



Original Article

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Sensations Reported During Urodynamic Bladder Filling in Spinal Cord Injury Patients Give Additional Important Information

Jean-Jacques Wyndaele¹, Michel Wyndaele², Peter F.W.M. Rosier²

¹Faculty GGW, University of Antwerp, Brasschaat, Belgium

²Department of Urology, University Medical Center Utrecht, Utrecht, The Netherlands

Purpose: This study investigated the sensations reported during filling cystometry in patients with spinal cord lesions (SCLs) of different levels and completeness.

Methods: In this retrospective cohort study, information was gathered on patients' age and sex, cause of SCL, American Spinal Injury Association Impairment Scale (AIS), and lower urinary tract-related sensations in daily life. Filling cystometry (video-urodynamics) was performed following the International Continence Society Good Urodynamic Practice Guidelines. In addition to bladder filling sensations (first sensation of bladder filling, first desire to void, strong desire to void), other sensations, such as detrusor overactivity related sensation and pain, were noted.

Results: In total, 170 patients were included (age, 45 ± 17 years; 114 males and 56 females, 92 with complete and 78 with incomplete SCL). The test was done 6 ± 4 years post-SCL. Sensation was reported by 57% of all patients. Half of the patients with complete SCL (46 of 92) had sensation, while 36% of those with incomplete SCL (28 of 78) reported no sensation. Bladder awareness was not predictable by the AIS. The filling sensations reported were equivalent to those given in the terminology of ICS. Pain was seldom present (6%, 10 of 170), and detrusor overactivity contraction was felt by 45 of 78 (58%). Very few patients used sensory information for bladder management at home.

Conclusions: After SCL, most patients retained the ability to be aware of the lower urinary tract, and were assessable and gradable during urodynamic testing. The filling sensations were not different from those described in healthy individuals, but the number and sequence of the sensations were altered in a minority of patients. Pain and a sensation of unstable contractions gave additional important information. As different sensations relate to different spinal afferent pathways, the sensory evaluation during cystometry provided additional important information on the spinal cord's condition.


Keywords: Bladder sensation; Filling cystometry; Spinal cord lesion; Sensory pathways

- **Research Ethics:** This study was approved by Institutional Review Board (IRB) of Antwerp University Hospital (IRB No. 001176).
- **Conflict of Interest:** No potential conflict of interest relevant to this article was reported.

INTRODUCTION

The lower urinary tract (LUT) has extensive peripheral innervation that transfers afferent information from its different

parts to the spinal cord and brain [1]. The International Continence Society (ICS) and the International Urodynamic Basic Spinal Cord Injury Data Set have standardized terminology on sensations of bladder filling [2-4]: the first sensation of bladder

Corresponding author: Jean-Jacques Wyndaele  <https://orcid.org/0000-0002-0879-6854>
Faculty GGW, University Antwerp, Bredabaan 32 2930 Brasschaat Belgium
Email: Wyndaelej@skynet.be

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filling (FSF) is the feeling when the individual first becomes aware of bladder filling; first desire to void (FDV) is the first feeling that the individual may want to pass urine at the next convenient moment, but this can be delayed if necessary; and strong desire to void (SDV) is the persistent desire to void without the fear of leakage.

Other sensations during bladder filling include pain (an intense uncomfortable sensation in the lower abdomen/bladder) and the sensation of contractions during detrusor overactivity (DOA) (e.g., urgency or a rapid sensation of pressure). Each of these sensations is triggered by a different mechanism (stretch vs. nociceptive stimulation vs. pressure), originating from different sites in the LUT, conducted through different types of nerve fibers (A-delta or C-fibers), different peripheral nerves, and different spinal cord pathways [5].

