

## ARTICLE



# What do X-ray images of the bladder during video urodynamics show us in patients with spinal cord injury?

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**STUDY DESIGN:** Retrospective anonymized cohort study.

**OBJECTIVES:** To study X-ray images of video urodynamics (VUD) in patients with spinal cord injury (SCI).

**SETTING:** Single-center study.

**METHODS:** X-ray images during VUD were categorized. Relation with the American Spinal Injury Association Impairment Scale (AIS), time since and level of SCI, cystometric data, method of bladder management, findings of flexible cystoscopy, and renal ultrasound were evaluated. Changes over time were studied.

**RESULTS:** In 231 consecutive patients, VUD was done at a mean of 8.5 years after SCI. X3-ray bladder appearance was categorized as normal/standard, tonic, or flaccid. In 19 patients, specific findings were seen: diverticula, cystocele, vesicoureteral reflux. X-ray images differed by maximum cystometric capacity, presence of neurogenic detrusor overactivity, and maximum detrusor pressure during detrusor overactivity, but not by bladder compliance. There was no difference in the categories found in different levels and completeness of SCI. In the 23 patients able to void no pathology was seen on urethral images. Renal ultrasound was normal in >99%. In 86 patients, repeated testing after  $72 \pm 143$  weeks showed changed findings in 30%. Cystoscopy showed significantly more local pathologies.

**CONCLUSION:** Complications in the lower urinary tract were seen on imaging only in a limited number of our cohort. As our findings represent a real-life example of the actual yield of VUD in patients with neurogenic bladder due to SCI treated following the international guidelines, further multicentre evaluation is needed to determine when imaging should be used or not.

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## INTRODUCTION

Cystometry is widely used for the evaluation of lower urinary tract (LUT) function in many indications. Video urodynamics (VUD), which is the combination of cystometry with contrast fluid filling and X-ray imaging, is considered the optimum procedure for urodynamic investigation in neuro-urological disorders [1] including spinal cord injury (SCI) [2]. Radiographical observations during cystometry may affect the interpretation of pressure measurements. For example, the pop-off of bladder pressure by vesicoureteral reflux may lead to underestimation of bladder compliance. Concomitant radiography also allows diagnosis and follow-up over time of aberrant LUT morphology or function, such as bladder diverticula or bladder neck insufficiency. The variables and instructions for data collection of imaging in patients with SCI have been published in the International Urinary Tract Imaging Basic SCI Data set [3]. Despite the strong support in expert opinion and guidelines, and the accepted benefit it provides to the interpretation of cystometry, determining the real-life clinical value of VUD today could benefit from further research.

In this study, we retrospectively evaluated the radiographical observations during VUD in a cohort of SCI patients with neurogenic bladder. We categorized the images and investigated their presence in different types of SCI and in different clinical and

urodynamic diagnoses. Finally, we evaluated the change in radiographical findings over time. Our aim was to gather real-life data and to describe the yield of radiography during urodynamics in a cohort of SCI patients as indicated by current guidelines.

## METHODS

VUD data from consecutive patients with neurogenic bladder due to SCI were evaluated retrospectively. Patient age and sex, time since SCI, etiology of SCI, level of SCI, the neurological status determined according to the ASIA/ISCoS International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) and American Spinal Injury Association Impairment Scale (AIS) score, method of bladder emptying, and treatment with bladder relaxing drugs were collected from the records.

