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Neurogenic Lower Urinary Tract Dysfunction in the First Year After Spinal Cord Injury: A Descriptive Study of Urodynamic Findings

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Study Need and Importance: Most patients with spinal cord injury (SCI) progressively develop neurogenic lower urinary tract dysfunction, which not only impairs health-related quality of life, for example, due to urinary incontinence, but also represents a significant risk for deterioration of renal function. Urodynamic investigation is considered the gold standard to objectively assess lower urinary tract function. The first year after SCI is of special interest due to the potential for neurological changes, implying that lower urinary tract function is also not stable during this time period. It also represents a window of opportunity as early diagnosis and treatment based on urodynamic findings could play a pivotal role in long-term urological outcomes. Nevertheless, guidelines and recommendations on evaluation and diagnosis of neurogenic lower urinary dysfunction do not provide a predefined follow-up schedule for the first year after SCI.

What We Found: In our cohort of 97 patients we observed 1 or more unfavorable urodynamic parameters in 87 patients (90%) within the first year after SCI (see Table).

Limitations: Our department is part of a specialized university SCI center, and thus selection toward more severe cases cannot be ruled out, and transportation of the findings to other settings should be undertaken with caution. Furthermore, our study population received neuro-urological treatment guided by urodynamic findings, so it reflects the outcomes that are observed in routine clinical practice.

Interpretation for Patient Care: We found that almost all of the patients showed at least 1 unfavorable urodynamic parameter within the first year after acute SCI. As early treatment based on urodynamic findings might decrease the risk of deterioration of the upper urinary tract, an early urodynamic investigation and standardized follow-up schedule seem to be of utmost importance.

Table. *Unfavorable Urodynamic Parameters*

Parameter	Within the first year of SCI	1-Mo follow-up	3-Mo follow-up	6-Mo follow-up	12-Mo follow-up
Urodynamics performed, No. (%)	97 (100)	90 (93)	85 (88)	75 (77)	73 (75)
DO and DSD, No. (%)	85 (88)	61 (68)	63 (74)	55 (73)	52 (71)
Maximum storage detrusor pressure $\geq$40 cm H_2O, No. (%)	38 (39)	21 (23)	18 (21)	24 (32)	11 (15)
Filling volume when pDet = 40 mL, median (Q1-Q3)	-	505 (215-610)	525 (278-753)	398 (258-663)	300 (195-500)
Bladder compliance <20 mL/cm H_2O, No. (%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Videourodynamics performed, No. (%)	96 (99)	88 (98)	76 (89)	67 (89)	68 (93)
Vesicoureteral reflux, No. (%)[a]	7 (7)	4 (5)	5 (7)	2 (3)	2 (3)
At least 1 unfavorable parameter, No. (%)	87 (90)	65 (72)	67 (79)	61 (81)	55 (75)

Abbreviations: DO, detrusor overactivity; DSD, detrusor sphincter dyssynergia; pDET, detrusor pressure; Q, quartile; SCI, spinal cord injury.
[a] Vesicoureteral reflux grade: 1 month, 4 grade I; 3 months, 1 grade I, 3 grade II, 1 grade III; 6 months, 1 grade II, 1 grade III; 12 months: 2 grade I.

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Neurogenic Lower Urinary Tract Dysfunction in the First Year After Spinal Cord Injury: A Descriptive Study of Urodynamic Findings

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Purpose: We aimed to provide a real-world description of neurogenic lower urinary tract dysfunction within the first year after spinal cord injury with a focus on unfavorable urodynamic parameters that are associated with urological morbidity.

Materials and Methods: Urodynamic investigations from 97 patients with traumatic or ischemic acute spinal cord injury and managed according to the European Association of Urology Guidelines on Neuro-Urology were analyzed at a single university spinal cord injury center at 1 month, 3 months, 6 months, and 12 months after injury. Unfavorable urodynamic parameters were defined as detrusor overactivity in combination with detrusor sphincter dyssynergia, maximum storage detrusor pressure of 40 cm H_2O or higher, bladder compliance less than 20 mL/cm H_2O, and vesicoureteral reflux of any grade.