After a spinal cord lesion (SCL), LUT dysfunction will develop in approximately 90% of patients [6], and the pathophysiology depends on the lesion's level and completeness. Bladder proprioception is likely to be lost in traumatic and nontraumatic SCL affecting the dorsal tracts. However, clinical observations have indicated that the bladder filling sensation may depend on afferent potentials transported via other routes than those involved in classical detrusor stretch proprioception. Non-bladder-related awareness, as occurs with autonomic dysreflexia (AD), was not investigated in this paper.

LUT dysfunction is among the most dangerous hazards in SCL patients, causing a high rate of readmissions and a substantial negative impact on the prognosis and the quality of life [7]. To fully understand the impact of SCL on LUT function, information on the remaining sensory function is essential. We evaluated the bladder sensations reported during filling cystometry in a cohort of SCL patients. Our study aimed to explore sensory types and prevalence, as well as to study the clinical value of bladder filling-related sensory information in patients with SCL

MATERIALS AND METHODS

We present a retrospective cohort analysis of patients with chronic SCL who underwent video-urodynamics (VUD) during 2 consecutive years.

Patients' age and sex, time since SCL, the cause and level of SCL, the American Spinal Injury Association Impairment Scale (AIS) score, the method of bladder emptying, and LUT-related sensations in daily life were collected from the records. Previous

diseases of the urinary tract and drug intake were noted. The exclusion criteria were fever, signs/symptoms suggestive of urinary tract infection (UTI), hematuria, inflammation in the pelvic region, refractory AD, and insufficient patient cooperation and cognitive function as evaluated by the clinician [8].

VUD was performed following the Good Urodynamic Practice Guidelines of ICS [9], either as part of routine follow-up or prompted by a change in symptoms. Five-channel urodynamic equipment was used (Medical Measurement Systems, Gladbeck, Germany). Filling cystometry was done through a transurethral 8F double-lumen catheter connected to an external transducer. A radiocontrast solution (Urografin 30%; Schering AG, Berlin, Germany) at room temperature was used to fill the bladder at a continuous flow rate of 30 mL/min (infusion pump) and with the filling bag hanging from a load cell [9]. Patients were asked to report and describe all sensations between the start and end of bladder filling. The filling was stopped at a maximum capacity of 550 mL (volume of the infusion bottle, excluding diuresis) if no or little bladder pressure developed. The filling was stopped earlier if neurogenic DOA (NDOA) occurred with leakage, if detrusor pressure consistently rose above 40 cm H₂O, if the patient reported a strong desire to void, or if pain occurred.

The sensations of bladder filling were categorized as FSF, FDV, SDV [4], and pain or DOA sensation (DOAS). Patterns were classified as the absence of a sensation, the presence of 1 type of filling sensation, or any combination of 2 or more sensations. An investigator was present during the entire cystometry process, making it possible to ask additional questions to define further or specify the reported sensations if needed.

After the urodynamic test, cystoscopy was done in all patients, as per our standard of care, and renal ultrasonography was performed in 114 patients. One sachet of fosfomycin (3 g) was given after the test to prevent UTI.

The statistical analysis was carried out with IBM SPSS Statistics ver. 27.0 (IBM Co., Armonk, NY, USA), using the chi-square test for categorical variables and 1-way analysis of variance (ANOVA) for continuous variables. Statistical significance was set at $P < 0.05$.

RESULTS

Fifteen patients met the exclusion criteria, which left 170 patients to be included (age, 45 ± 17 years, 114 males and 56 females). The time since SCL was 6 ± 4 years. The indication for

Table 1. Cause of spinal cord lesion

Cause of spinal cord lesion	No. of patients
Road traffic accident	73
Fall	34
Sports	14
Infection	11
Vascular	6
Spine surgery	15
Myelopathy	4
Tumor	5
Work accident	6
Disc herniation	1
Gun shot	1
Total	170

filling cystometry was routine follow-up in 109 patients and an evaluation due to changes in urological and other conditions in 55 patients. The indication was missing for 6 patients. The distributions of cause, level, and completeness of SCL, as well as the method of bladder emptying, are provided in Tables 1–3.