VUD were performed according to a standardized protocol following the ICS guidelines on urodynamic equipment performance and ICS guidelines on good clinical practice [4, 5]. The standard evaluation for neuro-urological patients in our center also includes strict decubitus prevention, clinical neurological examination, renal ultrasound, and flexible cystoscopy. The patients were in the supine or half-sitting position between a C-arm X-ray unit (Ziehm 8000 Germany). Five-channel urodynamic equipment was used (Medical Measurement Systems, Gladbeck, Germany). The bladder was filled with a radiocontrast solution (Urografin 30%-Schering AG, Berlin, Germany) at room temperature through a transurethral 8Fr water-filled double lumen catheter connected to an external transducer,

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and at a continuous inflow rate of 30 ml/min (infusion pump), with the filling bag hanging at a load cell. The filling was stopped at 500 ml or earlier if neurogenic detrusor overactivity (NDO) occurred with leakage, if persistent leakage was seen without detrusor contraction, if detrusor pressure consistently rose above 40 cm H<sub>2</sub>O, if the patient reported a strong desire to void, or if pain or autonomic dysreflexia occurred. Video images were taken before starting with an empty bladder, when sensations of bladder filling occurred, at each consecutive 200 ml of filling if no sensation was reported, at the end of the test, when sustained leakage and/or detrusor overactivity occurred, and during voiding (if applicable). After VUD, all patients received one-time antibiotic prophylaxis with Fosfomycin 3 g.

The radiation exposure was recorded in every patient and every clinician, and data were reviewed by the radiation committee of the hospital following the National Law of 30 August 2001 on protection against ionizing radiation for education, information, equipment, and control. The aim was to keep the total radiation exposure below 0.5 mSv and the fluoroscopic exposure time under 100 s. In patients with known radiocontrast allergy, VUD was not performed and the patient was not included in this study. Further exclusion criteria were symptomatic urinary tract infection, difficulties to control autonomic dysreflexia, insufficient patient cooperation and/or cognitive function, hematuria, pain, and inflammation in the pelvic region ( $n = 26$ ) [6].

Radiographical observations of the bladder were categorized based on expert opinion as normal/standard, tonic (pinecone/Christmas tree), or flaccid. Cartoon drawings for clarification are presented in Fig. 1. The nomenclature and categories were based on (our) expert opinion as there is currently no ICS terminology describing cystographic observations during urodynamics. Other findings such as vesicoureteral reflux, bladder diverticula, cystocele, the image of enterocystoplasty, an open bladder neck during filling, and the presence of foreign material were recorded. If voiding was possible or if sustained leakage filled the urethra, urethrography images were also included in the evaluation.

The time since SCI was categorized into: the period of spinal shock and of first rehabilitation (till 26 weeks in our management schedule), the period of continued rehabilitation until discharge (between 26 and mean 78 weeks), and the period of chronic follow-up (after discharge). The etiology of SCI was classified as traumatic or non-traumatic. The findings on renal ultrasound and during flexible cystoscopy were also described.

Ethical approval was obtained from the local review board (Edge number 001176).

Statistical analysis was done with SPSS26. Continuous variables are expressed as mean  $\pm$  standard deviation. Chi-Square was used for categorical data and nonparametric Kruskal–Wallis for continuous data. Statistical significance was set at  $p < 0.05$ .

## RESULTS

Two hundred thirty-one patients with SCI (159 men and 72 women), with a mean age of 49 years ( $\pm 17$  years, Range 11–88 years) were included in the study. Mean time since injury was 437 weeks ( $\pm 599$  weeks). The etiology of SCI was traumatic in 191 (83%) patients and non-traumatic in 40 (17%). AIS scores and SCI level are presented in Table 1: 72% had cervical or thoracic lesion above T10, and 61% of patients had a complete injury (AIS A).

The radiographical observations during VUD are presented in Table 2: in 34% of patients, the radiography was not categorized as normal/standard. The bladder neck was clearly open in only one patient, a 21-year-old man with a complete C4 lesion after a gunshot wound. His bladder image was categorized as normal/standard and he had no NDO on VUD.

The categories of radiographical observations did not differ by AIS score ( $p = 0.759$ ). Vesicoureteral reflux was found in two patients at 6 and 9 weeks after SCI, but of low grade and disappearing on a subsequent test after bladder management was changed from an indwelling catheter to CIC. A tonic bladder image was seen as early as eight weeks after SCI. Diverticula on the other hand were only seen in patients on long-term follow-up.

