accurately calculate bladder compliance.				

Variable	Without UTI (n = 249)	With UTI (n = 22)	Test Statistic	P-value
Demographics data				
No	138(55.4)	9(40.9)		
Yes	111(44.6)	13(59.1)		
Urgency urinary incontinence, n (%)			1.964	0.161
No	182(73.1)	13(59.1)		
Yes	67(26.9)	9(40.9)		
Maximum detrusor pressure during storage (cmH ₂ O), median (IQR)	25 (14,45.5)	31 (20,51)	-1.035	0.301
Low bladder compliance (< 30 ml/cmH ₂ O), n (%)			4.028	0.133
No	174(69.9)	11(50.0)		
Yes	62(24.9)	8(36.4)		
Non-measurable ^b	13(5.2)	3(13.6)		
Maximum cystometric capacity (ml), median (IQR)	353 (292,400)	368 (230,400)	17.960	0.376
pre-urodynamic bladder management method, n (%)			17.960	<0.001
IUC Group	89(35.7)	18(81.8)		
CIC Group	160(64.3)	4(18.2)		
^a a: eGFR was not routinely calculated for pediatric patients per hospital protocol. Data on eGFR are missing for 17 patients (7 from the IUC group and 10 from the CIC group). Comparisons for eGFR were performed using available data.				
^b b: “Non-measurable” indicates that the patient’s effective bladder filling volume is too low to accurately calculate bladder compliance.				

Sex, time from SCI to UDS, use of anticholinergics or β 3-agonists, neurogenic detrusor overactivity, bladder compliance, maximum cystometric capacity, and bladder management strategy were included in the logistic regression model (Model Chi-square: 22.042, $P = 0.005$; Hosmer-Lemeshow test: $P = 0.643$). As shown in Table 4, multivariate logistic regression analysis revealed that the incidence of UTI in the IUC group was 5.149 times higher than that in the CIC group (95%CI:1.426–18.594, $P = 0.012$), indicating that the use of CIC prior to UDS was a protective factor against UTI. The overall accuracy of the model was 91.9%, with an AUROC of 0.787 (95% CI: 0.689–0.884). The maximum Youden index was 0.510, corresponding to a sensitivity of 0.727 and a specificity of 0.783.

Table 4
Multivariate analysis for UTI, conducted through logistic regression. (n = 271)

Risk Factor	β Coefficient	S.E.	WALD	OR(95%CI)	P-value
constant	-3.489	1.483	5.533	0.031	
IUC Group (reference = CIC Group)	1.639	0.655	6.256	5.149(1.426,18.594)	0.012
OR = Odds Ratio. CI = Confidence Interval.					

Discussion

The principal finding of this prospective cohort study confirms our hypothesis that in patients with NLUTD following acute SCI, using a CIC regimen prior to the initial UDS, as opposed to maintaining a continuous IUC, was associated with a much lower risk of symptomatic UTI requiring antibiotic treatment within 72 hours post-procedure (2.4% vs. 16.8%; adjusted OR = 5.149). Concurrently, the CIC group demonstrated a superior bladder storage profile at the time of UDS, characterized by significantly better stability and compliance, and larger maximum cystometric capacity. This evidence provides strong support for implementing CIC early after SCI, even when definitive UDS guidance is not immediately available, to reduce complication risk associated with this essential diagnostic procedure.

Certain baseline differences between the cohorts merit consideration. The proportion of males in the IUC group was higher (78.5% vs. 67.1%). First, this may be related to the anatomical characteristics of the male urethra. Compared with females, the male urethra is longer, more curved, and is part of the genital tract (serving both urinary and reproductive functions), which may contribute to greater psychological resistance to urethral catheterization, thereby making it more difficult for them to accept CIC[20]. In addition, we suggest that this finding may also be related to referral bias. As our hospital is a top-tier regional hospital, we receive a large number of referred patients. A considerable proportion of these patients come from primary hospitals that lack the facilities for CIC, leaving IUC as the only option. Given that the proportion of male patients with SCI is significantly higher than that of females[21], this leads to a higher absolute number of male patients transferred from lower-level hospitals without CIC capacity, thereby increasing the proportion of male patients in the IUC group.