Table 4 presents an overview of bladder sensations during filling cystometry in patients with different levels and completeness of SCL, the types of sensations reported, and the eventual combinations. The numbers of filling sensations are given as 1 to 3, but these numbers do not necessarily correspond to FSF, FDV, and SDV, as explained below. No sensation was reported by 43.5% (74 of 170) of patients, while 33.5% (57 of 170) reported more than 1 sensation. Fifty percent (46 of 92) of patients with complete (AIS A) SCL and 36% (28 of 78) of those with incomplete (AIS B–D) SCL reported no sensation. The sensation patterns were not related to maximum cystometric capacity ($P=0.115$) or to bladder compliance from the start to the end of filling except DOA contractions ($P=0.406$).

When only 1 sensation of bladder filling was reported ($n=36$ —with or without pain or DOA) this was described as FSF by 31 patients (86%), FDV by 3 patients, and SDV by 2 patients. When 2 sensations of bladder filling were reported ($n=22$ —with or without pain or DOA), this was described as FSF+FDV by 21 patients and FSF+SDV by 1 patient.

No difference was found between groups with 1, 2, or 3 bladder filling sensations (without pain or DOA) for volume and detrusor pressure at FSF, FDV, and SDV (Table 5). Both volume and detrusor pressure increased significantly between the consecutive sensations (ANOVA $P<0.001$) and were not signifi-

Table 2. Level and completeness of SCL

AIS score completeness	Spinal cord level	Number
AIS A (complete)	C1–C8	31
	T1–T9	39
	T10–L1	16
	L2–S3	3
	Cauda	3
AIS B-D (incomplete)	C1–C8	38
	T1–T9	14
	T10–L1	13
	L2–S3	9
	Cauda	4
Total		170

AIS, American Spinal Injury Association Impairment Scale.

Table 3. Method of bladder emptying

Method	No. of patients
Clean intermittent catheterization	68
Indwelling transurethral catheter	54
Suprapubic catheter	15
Suprapubic tapping	40
Crede/Valsalva	3
Normal voiding	19
Complete incontinence	1
Total	170

cantly different among patients with different levels and completeness of SCL (P -values between 0.105 and 0.992) (detailed data not shown).

DOA was present in 78 patients, and contractions were felt by 45 (58%). The mean volume and pressure at which the DOAS was reported were 188 ± 132 mL and 55 ± 38 cm H₂O, respectively. A filling sensation was present in 54 of 78 patients with DOA and in 34 of 71 patients without DOA (chi-square $P=0.006$). A filling sensation was more likely to be reported in the absence of DOAS (chi-square $P=0.008$).

Pain during cystometry was reported by 10 patients (6%). Subsequent urethrocystoscopy revealed pathological findings in 5 cases: severe inflammation from the indwelling catheter in 1 case, bladder stones in 3 cases, and a polyp behind the trigone in 1 case. In the other 5 cases, cystoscopy indicated no abnormalities. Pathological findings on cystoscopy were also present in 40.5% (30 of 74) of patients with a complete absence of sen-

Table 4. Overview of bladder sensations during filling cystometry in different level and completeness of spinal cord lesion and eventual combinations

Bladder sensation	AIS A					AIS B-D					Total
	C1-C8	T1-T9	T10-L1	L2-S3	Cauda	C1-C8	T1-T9	T10-L1	L2-S3	Cauda	
Absent	18	19	6	2	1	13	3	7	3	2	74
Pain only	0	1	0	0	0	1	0	1	1	0	4
1 Sensation of bladder filling	2	6	5	1	0	6	4	1	1	0	26
2 Sensations of bladder filling	2	3	0	0	1	5	2	0	0	0	13
3 Sensations of bladder filling	1	2	1	0	1	3	2	2	1	0	13
DOAS	3	2	0	0	0	4	0	0	0	0	9
1 Sensation of bladder filling + DOAS	1	1	2	0	0	1	1	1	0	0	7
2 Sensations of bladder filling + DOAS	2	0	0	0	0	3	0	1	1	0	7
3 Sensations of bladder filling + DOAS	1	3	2	0	0	3	1	0	1	0	11
1 Sensation of bladder filling + pain	0	1	0	0	0	0	0	0	0	2	3
2 Sensations of bladder filling + pain	1	0	0	0	0	0	0	0	1	0	2
3 Sensations of bladder filling + pain	0	1	0	0	0	0	0	0	0	0	1
Total	31	39	16	3	3	39	13	13	9	4	170