There was no significant association between bladder compliance and radiographical category ( $p = 0.259$ ). Maximum cystometric capacity was significantly lower in bladder images categorized as tonic and with diverticula compared to normal/standard and flaccid

classified bladders (tonic 284 ml  $\pm$  126, diverticula 229 ml  $\pm$  148, normal/standard mean 367 ml  $\pm$  132, flaccid 495 ml  $\pm$  115).  $P < 0.05$ . The presence of NDO differed significantly between patients with different radiographical bladder categories ( $p < 0.001$ ): it was present in 80% (40/50) of patients with a tonic categorized bladder, but also in 30% (3/10) with a flaccid categorized bladder and in 48% (73/152) with a normal/standard categorized bladder. NDO was also found in 5/5 (100%) patients with diverticula, while in 1/4 (25%) patients with enterocystoplasty undulations with high pressure were seen. NDO was not seen in patients with cystocele, reflux, or the patient with a ureteric catheter. Maximum detrusor pressure during filling above 40 cm H<sub>2</sub>O was also associated with radiographical bladder category ( $p = 0.016$ ): it was present in 24% (12/50) of patients categorized as having a tonic bladder image, 10% (1/10) with flaccid, 11% (16/152) with normal/standard categorized bladder, and in 80% (4/5) of patients with diverticula.

Table 3 shows that 78% of patients had catheter-assisted bladder emptying, either by performing clean intermittent catheterization (CIC–43%) or through an indwelling transurethral (27%) or suprapubic catheter (9%). These patients were often categorized as having a normal/standardized radiographical bladder image (69%, 71%, 68%, and 65%, respectively), and as having a tonic bladder in 19%, 17%, 26%, and 26%, respectively. Three out of four patients with diverticula used tapping as the means to empty the bladder, whereas only one out of five patients with a cystocele emptied the bladder using Crede/Valsalva. Eleven percent of patients used standard voiding. Vesicoureteral reflux was found in four patients, of which three had a transurethral catheter. As mentioned above, the finding disappeared in two patients after switching to CIC.

Renal ultrasound revealed a pathological finding in only two patients: one had limited hydronephrosis and another a shrunken kidney on the right side. Cystoscopy findings are presented in Table 4 (161 patients). Forty-six patients with radiographically classified normal/standard bladders had aberrant findings on cystoscopy. “Eggshell” bladder stones were found on cystoscopy in 20, whereas none had been seen on plain X-ray. Diverticula were found in twice as many patients on cystoscopy than seen during VUD, and trabeculation is also underestimated when evaluated by cystography alone.