Furthermore, baseline disease duration differed significantly between the CIC and IUC groups (103.5 vs. 47.5 days), likely attributable to the lengthy process of establishing a stable CIC regimen. CIC requires patients or caregivers to undergo systematic catheterization training, possess adequate functional capacity, and possibly receive empirical medication adjustments before a stable and effective voiding regimen can be achieved in the acute/subacute phase. This process often takes several weeks, reasonably explaining the longer disease duration observed in the CIC group. On the other hand, after regrouping patients based on whether they developed a UTI following UDS, we found that the infected group had a significantly shorter disease duration than the non-infected group. This phenomenon may

be related to spinal cord injury-induced immunosuppression syndrome (SCI-IDS) occurring in the early phase after SCI. SCI-IDS is a systemic immune dysfunction that develops early after SCI, resulting from disruption of the neuroendocrine-immune axis and impairment of specific immune pathways, which leads to a marked reduction in host resistance to pathogens[22, 23]. One study reported that the cumulative incidence of the first UTI within six weeks after SCI is approximately 50%[24]. Therefore, during this phase, patients are at high risk of developing UTI even when undergoing invasive UDS. This finding also reminds us that implementing CIC as early as possible after injury may help reduce infection risk in two ways: on the one hand, it decreases the additional infection risk associated with IUC-related biofilm formation; on the other hand, since establishing a stable CIC regimen requires time, early initiation of CIC allows invasive UDS to be safely deferred until after passing through the early “infection-prone” phase of SCI-IDS.

Notably, the CIC group had a significantly higher utilization of anticholinergic or β 3-agonist therapy (36.6% vs. 4.8%). This difference likely reflects the clinical reality that with an IUC continuously draining the bladder, symptoms of detrusor overactivity such as urgency incontinence are masked. In contrast, the CIC regimen, by allowing bladder filling, makes such overactivity manifest, logically prompting pharmacological management. This higher rate of empirical drug treatment in the CIC group is an integral part of the proactive clinical pathway it represents and contributed to its superior UDS profile in terms of compliance and capacity[25, 26]. As medications for neurogenic bladder were routinely unchanged prior to urodynamic testing, utilization of anticholinergic or β 3-agonist therapy also contributed to the superior bladder storage function observed in the CIC group.

The conventional view attributes the long-term UTI risk reduction with CIC compared to IUC primarily to the decreased dwelling time of the catheter, thereby limiting bacterial biofilm formation, and additionally to the periodic complete emptying of the bladder, which reduces bacterial colonization[1, 27]. Although the significantly lower infection risk observed in our CIC group is directionally consistent with this consensus, a critical distinction must be made. Our study focused on a specific, short-term risk following a single invasive procedure, not long-term incidence. We propose that during the pre-UDS period, a key protective effect of CIC may stem from optimizing bladder functional status, thereby enhancing its resilience to cystometric filling stress. Urodynamic parameters support this: the CIC group exhibited a profile indicative of greater safety reserves. A growing body of evidence causally links abnormal bladder dynamics to UTI susceptibility[28]. Specifically, the high-pressure state represented by low compliance continuously compresses the bladder mucosa, leading to reduced blood perfusion, local ischemia, and consequently, a compromised physical barrier function and local immune response of the urothelium[1]. Thus, the functionally superior bladders in the CIC group, conditioned by periodic cycles, were likely less susceptible to the micro-injury potentially incurred during UDS, maintaining a more robust barrier against post-procedural bacterial invasion.

Given the short disease duration, the reduced compliance and capacity in the IUC group likely reflect functional maladaptation rather than intrinsic damage. The continuously drained IUC bladder, deprived of phasic stretch, becomes stiff and unprepared for rapid UDS filling, leading to exaggerated pressure rises

and premature filling termination. Evidence from studies involving repeated cystometry suggests the presence of dynamic elasticity in human bladders, where repeated filling can "soften" the bladder wall, allowing for increased volumes and improved compliance with subsequent fills[29–31]. In contrast, CIC bladders, accustomed to filling-voiding cycles, are mechanically conditioned, demonstrating superior tolerance.

A recent retrospective cohort study found that CIC was associated with a significantly higher likelihood of bladder recovery within one year compared to IUC[32], aligning with our observation of improved urodynamic profiles even after a short period of CIC. Since CIC can help with bladder recovery, we recommend not delaying CIC while waiting for UDS, especially in settings where timely UDS evaluation is challenging. CIC should be implemented as early as clinically feasible.

