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Association of bladder trabeculation and neurogenic bladder with spinal cord injury

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Abstract

Objective: To compare clinical findings and urodynamic parameters according to trabeculation grade and analyze their correlations with trabeculation severity in neurogenic bladder caused by suprasacral spinal cord injury (SCI).

Methods: A retrospective chart review was performed of neurogenic bladder caused by SCI. Bladder trabeculation grade was compared with SCI-related clinical parameters and bladder-related urodynamic parameters.

Results: In SCI patients, factors such as disease duration, bladder capacity, detrusor pressure, peak detrusor pressure values, and compliance were significantly different between different grades of bladder trabeculation, while neurological level of injury, completeness, and detrusor sphincter dyssynergia had no clear relationship with bladder trabeculation grade. In the correlation analysis, vesicoureteral reflux was moderately correlated with trabeculation grade (correlation coefficient 0.433), while the correlation coefficients of disease duration, involuntary detrusor contraction, and bladder filling volume were between 0.3 and 0.4.

Conclusion: Bladder trabeculation with suprasacral-type neurogenic bladder was graded. Although disease duration was positively correlated with bladder trabeculation grade, differences in the neurological level of injury or American Spinal Injury Association Impairment Scale score were not observed. Bladder volume, peak detrusor pressure, compliance, reflex volume, and vesicoureteral reflux also showed significant differences according to trabeculation grade. Vesicoureteral reflux was moderately correlated with trabeculation grade.

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Introduction

In spinal cord injury (SCI), different forms of neurogenic bladder occur depending on the injury level and completeness. In patients with neurogenic bladder caused by SCI, a failure of bladder emptying or bladder storage may occur; urinary retention, incontinence, and voiding difficulties follow. Suprasacral lesions in SCI mainly present as detrusor overactivity or detrusor sphincter dyssynergia (DSD), while sacral lesions may present as detrusor acontractility; therefore, the presentation of neurogenic bladder caused by SCI can vary considerably.[1–5]

Bladder trabeculation is defined as a hypertrophic detrusor muscle with irregular intraluminal contours, and can be divided into grades 0 to 3 based on fluoroscopic or cystoscopic imaging findings.[6,7] The mechanism of trabeculation has been explained as compensatory hypertrophy caused by the contracting detrusor smooth muscle in response to outflow obstruction.[8] Electron microscopy of bladder trabeculation has revealed histopathological alterations in both intervening connective tissue infiltration and detrusor muscle in the chronic obstructed bladder, observed as multidirectionally arranged myofilaments in smooth muscles cells and abnormally distorted dense areas in the cytoplasm of the detrusor muscle.[9,10] Many studies of male prostatism and female pelvic organ prolapse, in which obstruction of the lower urinary tract occurs, have reported that trabeculation is related to bladder outlet obstruction (BOO) or pelvic organ prolapse.[11–16]

Few studies have been conducted on trabeculation of the neurogenic bladder in SCI,[17–19] and these were published in the 1980s and do not reflect the latest changes in SCI classification, the trabeculation grading system, and urodynamic parameters. Thus, we aimed to compare various bladder-related clinical symptoms and urodynamic parameters according to trabeculation grade, and identify the factors with the highest correlations with trabeculation of the neurogenic bladder in patients with SCI.

Subjects and methods

Subjects

A retrospective chart review of SCI patients with neurogenic bladder was implemented in a tertiary university hospital. Patients with SCI who were admitted to a rehabilitation unit or followed up in an outpatient clinic for voiding dysfunction between 2010 and 2018 were included. All participants had completed a urodynamic study (UDS) at least once. Patients with neurological disorders other than SCI were excluded. Patients with lower motor neuron injury alone or combined with cauda equina syndrome were also excluded. In addition, patients with an evaluation date interval of more than 4 weeks between the UDS and voiding cystourethrography (VCUG) were excluded. Patients with the

reevaluation of UDS and VCUG within 4 weeks of taking medication because of severe bladder symptoms were also excluded. The reporting of this study conforms to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[20] This study was approved by the Jeonbuk National University Hospital institutional review board (CUH 2019-03-032) and any requirements for informed consent were waived because of the study design (a retrospective medical chart review).