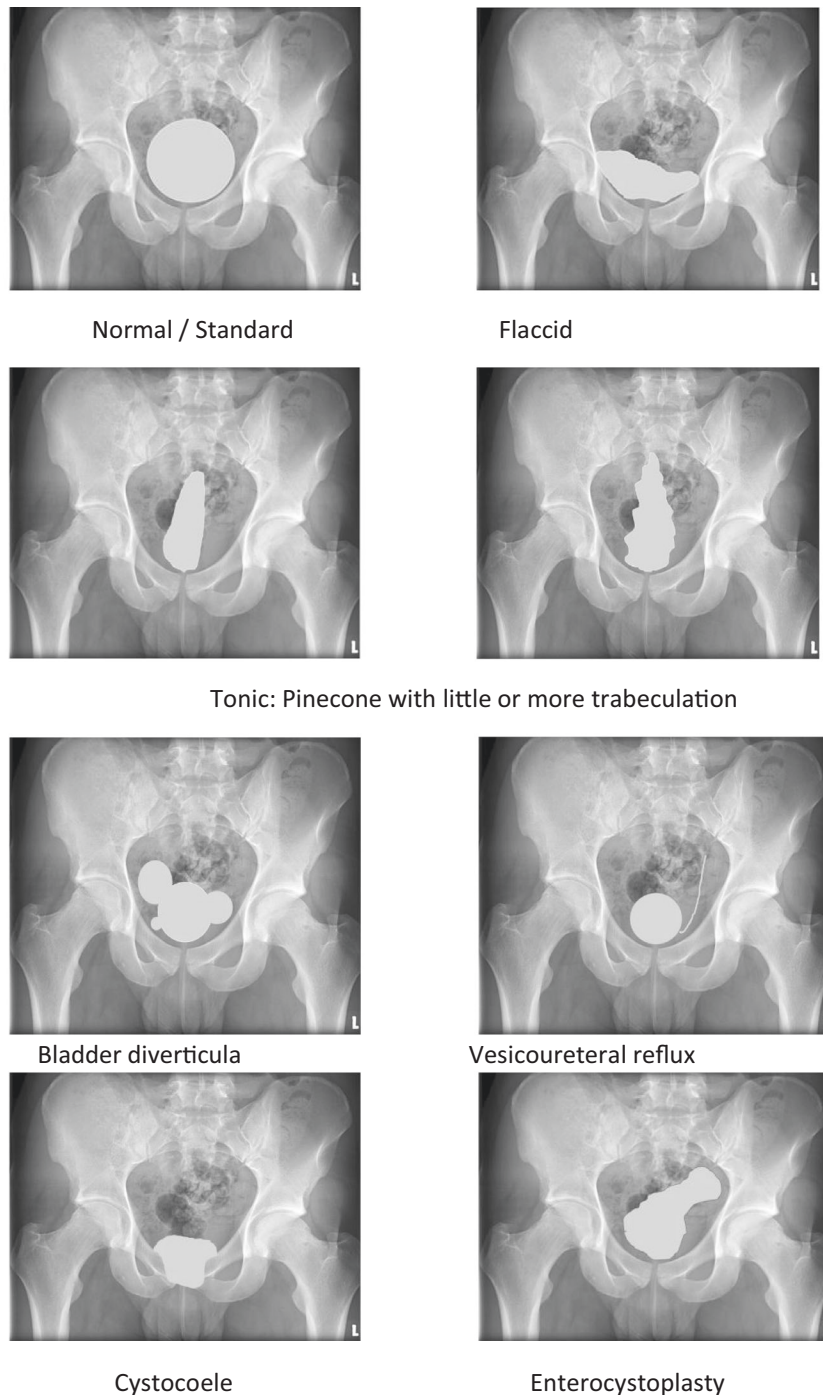
Antimuscarinics were taken at the time of examination by 46% with tonic, 40% with flaccid, and 40% with normal/standard categorized bladders. Injections of botulinum toxin A (300 IE) had been done once or several times in 17% of patients categorized as tonic, in 20% with flaccid and 12% with normal/standard bladder image, but not during the ten months preceding VUD.

Eighty-six patients had repeated tests with 72  $\pm$  143 weeks (range 3–1007 weeks) intervals. In 59 (70%), the radiographic bladder category was unchanged. The changes in the other 27 patients were from normal/standard to tonic ( $N = 9$ ), tonic to normal/standard ( $N = 11$ ), flaccid to normal/standard ( $N = 3$ ) and flaccid to tonic ( $N = 2$ ). Vesicoureteral reflux appeared in 1 and disappeared in 2. The double J catheter had been removed in one patient.

In this cohort, the influx into the prostate, urethral signs of detrusor sphincter dyssynergia, or other urethral pathology were not seen during sustained leakage or during voiding in those who could void (14 men and 9 women).