Results: One or more unfavorable urodynamic parameter was observed in 87 out of 97 patients (90%) within the first year after spinal cord injury. Eighty-eight percent of the patients showed detrusor overactivity with detrusor sphincter dyssynergia, 39% a maximum storage detrusor pressure of 40 cm H_2O or higher, and 7% vesicoureteral reflux. No patient developed a low-compliance bladder.

Conclusions: Using a standardized urodynamic follow-up schedule, we found unfavorable urodynamic parameters in a majority of the population within the first year after spinal cord injury. As early treatment based on urodynamic findings might reduce the risk of deterioration of upper and lower urinary tract function, thereby improving long-term outcomes, there is need for further research regarding recommendations for a urodynamic follow-up schedule during the first year after spinal cord injury.

Key Words: urodynamics; spinal cord injuries; urinary bladder; neurogenic; urinary bladder; overactive

Most patients with spinal cord injury (SCI) progressively develop neurogenic lower urinary tract dysfunction (NLUTD), which not only impairs health-related quality of life, eg, due to urinary incontinence, but also represents a significant risk for deterioration of renal function.[1,2] Urodynamic

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investigation (UDI) is considered the gold standard to objectively assess lower urinary tract (LUT) function.[2] Furthermore, the association of clinical symptoms and urodynamic findings has been shown to have limited reliability in patients with SCI.[3] Detrusor overactivity (DO) with detrusor sphincter dyssynergia (DSD),[4] high maximum detrusor pressure (pDetmax; $\geq$40 cm H_2O) during the storage phase,[5,6] low bladder compliance ($<$20 mL/cm H_2O),[7] and vesicoureteral reflux (VUR) are considered unfavorable urodynamic parameters[8] that are associated with elevated risk for upper urinary tract (UUT) complications[4] and renal failure.[9,10] In contrast to the established assumption that the spinal shock phase, which can last for months, is characterized by an acontractile detrusor, up to two-thirds of patients may already show unfavorable urodynamic parameters within 40 days after SCI.[11]

The first year after SCI is of special interest due to the potential for neurological changes, implying that LUT function is also not stable during this time period. It also represents a window of opportunity as early diagnosis and treatment based on urodynamic findings could play a pivotal role in long-term urological outcomes.[8] Nevertheless, guidelines and recommendations on evaluation and diagnosis of NLUTD do not provide a predefined follow-up schedule for the first year after SCI. UDI should be performed as a mandatory baseline diagnostic measurement and should be repeated if changes in signs or symptoms or new complications occur.[2,12] These recommendations reflect a lack of knowledge about NLUTD within the first year after SCI in a real-world setting. Therefore, we aimed to describe NLUTD within the first year after SCI, with a particular focus on the prevalence of unfavorable urodynamic findings at 4 standardized time points: 1 month, 3 months, 6 months, and 12 months after SCI in patients managed according to the European Association of Urology (EAU) Guidelines on Neuro-Urology.[2]

PATIENTS AND METHODS

Patients

From January 2014 to December 2019 patients with acute traumatic or ischemic SCI that participated in the prospective, population-based European Multicenter Study on Spinal Cord Injury (EMSCI, www.emsci.org) study received UDI at the Department of Neuro-urology, Balgrist University Hospital, Zürich, Switzerland. Inclusion criteria were: adults (age $\geq$18) with SCI from a single traumatic or ischemic event. Patients with severe brain injury, preexisting dementia or severe cognitive impairment were excluded. During the study period, the EMSCI participation rate was 77%. Furthermore, 4 patients that did not undergo any UDI (3 refusals, 1 death) were excluded from the current analysis. Within the EMSCI framework, patients underwent assessments, including UDI, at 4 standardized time points during the first year after SCI: 1 month (EMSCI Acute I; within 40 days after SCI), 3 months (EMSCI Acute II; 70-98 days after SCI), 6 months (EMSCI Acute III; 150-186 days after SCI), and 12 months after SCI (EMSCI Chronic; 300-546 days after SCI). In case of changes in or new onset of symptoms, eg, urinary incontinence, an additional UDI was performed by indication. The study was approved by the Zürich Cantonal Ethics Committee (PB_2016-00293, EK-03/2004), and all participants provided written informed consent.