DOAS, sensation of detrusor overactive contraction; The numbers of sensations of filling is given as 1 to 3, not necessarily corresponding with the First sensation of filling, First desire to void, Strong desire to void sequence. AIS= American Spinal Injury Association Impairment Scale (AIS), A represents a complete lesion, B-D different types of sensory and/or motor incomplete lesions. Chi-square $p=0.045$.

Table 5. Volume and pressure at the different sensations of bladder fullness in patients

Volume & pressure	Sensations of bladder fullness during cystometric bladder filling				P-value (ANOVA)
	1 Sensation	2 Sensations	3 Sensations	Mean	
FSF volume (mL)	214 ± 108	204 ± 90	221 ± 136	214 ± 113	0.871
FSF pressure (cm H ₂ O)	25 ± 26	26 ± 19	20 ± 18	23 ± 21	0.584
FDV volume (mL)	323 ± 45	283 ± 116	265 ± 121	276 ± 115	0.670
FDV pressure (cm H ₂ O)	-	32 ± 22	24 ± 17	28 ± 19	1.185
SDV volume (mL)	310 ± 199	250	325 ± 129	313.2 ± 133	0.334
SDV pressure (cm H ₂ O)	-	-	-	33 ± 26	NA
P-value					<0.001

Values are presented as mean ± standard deviation.

ANOVA, analysis of variance; FSF, first sensation of bladder filling; FDV, first desire to void; SDV, strong desire to void; NA, not available.

The number of sensations reported are given and the type of sensation to which this number corresponded.

sation during bladder filling, and in 39.5% (38 of 96) of patients with sensation during bladder filling but without pain ($P=0.625$).

Five patients reported a sensation of bladder fullness in daily life, 2 reported pain, and 5 reported urgency. A urodynamic filling sensation was present, respectively, in 2, 1, and 2 patients. Five of these 12 patients used this sensory information to guide bladder emptying in daily life, 2 for clean intermittent catheterization, and 3 for normal voiding, corresponding to only 3% of the study group.

Consecutive filling sensations in patients with a cauda and conus lesion were perceived at volumes of 294 ± 49.5 , 346 ± 9.2 , and 362 mL, and at pressures of 52 ± 7.7 , 21 ± 14 , and 32 cm H₂O, respectively. These were not significantly different from the volume and pressure values recorded for patients with SCL at other levels ($P=0.309-0.988$).

Renal ultrasonography showed changes in 19 of 114 patients (minor pyelocaliceal dilatation in 11, hydronephrosis in 3, renal cysts in 2, renal atrophy in 2, and signs of previous pyelonephri-

tis in 1), of whom 7 had a filling sensation and 12 did not ($P=0.263$).

DISCUSSION

The sensory innervation of the LUT is complex and involves autonomic and somatosensory peripheral nerves running to the lower parts of the spinal cord and ascending to the brainstem and the cortex. There is increasing knowledge of the bladder wall mechanisms involved in capturing local changes as stretches of the wall, pressure, nociceptive impulses, and the different nervous pathways used to transfer this information upwards [10-12]. However, the mechanisms through which interacting receptors and pathways create sensations during bladder filling remain to be fully elucidated [13]. It is relevant to recognize that the bladder afferent system has diverse pathways, and that it is plausible to distinguish between afferent activity and sensory information and to include a central interpretation when reported sensations are explored [14]. Bladder emptying based on LUT sensations is a process under cognitive control, influenced by multiple elements, of which bladder awareness is one [15].