## DISCUSSION

Deterioration of the urinary tract is no longer the leading cause of death after SCI [7]. This great improvement is partly due to significant progress in urological diagnosis and management in the last decades. Cystography can help to document anatomical pathology in the LUT. VUD presents a combination of standard urodynamic techniques (cystometry, pressure flow studies) and cystography [2]. Examples of the radiographic features which can be studied are bladder shape, the configuration of the bladder wall,



**Fig. 1** Cartoon drawings of the types of bladder morphology during video urodynamics in patients with Spinal Cord Injury.

trabeculation, sacculations, diverticula, and vesicoureteral reflux [8]. There are no absolute indications for VUD, but patients with neurogenic bladder are considered the most important target group [9, 10]. Adding video to the urodynamic investigation is advocated by several authors and guidelines. Wöllner and Pannek made a strong statement in favor of adding imaging in patients with SCI [11–13]. Suskind et al. [14] found VUD to be a clinically useful tool that altered the clinical impression and treatment plan in 29.5% of carefully selected patients including some with neurogenic bladder. In our setting, VUD was done in all SCI patients.

However, critical notes have recently been expressed by world experts taking part in two ICI-RS (International Consultation on

Incontinence Research Society) Think Tanks (working groups) on the added value of video to urodynamics in children and adults with LUT dysfunction. The body of evidence for the addition of cystography to filling and voiding cystometry was considered scant and insufficient. Standards were judged to be poor and variable, and practice to be dominated by uncontrolled expert opinion. The evidence was considered low level and improved standardization of the tests and better evaluation of the added value were strongly advocated [15, 16]. This was the main reason we decided to make an evaluation of the added value of X-ray during urodynamics in a cohort of our SCI patients. In this study, we described and categorized the radiographical bladder images



**Table 1.** AIS score of the cohort of SCI patients.

<b>N = 203</b>	<b>SCI level</b>	<b>N (%)</b>
Complete (AIS A)	C1-C8	41 (20%)
	T1-T9	51 (25%)
	T10-L1	25 (12%)
	L2-S3	3 (2%)
	Cauda	3 (2%)
Incomplete (AIS B-D)	C1-C8	37 (18%)
	T1-T9	17 (8%)
	T10-L1	14 (7%)
	L2-S3	8 (4%)
	Cauda	4 (2%)

AIS score was missing in 27/231 (12%) of patients.  
SCI spinal cord injury, N number, AIS American Spinal Injury Association Impairment Scale.

**Table 2.** Radiographical observations during VUD in patients with SCI.

<b>Radiographical observation</b>	<b>N (%)</b>
Standard/normal bladder	152 (66%)
Tonic bladder	50 (22%)
Flaccid bladder	10 (4%)
Cystocele	6 (3%)
Diverticula	5 (2%)
Vesicoureteral reflux	4 (2%)
Enterocystoplasty	3 (1%)
Foreign material: double J catheter after kidney stone procedure done some months before	1 (<1%)

VUD video urodynamics, SCI spinal cord injury.  
The categories of radiographical observations are illustrated in Fig. 1.

found during VUD. We evaluated the presence of these radiographical observations in patients with different types of SCI (level, AIS score, and time since SCI) and we examined whether the findings were different in SCI patients with different urodynamic findings and different methods of bladder emptying. Finally, an assessment of changes in the findings over time was made.

VUD were performed according to the ICS good urodynamic practice guidelines [5]: the contrast medium was specified, X-ray images were made at relevant moments during filling, and the protection against and the exposure to radiation are reported, showing strict adherence to the ALARA (As Low As Reasonably Achievable) principle [17].

One-third of the SCI patients in our cohort were found to have an aberrant (not normal/standard) bladder appearance during VUD (Table 2). Other than we expected, the categories of radiographical observations did not differ by AIS score. A tonic bladder appearance was the most frequent finding in 63% (Table 2— $N = 50/72$ ). These latter patients had a significantly lower maximum cystometric capacity, showed more NDO (80%), and  $\frac{1}{4}$  was found to have pressures during NDO above 40 cm H<sub>2</sub>O. The category of the tonic bladder was found as early as eight weeks after SCI. Continuous bladder drainage can have played a role: one-third of patients with a tonic bladder image during VUD had an indwelling transurethral or suprapubic catheter.