Limitation

This study has several inherent limitations. First, although it adopted a prospective design, it remains a non-randomized observational study, which may introduce selection bias. Clinicians might have been more inclined to choose the "CIC-first" pathway for patients expected to have better neurological recovery potential, hand function, or cognitive capacity, while reserving IUC for those with more severe conditions or poorer rehabilitation prospects. However, our detailed baseline comparisons—encompassing injury level, severity, the number of general complications/comorbidities, and ADL status—demonstrated that the clinical profiles of the two groups were fundamentally comparable, which partially mitigates this concern. Second, we did not obtain pre-urodynamic urine culture results for all patients. This is primarily because, in routine clinical practice, urine cultures are not performed in asymptomatic patients, as asymptomatic bacteriuria is generally not considered to require treatment[33]. Nevertheless, the lack of these data limited a deeper microbiological exploration of the mechanisms underlying UTI, particularly the relationship between asymptomatic bacteriuria and symptomatic infection. Third, this is a single-center study, and all patients were recruited from a tertiary referral center in one region; thus, referral bias may exist, and the generalizability of our findings to primary hospitals or other healthcare systems should be exercised with caution. Future multicenter, randomized controlled trials are needed to further validate the advantages of the CIC-first strategy in reducing post-urodynamic infection risk and improving bladder function.

Conclusion

In conclusion, our findings suggest that in patients with neurogenic lower urinary tract dysfunction following acute spinal cord injury, a "CIC-first" clinical pathway prior to UDS is associated with a lower risk of post-procedural symptomatic UTI and better bladder storage function compared with an "IUC-first" pathway. Based on these observations, we propose that the role of UDS may be redefined from the conventional "starting point of treatment" to a "checkpoint for calibrating and optimizing the treatment plan". In real-world practice, particularly in primary care settings where access to urodynamic equipment is limited and the first UDS is often delayed, early implementation of CIC combined with

empirical anticholinergic or β 3-agonist therapy (when detrusor overactivity is anticipated) may be considered.

Declarations

Conflict of Interest:

The authors declare that they have no competing interests.

Declaration of AI Usage

During the preparation of this manuscript, the authors used DeepSeek for language optimization, grammar proofreading, and structural adjustments of certain paragraphs. All AI-generated content has been carefully reviewed and revised by the authors, who take full responsibility for the entire manuscript, including data interpretation, conclusions, and final text. The authors confirm that no AI was used to ghostwrite, generate core scientific content, analyze data, or fabricate original data. The AI tool was not listed as an author and was not involved in the conception, design, data collection, analysis, or conclusion-drawing of the study.

Funding:

This work was supported by the Tongji Hospital Scientific Research Fund [Grant Number AI2024B08] and the National Natural Science Foundation of China [Grant Number 72504099].

Author Contributions:

Y.C. and M.Z. conceived and designed the study. L.R., D.L., K.L., L.L. and J.C. performed data acquisition and curation. Y.C. performed the statistical analysis. Y.C., Z.C., T.X. and L.M. interpreted the data. Y.C. and M.Z. drafted the manuscript. All authors reviewed and approved the final manuscript.

Acknowledgments:

The authors thank all the participants in this study.

Data Availability Statement:

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Fitzpatrick, M.A. and N. Nwafo, *Urinary Tract Infection Diagnostic and Management Considerations in People with Spinal Cord Injury and Neurogenic Bladder*. Infect Dis Clin North Am, 2024. 38(2): p. 381–393.
2. Crescenze, I.M., et al., *Self-Reported Urological Hospitalizations or Emergency Room Visits in a Contemporary Spinal Cord Injury Cohort*. J Urol, 2021. 205(2): p. 477–482.
3. Liu, J., et al., *Urinary tract infections and intermittent catheterization among patients with spinal cord injury in Chinese community*. Sci Rep, 2023. 13(1): p. 17683.
4. Liu, J., et al., *Value of sufficient clean intermittent catheterization in urinary tract infection and upper urinary tract protection in children with neurogenic bladder*. J Pediatr Urol, 2022. 18(4): p. 499 e1-499 e6.
5. Al Salhi, Y., et al., *Impact of early self-clean intermittent catheterization in orthotopic ileal neobladder: prospective randomized study to evaluate functional outcomes, continence status and urinary tract infections*. Minerva Urol Nephrol, 2023. 75(1): p. 59–65.
6. Milicevic, S., et al., *Urinary Tract Infections in Relation to Bladder Emptying in Patients with Spinal Cord Injury*. J Clin Med, 2024. 13(13).
7. Groen, J., et al., *Summary of European Association of Urology (EAU) Guidelines on Neuro-Urology*. Eur Urol, 2016. 69(2): p. 324–33.
8. de Jong, T.P. and A.J. Klijn, *Urodynamic studies in pediatric urology*. Nat Rev Urol, 2009. 6(11): p. 585–94.
9. Welk, B., et al., *Early urological care of patients with spinal cord injury*. World J Urol, 2018. 36(10): p. 1537–1544.
10. Wu, X.Y., et al., *Prophylactic Antibiotics for Urinary Tract Infections after Urodynamic Studies: A Meta-Analysis*. Biomed Res Int, 2021. 2021: p. 6661588.
11. van Beek, J., et al., *Patient-reported signs and symptoms of urinary tract infections after video-urodynamic studies in individuals with neurogenic lower urinary tract dysfunction-A single-center observational study*. Neurourol Urodyn, 2024. 43(7): p. 1609–1616.
12. Bothig, R., et al., *Morbidity of urinary tract infection after urodynamic examination of hospitalized SCI patients: the impact of bladder management*. Spinal Cord, 2013. 51(1): p. 70–3.
13. He, W., et al., *Efficacy and safety of preventing catheter-associated urinary tract infection by inhibiting catheter bacterial biofilm formation: a multicenter randomized controlled trial*. Antimicrob Resist Infect Control, 2024. 13(1): p. 96.
14. Kinnear, N., et al., *The impact of catheter-based bladder drainage method on urinary tract infection risk in spinal cord injury and neurogenic bladder: A systematic review*. Neurourol Urodyn, 2020. 39(2): p. 854–862.
15. Hornby, T.G., et al., *Clinical Practice Guideline to Improve Locomotor Function Following Chronic Stroke, Incomplete Spinal Cord Injury, and Brain Injury*. J Neurol Phys Ther, 2020. 44(1): p. 49–100.