Neuro-urological Evaluation and Management

Neurological level and SCI completeness (American Spinal Injury Association Impairment Scale [AIS] grade) were obtained from the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) assessment.[13] Neuro-urological evaluation was performed as described previously.[1]

Videourodynamics was performed according to good urodynamic practices following International Continence Society (ICS) recommendations.[14] Supplement 1 (https://www.jurology.com) describes the UDI protocol in detail. Autonomic dysreflexia (AD) was defined according to the International Standards to Document Remaining Autonomic Function after SCI as an increase in systolic blood pressure of $\geq$20 mm Hg from baseline.[15] DSD was defined as either detrusor contraction concurrent with involuntary contraction of the urethral and/or periurethral striated muscle[16] on pelvic floor electromyography and/or a dilated posterior urethra obstructed by the external urethral sphincter on fluoroscopy during videourodynamics.[17] Asymptomatic bacteriuria was not treated and no antibiotic prophylaxis was administered for UDI. Antimuscarinics and other bladder medications generally were not stopped prior UDI.

In order to reduce the risk of assessor bias, all UDIs were randomly assigned on a per-patient basis to 2 experienced neuro-urologists (MK, VB) for assessment according to ICS recommendations. All definitions, methods and units are also presented according to ICS standards.[16] Unfavorable urodynamic parameters, especially high pDetmax ($\geq$40 cm H_2O) during the storage phase and VUR, and/or storage symptoms were treated according to the EAU Guidelines on Neuro-Urology. Antimuscarinic medication was the first-line treatment for DO and storage symptoms and intradetrusor onabotulinumtoxinA injections were initiated if antimuscarinic therapy was ineffective or had to be suspended due to side effects.[2] Information on the use of medications potentially affecting the LUT and bladder emptying method was extracted from patients' records.

Outcome Measures

Outcome measures were urodynamic findings at the time points 1 month, 3 months, 6 months, and 12 months after SCI according to the EMSCI framework. Unfavorable urodynamic parameters were defined as DO with DSD, pDetmax $\geq$40 cm H_2O during the storage phase, bladder compliance $<$20 mL/cm H_2O, and VUR of any grade.[8]

Statistical Analyses

Statistical analyses were performed using Stata version 16.1. Many UDI parameters did not show a normal distribution, so continuous variables are displayed using medians, and first and third quartiles (Q1-Q3). For

analysis, the values with the highest impact on urological management (eg, initiation of treatment) of the same-session repeat filling cystometry and pressure flow assessments were utilized, eg, the highest value for pDetmax during the storage phase was taken. Identification of an unfavorable urodynamic parameter, AD or any sensation in either measurement was counted. The lower value was taken for volume when DO first occurred, DO exceeded 40 cm H_2O, and bladder compliance. The average of the 2 measurements was used for sensation variables and maximum cystometric capacity. For pressure flow studies, results from the measurement with the higher maximum flow rate were utilized. In 5 patients where the 1-month neurological assessment was missing or not testable, a next observation carried backward approach was used. In addition to the main analyses, the relationship between patient and SCI characteristics and missed UDI visits during follow-up was evaluated (Supplement 2, https://www.jurology.com).