Vesicoureteral reflux is a potential kidney- and life-threatening complication in SCI, and missing its presence during urodynamics may lead to an underestimation of bladder pressures during filling (compliance and/or presence and amplitude of NDO). The incidence of reflux in a previously published large

cohort during long-term follow-up was 5% and mostly low grade [18, 19]. The prevalence in our cohort was 2%, the grade was low, and the finding disappeared in two of four patients after changing from an indwelling catheter to CIC. In these two patients, vesicoureteral reflux was found early after SCI. This is in line with previous reports [20]. Furthermore, only two patients in our cohort had aberrant findings on renal ultrasound. Bladder stones are the second most common urological complication in SCI patients [21]. Approximately 36% of those with an indwelling catheter develop bladder stones within eight years [22], but the 5-year cumulative incidence rate has declined during the past decades [23]. As previously reported, the detection by X-ray is 28.6% for struvite stones and 41.9% for calcium phosphate stones, and 78% of such bladder stones are not visible on plain X-ray. This may be explained by a combination of low stone contrast, a shell-like form, and by gas and feces in the bowel obstructing the view [24, 25]. In our cohort, no bladder stones were diagnosed through VUD. Nevertheless, 20 patients out of 161 who underwent cystoscopy were found to have bladder stones, which indeed had a shell-like form.

Nordling et al. [26] previously reported that trabeculation, diverticula, and a Christmas tree appearance were not related to the level of the lesion or the reflex pattern of the detrusor in a cohort of 57 patients with localized neurological lesions. In our cohort, the presence of NDO and increased amplitude of NDO were found more often in patients with a tonic bladder appearance and with bladder diverticula. Bladder compliance, on the other hand, did not differ between bladder appearance categories. Furthermore, diverticula were more often seen on cystoscopy than during cystography. This could be explained in several ways: superposition in a 2-D image, a narrow entrance of the diverticula, or insufficient contrast filling in large diverticula. Our study also illustrated that diverticula take long to develop as they were only seen in patients during long-term follow-up.

Finally, VUD could also be used to assess the urethra. However, voluntary voiding was rare and no major urethral pathology was seen in our SCI cohort.

Repeating VUD after ~1.5 years showed a change in bladder appearance category in 30% of patients. A normalization, from tonic or flaccid to normal/standard, was seen in 50% of these. In the other half, a new aberrant image was seen. These changes could have been caused by neurological changes, long-term bladder dysfunction, or a change in drug intake and/or bladder drainage method. However, we accept that this is pure speculation as pre- and post-event controls of treatment were not available.

The findings from our study have to be put into perspective. Our study was retrospective. Nevertheless, the data available in the files were standardized, reliable, and nearly complete. Our sample size was not small but from one single center. Evaluation in a much larger multicenter sample could provide further insights. Our findings reflect our way of management from the day of admission and may be different when other management rules are used. The data are from a Western country and may not represent the situation in other parts of the world. Our data are from a cohort of SCI patients, which is an acquired neurological disorder, and can thus not be extrapolated to congenital spinal cord deficiencies and progressive neurologic diseases. Finally, we cannot compare with alternative X-ray techniques or ultrasound as these data are not available.

This retrospective study presents a real-life example of the yield of VUD in a cohort of our patients with SCI. It is an illustration of diagnostic management according to current standards and therefore has not the aim nor the possibility to influence future guidelines. Nevertheless, it may serve as a background to stimulate large high-quality studies that evaluate the role of cystography added to urodynamics in patients with neurogenic bladder.

**Table 3.** Techniques used for bladder emptying in SCI patients with different radiographical bladder categories during VUD.