SCL induces neurogenic bladder dysfunction in most patients and poses a significant threat if the sensation of a full bladder or overactive detrusor contractions remains unnoticed while high detrusor pressures develop.

SCL causes important changes in afferent innervation, beyond the lesion itself during and after the spinal shock phase: plasticity in bladder C-fiber afferent nerves have been shown in animals and humans [16]. The mechanisms generating awareness may be intensified or lost after SCL.

The spinal cord pathways for LUT sensory impulses have been well described, but it remains uncertain which peripheral nerves conduct each specific filling sensation [5,17]. Considering the topography of different nerves, it seems likely that a specific filling sensation may be carried by more than 1 type of peripheral nerve. Knowledge of spinal cord pathways is more extensive: the fasciculi gracili conduct signals caused by stretching (bladder filling), the anterior spinothalamic tracts transmit afferent stimuli from contractions, and the lateral spinothalamic tracts conduct noxious stimuli as pain [18]. An SCL may entirely or partially destroy 1 or more sensory pathways. Evaluating the sensations reported during cystometry can help determine which spinal pathways are most probably still active/intact and which are not. This needs further confirmation, but

could potentially aid in a more detailed/accurate classification of SCL patients.

In our cohort of patients with different levels and completeness of SCL, most patients reported bladder sensations during filling cystometry. Remarkably, half of those with a complete SCL (AIS A) reported at least 1 bladder sensation, confirming that the somatomotor typing (AIS score) underevaluates the sensation of the LUT perceived by the patient [19]. The types of filling sensations and their sequence were mostly the same as given in the terminology reports. It has been documented that the different sensations of bladder filling are recognized by patients with SCL without great difficulty, as they represent what was familiar before the lesion. They are reproducible and are communicated to the investigator without difficulty [20]. In the present cohort, roughly a quarter (25 of 96) of patients with preserved sensation reported all 3 (standard) consecutive sensations of bladder filling, while the others showed different combinations of 1 or 2 sensations. Such different patterns of sensation after SCL have been described before [20]. Our findings agree with those of previous studies suggesting that after an SCL, qualitative and quantitative changes occur in bladder sensations compared to what had been felt before the lesion [21]. We found no significant difference between volumes or detrusor pressure in different patterns of sensation of bladder filling. Our data also do not confirm that the sensations of patients with complete cauda and conus lesions are only perceivable at a very high volume threshold.

A previous study in a cohort of patients with nontraumatic spinal cord myelopathy showed that 46% voided guided by sensations of bladder filling [22]. Another study with ambulatory urodynamics in patients with SCL described that 73% reported bladder sensation daily, and 41% experienced DOA [23]. Only a minority of patients reported LUT sensations in daily life in our study, and few used this information at home to guide their bladder emptying (7%, 12 of 170). A reason may be that no attention was given to these sensations during rehabilitation.

Reitz [21] found that in patients with a complete cauda or lower conus lesion, sensory input from the bladder was preserved, while all sensation was absent in patients with AIS A lesions below T6 and above T12. Furthermore, Ersoz and Akyuz [24] found that sensation was preserved in twice as many patients with a complete lesion under T10 compared with patients with a complete lesion below T11. These findings imply that in such cases, sensation during bladder filling is probably transferred through the intact hypogastric plexus to the thoracolum-

bar spinal cord. In our study, 48% of patients with a complete lesion above the thoracic-lumbar level reported sensation, compared to 58% with a complete lesion under this level. This finding shows that in AIS-complete SCL above the inflow level of the hypogastric plexus, sensory nervous pathways may continue to function [25].

Ersöz and Akyuz [24] found clinical value in using sensations to guide bladder emptying, and Ersöz and Sayılır [26] found that preserving the sensation of bladder filling had a preventive effect on upper urinary tract deterioration in chronic SCL patients. In our cohort, pathology of the upper urinary tract was found on renal ultrasonography in 11% of patients, with no statistically significant difference between those with and without sensation during bladder filling. Therefore, more factors should probably be considered, such as the method of bladder emptying, UTI, reflux, intravesical pressure development, and drug intake.