RESULTS

Patient characteristics are presented in Table 1. Of the 97 patients enrolled 33 (34%) were female. Median age at SCI was 57 years (42-69 years). Overall, 75 (77%) had a traumatic SCI, 21 (22%) had a complete SCI (AIS A) and 43 (44%) had a cervical lesion. Persons aged ≥76 had a higher risk of missing UDIs and/or missing the 12-month UDI (Supplement 2, https://www.jurology.com). Table 2 shows the percentage of patients receiving medication potentially affecting the LUT and the bladder emptying method at each UDI time point. Findings from 342 total urodynamics investigations are displayed per follow-up time point in Table 3. Cumulatively, AD was observed in 73 patients during the first year after SCI, of whom 31 (42%) had a neurological level below T6. Unfavorable urodynamic parameters for each follow-up time point and cumulatively within the first year are listed in Table 4.

Table 1. *Baseline Characteristics of the Study Population (N = 97)*

Characteristic	Population statistic
Continuous variables, median (Q1-Q3)	
Age at SCI, y	57 (42-69)
Length of stay, d	112 (57-167)
Categorical variables, No. (%)	
Age at SCI, y	
18-30	10 (10)
31-45	18 (19)
46-60	28 (29)
61-75	32 (33)
76+	9 (9)
Sex	
Female	33 (34)
Male	64 (66)
SCI etiology	
Traumatic SCI	75 (77)
Ischemic nontraumatic SCI	22 (23)
Neurological level[a]	
C1-C4	26 (27)
C5-C8	17 (17)
T1-T6	10 (10)
T7-T12	27 (28)
L1-L5	17 (18)
AIS grade[a]	
A	21 (22)
B	10 (10)
C	16 (16)
D	50 (52)
Length of stay, d	
1-60	27 (28)
61-120	24 (25)
121-180	24 (25)
181+	22 (22)

Abbreviations: AIS, American Spinal Injury Association Impairment Scale; Q, quartile; SCI, spinal cord injury.
[a] In 5 patients missing neurological data 1 month after SCI, a next observation carried backward approach was used, ie, data were taken from the next time point where they were available.

DISCUSSION

Main Findings

In our study of 97 patients with acute SCI, 90% exhibited at least 1 unfavorable urodynamic parameter within the first 12 months after SCI. About 3 quarters had DO with DSD and almost 40% had a pDetmax jeopardizing the UUT (≥40 cm H_2O) during the storage phase. VUR was detected in 7%.

Findings in Context of Existing Evidence

Within the first month after acute SCI, over 70% of the patients already showed unfavorable urodynamic parameters, in contradiction to the assumption of an acontractile detrusor during this period. These findings are in line with the study by Bywater et al that reported the same overall percentages for unfavorable urodynamic parameters this early period, but with a slightly higher percentage of patients with a high-pressure system during urine storage (pDetmax ≥40 cm H_2O), 31% compared to 23% in the present study.[11] This difference could be due to the fact that our study population consisted of a higher proportion of patients with a less severe injury, ie, AIS grade D (52% vs 33%).

To our knowledge, this is the first study that reports the prevalence of NLUTD within the first year after SCI in patients receiving guideline-conforming neuro-urological management. So far, studies that focused also on NLUTD from the initial phase after SCI until the chronic phase either performed only 1 UDI per patient during the time period,[18,19] or examined a wide time span after acute SCI (ie, 2-84 months).[19] This resulted in a heterogeneous population with acute SCI and chronic SCI with already established NLUTD. In a retrospective study of 101 patients with complete and incomplete suprasacral SCI divided into groups to receive 1 single UDI between 0-90 days or 91-365 days after SCI, DO prevalence increased over time, but antimuscarinic therapy was stopped 1 week before UDI.[18] This is in contrast to our findings that showed a decrease of