	CIC	Transurethral indwelling	Suprapubic	Tapping	Crédé/Valsalva	Standard voiding	Total incontinence	Total
Normal/standard	65	41	13	7	5	15	1	147
Tonic	18	10	5	4	1	6	0	44
Flaccid	6	0	0	1	1	2	0	10
Diverticula	0	1	0	3	0	0	0	4
Cystocele	1	2	1	0	1	0	0	5
Vesicoureteral reflux	1	3	0	0	0	0	0	4
Enterocystoplasty	3	0	0	0	0	0	0	3
Foreign material double J catheter	0	1	0	0	0	0	0	1
Total	94	58	19	15	8	23	1	218

Method of bladder emptying was missing value in 13 patients (6%).

SCI spinal cord injury, VUD video urodynamics, CIC clean intermittent catheterization.

**Table 4.** Findings on X-ray and on cystoscopy.

	X-ray (N = 231)	Cystoscopy (N = 161)
Normal/standard	103	57
Bladder stone	0	20
Trabeculation	11	37
Bladder wall edema/irritation	NA	35
Diverticula	5	9

NA not applicable.

Taking all data into consideration, it is clear that concomitant X-ray during filling cystometry in SCI patients can reveal pathological changes in bladder appearance and complications. However, in our cohort, as in other series in the literature, such findings were rare. A high-quality evaluation of the added benefit of cystography during VUD in patients with SCI is needed to help define the role of X-ray in VUD in SCI. The potential danger of repeated radiographical testing, and the cost-benefit should be part of this investigation, as should potential phenotyping of which patients need X-rays to be done during urodynamics.

#### DATA AVAILABILITY

The data such as curves of urodynamics testing with X-ray images are in the patient files. Data from the database are available on request to the corresponding author, blinded for patient name and file number and other information that might consist a breach of confidentiality.

#### REFERENCES

- Blok B, Castro-Diaz D, Del Popolo G, et al. Guidelines of the European Association of Urology on Neurourology 2020. <https://uroweb.org/guidelines/>.
- Madersbacher H, Dietz P. Urodynamic practice in neuro-urological patients: techniques and clinical value. *Paraplegia*. 1984;22:145–56.
- Biering-Sørensen F, Cragg M, Kennelly M, Schick E, Wyndaele JJ. International urinary tract imaging basic spinal cord injury data set. *Spinal Cord*. 2009;47:379–83.
- Gammie A, Clarkson B, Constantinou C, Damaser M, DRinnan M, Geleijnse G. International Continence Society Urodynamic Equipment Working Group et al. International Continence Society guidelines on urodynamic equipment performance. *Neurourol Urodyn*. 2014;33:370–9.
- Rosier PFWM, Schaefer W, Lose G, Goldman HB, Guralnick M, Eustice S, et al. International continence society good urodynamic practices and terms 2016: urodynamics, uroflowmetry, cystometry, and pressure-flow study. *Neurourol Urodyn*. 2017;36:1243–60.