Data on emptying and incontinence volumes and/or medication use were not included in the present study due to its retrospective nature and its specific scope and aim.

SCL can produce NDOA due to reorganization from a spinobulbospinal loop to a predominantly spinal network [27]. It was shown that DOA could be felt by half of nonneurogenic patients [28]. In our cohort, 42% of SCL patients with DOA felt a contraction. Pathological patterns of bladder filling sensation were found more frequently in those who had no DOAS, confirming that more severe spinal cord pathology exists when DOA contractions are not felt [28].

Pain during cystometry does not often occur in patients with SCL (6% in our population), but most clinicians would consider pain as a warning sign to investigate further possibilities, such as UTI (excluded in this study), stones, catheter-induced irritation, and other conditions. In our study, pathological outcomes of cystoscopy were noted in 44% and 41% of patients with an absence of pain and absence of overall sensation, respectively, indicating that pathology in the LUT often does not induce pain during cystometry in SCL patients.

The role of bladder sensations in the urological management of patients with SCL is currently minimal, both in diagnosis and in treatment. Increasing the use of bladder sensations in diagnosis and using urodynamics as biofeedback for patients in relation to their usual emptying routine (if intermittent) would be easy and worthwhile, as this sensory information conveys a substantial amount of information related to LUT innervation, bladder activity, and possible complications.

The most frequently used technique to empty the bladder, intermittent catheterization, is mostly performed on a schedule, although systems have been explored to better link bladder fullness and time to empty [29]. If bladder filling sensations were used, this would theoretically permit more than half of the patients to schedule catheterizations when a physiological need is present. In patients with continuous leakage or an indwelling (transurethral or suprapubic) catheter, sensation plays no apparent role in bladder emptying management.

Regarding limitations of this study, many of the patients in our cohort used antimuscarinic, spasmolytic, or analgetic drugs, and some previously had botulinum toxin injections in the bladder. The 1-time measurement made in the present study did not permit an analysis of the influence of these factors on filling sensations in the short and long term. Furthermore, we had no detailed information on the brain function, but the investigator subjectively assessed cognitive problems and lack of patient compliance, and the presence of these issues served as a contraindication for participation in this study. Another limitation of this study is that it is a retrospective study based on medical records. However, there were few missing data, and all available data were obtained from standardized urodynamic tests with identical questions about sensations in a high-volume setting. As stated before for urodynamics in general, more research is also needed on the sensory component of function [30]. Examples of urodynamic curves with sensation patterns can be found in the textbook *Urodynamic Testing after SCI: A Practical Guide* [8].

In conclusion, as the spinal cord pathways responsible for different LUT sensations are grossly known, sensations reported during cystometry may indicate the presence or absence of these pathways. There is a need for further research on the preservation, reoccurrence, and neurological rerouting of LUT sensations in combination with an in-depth analysis of the type of sensations and awareness reported after SCL, as well as the possible applications and implications for diagnosis and bladder management. Our data confirm that some sensation or awareness from the LUT after SCL is preserved or reoccurs more often than previously reported. The findings of the present study also show that the filling sensations described in the terminology reports are present after SCL. Pain and DOAS provide additional information about spinal cord pathways.

AUTHOR CONTRIBUTION STATEMENT

- Conceptualization: *JW*
- Data curation: *JW*
- Formal analysis: *JW*
- Methodology: *JW*
- Project administration: *JW*
- Writing-original draft: *JW*
- Writing-review & editing: *JW, MW, PFWMR*

ORCID

Jean-Jacques Wyndaele	0000-0002-0879-6854
Michel Wyndaele	0000-0003-1757-2569
Peter F.W.M. Rosier	0000-0003-0445-4563

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