Table 2. *Urological Management at the Time of Urodynamic Investigation*

Bladder management at time of urodynamics (N = 97)	1-Mo follow-up No. (%)	3-Mo follow-up No. (%)	6-Mo follow-up No. (%)	12-Mo follow-up No. (%)
Urodynamics performed	90 (93)	85 (88)	75 (77)	73 (75)
Medication				
Antimuscarinics	0 (0)	28 (33)	33 (44)	31 (42)
Alpha-blockers	4 (4)	14 (16)	12 (16)	13 (18)
Antidepressants/neuroleptics	33 (37)	37 (44)	38 (51)	38 (52)
Opioids	37 (41)	36 (42)	29 (39)	28 (38)
Intradetrusor onabotulinumtoxinA injections[a]	0 (0)	0 (0)	6 (8)[a]	12 (16)[a]
Bladder emptying method				
Transurethral indwelling catheter	60 (67)	11 (13)	1 (1)	0 (0)
Suprapubic indwelling catheter	6 (7)	24 (28)	27 (36)	24 (33)
Self-intermittent catheterization	3 (3)	13 (15)	11 (15)	14 (19)
Combined (spontaneous voiding+catheter)	4 (4)	14 (17)	16 (21)	12 (16)
Spontaneous voiding	17 (19)	23 (27)	20 (27)	23 (32)

[a] Intradetrusor onabotulinumtoxinA injection numbers are cumulative patients treated at each follow-up time point.

DO with DSD and especially in pDetmax of ≥40 cm H_2O during the storage phase over time if urodynamic findings and/or storage symptoms were treated according to the EAU Guidelines on Neuro-Urology.[2] Urodynamic findings at 12 months after SCI, the end of our observation period and considered as chronic phase, are in line with findings of a long-term study in SCI patients with NLUTD receiving a urodynamic-based treatment regimen.[20]

In NLUTD patients VUR can be a consequence of high filling pressures.[21] A study assessing the incidence of VUR in patients with suprasacral SCI found an overall incidence of VUR of 7.5 cases per 100 person-years, which is similar to our findings of 7% within the first year after SCI.[22] Of note is that VUR was already present in 5% of our patients at 1 month after SCI. The aforementioned study by Bywater et al detected a similar rate for VUR in the acute

Table 3. *Urodynamic Investigation Findings*

Parameter	1-Mo follow-up	3-Mo follow-up	6-Mo follow-up	12-Mo follow-up
Urodynamics performed, No. (%)	90 (93)	85 (88)	75 (77)	73 (75)
Time from SCI to UDI, median (Q1-Q3), d	30 (24-37)	85 (79-89)	175 (170-177)	365 (357-377)
Sitting position during urodynamics, No. (%)	57 (63)	61 (72)	60 (80)	58 (79)
Filling cystometry				
Any sensation, No. (%)	76 (84)	73 (86)	61 (81)	58 (79)
First sensation of filling volume, median (Q1-Q3), mL	225 (123-298)	298 (188-393)	245 (169-318)	280 (180-390)
First desire to void volume, median (Q1-Q3), mL	328 (235-468)	378 (265-500)	340 (263-450)	438 (260-515)
Strong desire to void volume, median (Q1-Q3), mL	463 (373-614)	474 (349-688)	475 (343-665)	509 (325-675)
Maximum cystometric capacity, median (Q1-Q3), mL	599 (420-725)	628 (453-805)	563 (413-795)	635 (420-825)
Compliance, median (Q1-Q3), mL/cm H_2O	71 (48-141)	90 (45-198)	72 (41-135)	75 (47-160)
DO				
Present, No. (%)	64 (71)	63 (74)	61 (81)	57 (78)
Start volume, median (Q1-Q3), mL	255 (178-445)	350 (200-455)	345 (170-450)	395 (185-490)
Maximum detrusor pressure-storage, median (Q1-Q3), cm H_2O	20 (8-39)	22 (10-36)	26 (13-44)	23 (11-34)
Pressure flow				
Detrusor sphincter dyssynergia, No. (%)	69 (77)	75 (88)	63 (84)	60 (82)
Spontaneous voiding, No, (%)	36 (40)	46 (54)	41 (55)	38 (52)
Maximum flow rate, median (Q1-Q3), mL/sec	15 (11-25)	14 (10-22)	15 (9-21)	14 (9-24)
Detrusor pressure during maximum flow rate, median (Q1-Q3), cm H_2O	43 (27-61)	34 (26-46)	31 (16-45)	32 (22-43)
Maximum detrusor pressure-voiding, median (Q1-Q3), cm H_2O	48 (27-78)	44 (27-68)	41 (23-53)	41 (31-56)
Voided volume, median (Q1-Q3), mL	260 (115-580)	275 (100-520)	300 (160-500)	300 (145-540)
Post-void residual, median (Q1-Q3), mL	200 (43-410)	225 (20-410)	200 (60-320)	215 (50-340)
Voiding profile[31,32]				
Female spontaneous voiders (excluding abdominal straining), No. (% of females)	13 (42)	13 (43)	13 (50)	7 (30)
Unobstructed	9 (69)	9 (69)	8 (62)	7 (100)
Obstructed	0 (0)	0 (0)	5 (38)	0 (0)
Male spontaneous voiders (excluding abdominal straining), No. (% of males)	20 (34)	27 (49)	21 (43)	19 (38)
Unobstructed	7 (35)	15 (56)	16 (76)	11 (58)
Equivocal	4 (20)	2 (7)	1 (5)	5 (26)
Obstructed	5 (25)	4 (15)	3 (14)	3 (16)
Autonomic dysreflexia observed, No. (%)	38 (42)	40 (47)	39 (52)	41 (56)