- Wyndaele JJ, Kovindha A. Urodynamic testing after spinal cord injury. A practical guide. Springer 2017; Chapter 3: 9–14.
- Osterthun R, Post M, van Asbeck FWA, van Leeuwen CMC, van Koppenhagen CF. Causes of death following spinal cord injury during inpatient rehabilitation and the first five years after discharge. A Dutch cohort study. *Spinal Cord*. 2014;52:483–8.
- Wyndaele M, Rosier PFWM. Basics of video urodynamics for adult patients with lower urinary tract dysfunction. *NUU*. 2018;37:S61–S66.
- Abrams P. The practice of urodynamics. In: Mundy AR, Stephenson TP, Wein AJ, editors. *Urodynamics. Principles, practice and application*. Churchill Livingstone; 1984. chapter 8: 90–92.
- Marks BK, Goldman HB. Video urodynamics: indications and technique. *Urol Clin North Am*. 2014;41:383–91.
- Wöllner J, Pannek J. Urodynamic or video-urodynamic assessment in patients with spinal cord injury: this is not a question! *Spinal Cord*. 2015;53:s22–24.
- Apostolides A, Drake MJ, Emmanuel A, Gajewski J, Hamid R, Heeshackers J, et al. Neurologic urinary and faecal incontinence. In: *Incontinence*, Abrams P, Cardozo L, Wagg A, Wein A, editors. *ICUD ICS 6<sup>th</sup> edition*, 2017; Urological Institute Bristol, Chapter 10: 1108.
- Çetinel B, Önal B, Can G, Talat Z, Erhan B, Gündüz B. Risk factors predicting upper urinary tract deterioration in patients with spinal cord injury: a retrospective study. *Neurourol Urodyn*. 2017;36:653–8.
- Suskind AM, Cox L, Clemens JQ, Oldenhof A, Stoffel JT, Maleab B, et al. The value of urodynamics in an academic speciality referral practice. *Urology*. 2017;105:48–53.
- Anding R, Smith P, de Jong T, Constantinou C, Cardozo L, Rosier P. When should video and EMG be added to urodynamics in children with lower urinary tract dysfunction and is this justified by the evidence? *ICI-RS 2014. Neurourol Urodyn*. 2016;35:331–5.
- Anding R, Rosier P, Smith P, Gammie A, Giarenis I, Rantell A, et al. When should video be added to conventional urodynamics in adults and is it justified by the evidence? *ICI-RS 2014. Neurourol Urodyn*. 2016;35:324–9.
- Giarenis I, Phillips J, Mastoroudes H, Srikrishna S, Robinson D, Lewis C, et al. Radiation exposure during video urodynamics in women. *Int Urogynecol J*. 2013;24:1547–51.
- Bunts RC. Management of urological complications in 1000 paraplegics. *J Urol*. 1958;79:733–41.
- Schöps TF, Schneider MP, Steffen F, Ineichen BV, Mehnert U, Kessler TM. Neurogenic lower urinary tract dysfunction (NLUTD) in patients with spinal cord injury: long-term urodynamic findings. *BJU Int*. 2015;115:33–38. Suppl 6
- Linsenmeyer TA, Stone JM, Stein S. Neurogenic bladder and bowel dysfunction. In: DeLisa JA, editor. *Rehabilitation Medicine Principles and Practice*. 4th edn. Philadelphia, PA: Lippincott-Raven; 2004. 1619–53.
- DeVivo MJ, Fine PR, Cutter GR, Maetz HM. The risk of bladder calculi in patients with spinal cord injuries. *Arch Intern Med*. 1985;145:428–30.
- Chen Y, DeVivo MJ, Lloyd LK. Bladder stone incidence in persons with spinal cord injury: derterminants and trends,1973-1996. *Urology*. 2001;58:665–70.
- Rapidi CA, Petropoulou K, Galata A, Fragkaki M, Kandykakis E, Venieri M, et al. Neuropathic bladder dysfunction in patients with motor complete and sensory incomplete spinal cord lesion. *Spinal Cord*. 2008;46:673–8.
- Wyndaele JJ, De Sy WA, Claessens H. Early urological complications in SCI patients treated with a foley catheter. *Acta Urol Belg*. 1982;50:335–42.

25. Linsenmeyer MA, Linsenmeyer TA. Accuracy of bladder stone detection using abdominal X-ray after spinal cord injury. *J Spinal Cord Med.* 2004;27:438–42.
26. Nordling J, Meyhoff HH, Olesen KP. Cysto-urethrographic appearance of the bladder and posterior urethra in neuromuscular disorders of the lower urinary tract. *Scand J Urol Nephrol.* 1982;16:115–24.

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#### AUTHOR CONTRIBUTIONS

W.J.-J. collected the file data, put them in a database, made evaluations, wrote and rewrote revision text. W.M. commented on the study design, made evaluations, corrected the text where needed, and rewrote revision text. R.A. and K.A. evaluated the text, made suggestions/corrections, and rewrote revision text.

#### COMPETING INTERESTS

The authors declare no competing interests.

#### ETHICS APPROVAL

We certify that all applicable institutional and governmental regulations concerning the ethical use of the data were followed during this research.

#### ADDITIONAL INFORMATION

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