16. Sun, H., et al., *Research on complications and bladder management of the chronic phase spinal cord injury in China*. Sci Rep, 2025. 15(1): p. 15718.
17. Wyndaele, J. and A. Kovindha, *Urodynamic Testing After Spinal Cord Injury: A Practical Guide*. 2017.
18. Rosier, P., et al., *International Continence Society Good Urodynamic Practices and Terms 2016: Urodynamics, uroflowmetry, cystometry, and pressure-flow study*. Neurourol Urodyn, 2017. 36(5): p. 1243–1260.
19. Aguirre-Guemez, A.V. and S.L. Groah, *Managing Recurrent Urinary Tract Infections After Spinal Cord Injury: Practical Approaches and Emerging Concepts*. Phys Med Rehabil Clin N Am, 2025. 36(1): p. 73–98.
20. Hao, F., et al., *Acceptance and the influencing factors towards intermittent self-catheterisation among patients with neurogenic lower urinary tract dysfunction in China: a multicentre cross-sectional study*. BMJ Open, 2024. 14(12): p. e090047.
21. Zhang, W., et al., *Epidemiological investigation of traumatic spinal cord injury caused by object strike in China: strategies for workplace safety improvement*. J Rehabil Med, 2024. 56: p. jrm40880.
22. Li, C., et al., *CCR7-mediated T follicular helper cell differentiation is associated with the pathogenesis and immune microenvironment of spinal cord injury-induced immune deficiency syndrome*. Front Neurosci, 2022. 16: p. 1019406.
23. Zeng, H., et al., *Unbiased multitissue transcriptomic analysis reveals complex neuroendocrine regulatory networks mediated by spinal cord injury-induced immunodeficiency*. J Neuroinflammation, 2023. 20(1): p. 219.
24. Schweizerhof, O., et al., *T-cell biomarkers improve urinary tract infection risk stratification beyond clinical characteristics after acute traumatic spinal cord injury*. Sci Rep, 2026. 16(1): p. 1320.
25. Kitta, T., et al., *Urodynamic evaluation of the efficacy of vibegron, a new β 3-adrenergic receptor agonist, on lower urinary tract function in children and adolescents with overactive bladder*. J Pediatr Urol, 2022. 18(5): p. 563–569.
26. Balla, H., et al., *Intracellular signaling pathways of muscarinic acetylcholine receptor-mediated detrusor muscle contractions*. Am J Physiol Renal Physiol, 2023. 325(5): p. F618-f628.
27. Vigil, H.R. and D.R. Hickling, *Urinary tract infection in the neurogenic bladder*. Transl Androl Urol, 2016. 5(1): p. 72–87.
28. Leitner, L., et al., *Urodynamic Risk Factors for Urinary Infection*. Eur Urol Focus, 2024. 10(5): p. 702–705.
29. Colhoun, A.F., et al., *A pilot study to measure dynamic elasticity of the bladder during urodynamics*. Neurourol Urodyn, 2017. 36(4): p. 1086–1090.
30. Ockrim, J., et al., *Variability of detrusor overactivity on repeated filling cystometry in men with urge symptoms: comparison with spinal cord injury patients*. BJU Int, 2005. 95(4): p. 587–90.
31. Gupta, A., G. Defreitas, and G.E. Lemack, *The reproducibility of urodynamic findings in healthy female volunteers: results of repeated studies in the same setting and after short-term follow-up*. Neurourol

Urodyn, 2004. 23(4): p. 311–6.