Abbreviations: DO, detrusor overactivity; Q, quartile; SCI, spinal cord injury; UDI, urodynamic investigation.

Table 4. *Unfavorable Urodynamic Parameters*

Parameter	Within the first year of SCI	1-Mo follow-up	3-Mo follow-up	6-Mo follow-up	12-Mo follow-up
Urodynamics performed, No. (%)	97 (100)	90 (93)	85 (88)	75 (77)	73 (75)
DO and DSD, No. (%)	85 (88)	61 (68)	63 (74)	55 (73)	52 (71)
Maximum storage detrusor pressure ≥40 cm H_2O, No. (%)	38 (39)	21 (23)	18 (21)	24 (32)	11 (15)
Filling volume when pDet = 40 mL, median (Q1-Q3)	-	505 (215-610)	525 (278-753)	398 (258-663)	300 (195-500)
Bladder compliance <20 mL/cm H_2O, No. (%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Videourodynamics performed, No. (%)	96 (99)	88 (98)	76 (89)	67 (89)	68 (93)
Vesicoureteral reflux, No. (%)[a]	7 (7)	4 (5)	5 (7)	2 (3)	2 (3)
At least 1 unfavorable parameter, No. (%)	87 (90)	65 (72)	67 (79)	61 (81)	55 (75)

Abbreviations: DO, detrusor overactivity; DSD, detrusor sphincter dyssynergia; pDET, detrusor pressure; Q, quartile; SCI, spinal cord injury.
[a] Vesicoureteral reflux grade: 1 month, 4 grade I; 3 months, 1 grade I, 3 grade II, 1 grade III; 6 months, 1 grade II, 1 grade III; 12 months: 2 grade I.

phase.[11] As there are no data on the prevalence of asymptomatic VUR in the adult population available we cannot infer whether VUR was preexistent or a short-term consequence of high pDetmax and indwelling urethral catheterization, both identified as predictive factors for VUR.[22] In our patients the prevalence of VUR decreased over time, which can be interpreted as a result of lowering pDetmax by use of antimuscarinic medication or intradetrusor onabotulinumtoxinA injections.

The prevalence of low-compliance bladder in the SCI population was found to be about 17% in long-term follow-up studies.[7] Our data indicate that the development of a low-compliance bladder in the first year after SCI might be prevented by urodynamic-based treatments.

AD is a potentially life-threatening condition following SCI that can be precipitated by noxious (eg, pain) or non-noxious stimuli (eg, bladder filling) below the level of injury.[15] Though the common notion is that AD occurs in patients with SCI at or above T6, AD can also occur with lesion levels below T6. A large prospective cohort study with 300 SCI patients showed that 32% of patients with AD had a lesion below T6.[23] We also saw AD in a high percentage (42%) of patients with lesions below T6. While AD may occur in the early phase, a majority of cases first present at 3-6 months after SCI.[24] Our findings with an increase of AD prevalence over time reflect this previously reported temporal development.[24]

Implications

The overall aim for the management of SCI patients during the first year after SCI is to identify and minimize risk factors for urological morbidity to improve long-term outcomes and consequently health-related quality of life. Therefore, ensuring efficient bladder emptying without abdominal straining or reflexive voiding and with low post-void residuals is essential.[8]

Another cornerstone of urological management during the first year after SCI should be the timely identification of unfavorable urodynamic parameters and consequent initiation of antimuscarinic therapy as first-line option whenever necessary to maintain safe urine storage. Though over the last decades research identified urodynamic parameters which are associated with long-term urological complications[4-7,9,10] guidelines and recommendations on the timing and frequency of UDI follow-up after SCI are vague. There is consensus that a UDI should be performed as a baseline assessment of LUT function but there are no clear recommendations regarding either the time point for the first UDI or the frequency for UDIs during the first year after SCI. UDI follow-ups should rather orientate on signs or symptoms or the onset of new complications.[2,12] However, studies could demonstrate that clinical symptoms have limited reliability in the SCI population[3] and even in the absence of neurological changes a thorough evaluation of the LUT by UDI can reveal urodynamic findings that require a change in urological management.[25] Considering that we observed a high prevalence of unfavorable urodynamic parameters within the first year after SCI and early diagnosis and proactive treatment initiation might improve long-term urological outcomes, it seems reasonable to implement a standardized UDI follow-up schedule for the first year after SCI in clinical practice.

Research

There is considerable interest in preventing the development of NLUTD after SCI. In animal studies early medication,[26] neuromodulative therapy,[27] and intradetrusor onabotulinumtoxinA injections[28] could positively modify long-term urinary tract function after SCI. Currently registered clinical trials aim to evaluate the effect of early transcutaneous tibial nerve stimulation (ClinicalTrials.gov NCT03965299)[29] or early sacral neuromodulation (ClinicalTrials.gov NCT03083366)[30] on the prevention of urological complications and the preservation of UUT and LUT function.

Facing a continuous rise in health care expenditures, early and tailored intervention based on urodynamic findings instead of waiting for irreversible complications of NLUTD could potentially spare

resources and reduce overall costs. Furthermore, there is debate on the UDI reimbursement by insurance companies. Therefore, further research on the development of unfavorable urodynamic parameters and recommendations on a UDI follow-up schedule within the first year after SCI are highly warranted.

Strengths and Limitations

To the best of our knowledge, this is the first study to use a standardized UDI follow-up schedule to describe the prevalence of unfavorable urodynamic findings during the first year after SCI. The population-based sampling frame and a good participation rate are strengths of this study. However, we cannot reliably infer for the 23% of the population that did not provide consent. Moreover, our department is part of a specialized university SCI center, thus selection towards more severe cases cannot be ruled out and transportation of the findings to other settings should be undertaken with caution. Additionally, missed UDI and attrition are linked to age, limiting the generalizability of inference for the oldest age groups, but they do not seem to be strongly related to other patient or SCI characteristics. Furthermore, our study population received neuro-urological treatment guided by urodynamic findings so while it reflects the outcomes that are observed in routine clinical practice, the impact of early versus late treatment could not be addressed.

CONCLUSIONS

Using a standardized UDI follow-up schedule, we found that 90% of the patients after acute SCI showed at least 1 unfavorable urodynamic parameter within the first year, and almost 40% of the patients had a pDetmax of $\geq$40 cm H_2O during the storage phase. As early treatment based on urodynamic findings might decrease the risk of deterioration of UUT and LUT function and subsequently improve long-term patient outcomes and reduce overall costs, there is need for further research regarding the development of unfavorable urodynamic parameters and recommendations for a UDI follow-up schedule during the first year after SCI.

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