32. Aude, C.A., et al., *Catheterization Method and Functional Recovery of Neurogenic Bladder in Spinal Cord Injury*. JAMA Netw Open, 2025. 8(7): p. e2522030.

33. Nicolle, L.E., et al., *Clinical Practice Guideline for the Management of Asymptomatic Bacteriuria: 2019 Update by the Infectious Diseases Society of America*. Clin Infect Dis, 2019. 68(10): p. e83-e110.

Figures

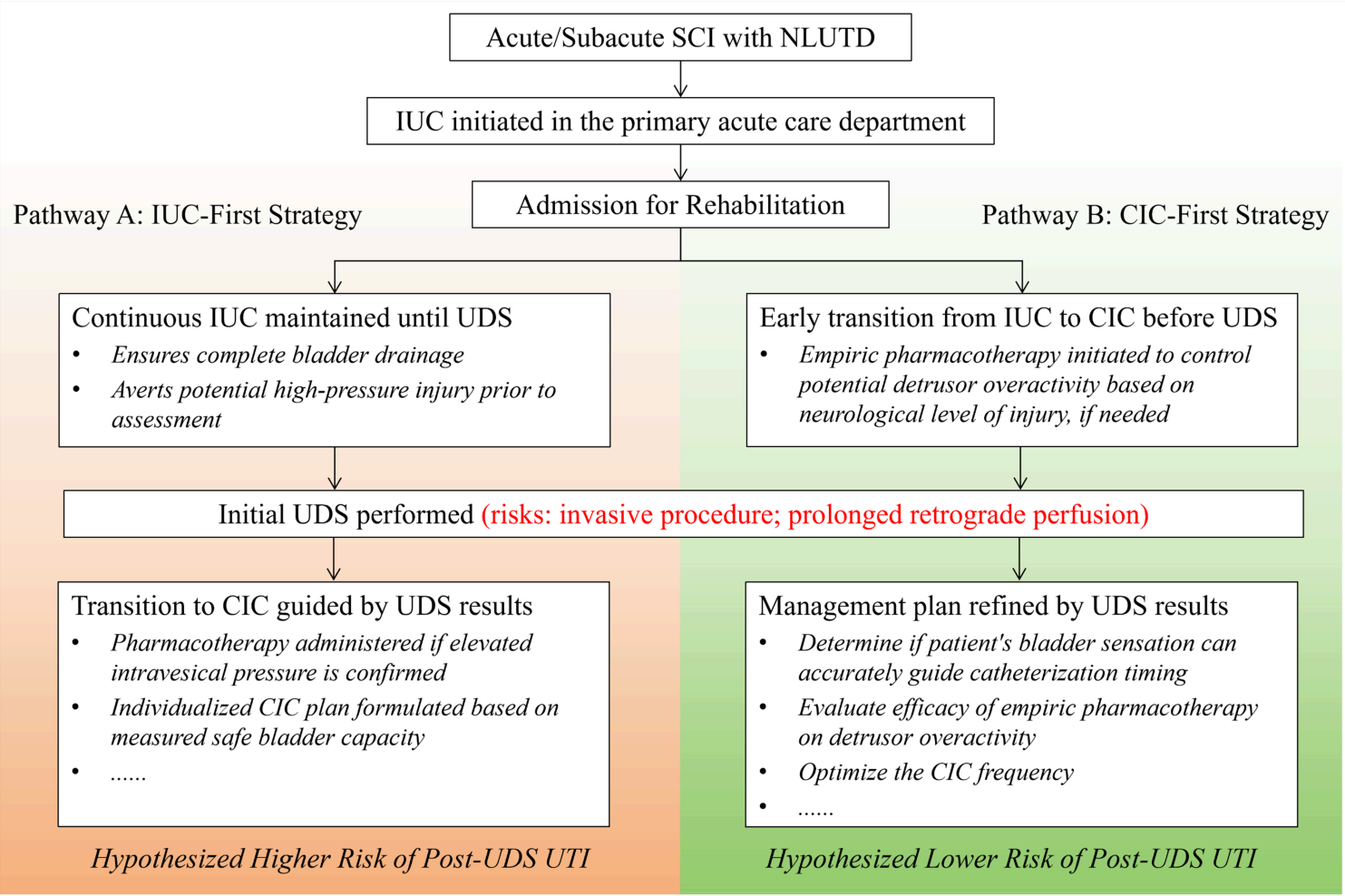


Figure 1

Schematic of the Two Clinical Pathways for Bladder Management Prior to Initial UDS

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [STROBEchecklistv4combinedPlosMedicine.docx](#)
- [Supplementfile1.docx](#)