Outcome measures

All participants reported their history and underwent a thorough physical examination. SCIs were confirmed by magnetic resonance imaging. The retrospective medical records of symptoms, voiding diaries, and parameters of UDS and VCUG were carefully reviewed, and all patient demographics, causes, dates, and levels of SCI were collected. All data were analyzed for associations between the collected parameters and the grade of bladder trabeculation. The level of diagnosed SCI was categorized using the American Spinal Injury Association Impairment Scale (AIS), and all terminology for the description of lower urinary tract function was based on the standardization of terminology of the International Continence Society (ICS).[21]

Voiding diary

Participants were asked to fill out a 3-day voiding diary just before their UDS test according to ICS standards. Voiding information, such as voiding methods (clean intermittent catheterization [CIC], Credé voiding, Valsalva voiding, percussion voiding, or indwelling catheter use), mean voided volume, voiding frequency, and symptoms such as incontinence were gathered with the voiding diary.

UDS

Conventional UDSs were performed using the Sensic Clinic® Urodynamic Systems (Mediwatch, Ltd., Coventry, UK) with each patient in a semi-recumbent position because of difficulties maintaining a sitting posture. Each UDS consisted of filling and voiding cystometry using normal saline mixed with radiopaque contrast. If a fluoroscopic C-arm machine was not available during UDS, VCUG was performed on a different day within 4 weeks, and fluoroscopic images were obtained during VCUG. A 6-F double-lumen urethral catheter was inserted transurethrally into the bladder and a 12-F abdominal catheter was inserted into the rectum using radiographic contrast. One lumen was used for bladder filling and the other was used to record intravesical pressure. Sphincter electromyography was performed using surface electrodes. A maximum volume of 500 mL of warm saline was infused into the bladder at a filling rate of 30 mL/minute. Bladder compliance refers to the relationship between bladder volume and detrusor pressure change during the filling phase, which was calculated by dividing the change in volume ($\triangle$V) by the detrusor pressure change ($\triangle$Pdet). Detrusor overactivity, including both phasic and terminal detrusor overactivity, was defined as an involuntary detrusor contraction (IDC) during the urodynamic filling phase. Detrusor sphincter dyssynergia (DSD) and BOO were investigated during the voiding phase. DSD is the involuntary contraction of the urethral sphincter muscle during contraction of the detrusor muscle in the voiding phase. It is diagnosed during voiding cystometry with electromyography using UDS. The DSD was classified as type 1, 2, or 3 based on characteristic electromyographic findings.[22]

Type 1 was defined as a crescendo increase of electromyographic activity during the detrusor contraction, type 2 as

interspersed clonic electromyographic activity during the detrusor contraction, and type 3 as sustained electromyographic activity during the detrusor contraction. Through all phases of the UDS, peak detrusor pressure values (PdetQmax) were collected, and bladder activity was determined. We also assessed the presence of vesicoureteral reflux (VUR), urethral leakage of urine, and the presence of diverticula in fluoroscopic images. Urine analysis was performed before the UDS. If there was evidence of a urinary tract infection, such as clinical symptoms of fever or chill combined with white blood cells, nitrites, or bacteria in the urine, UDS was not performed. After the UDS, patients took a one-time antibiotic prophylaxis.

Bladder trabeculation grading

Trabeculation was graded using fluoroscopic images during UDS or VCUG based on the grading system published by Cho et al.,[6] wherein the trabeculation grading system was measured by the maximum depth of trabeculation in fluoroscopic images. The following four trabeculation grades were noted: 0 (none), 1 (mild), 2 (moderate), and 3 (severe). Grade 0 refers to no trabeculation in the bladder; Grade 1 refers to mild trabeculation with a maximum depth of less than 5 mm and covering less than half the bladder surface; Grade 2 refers to moderate trabeculation with maximum depth between 5 mm and 10 mm and covering more than half the bladder surface, and Grade 3 refers to severe trabeculation with maximum depth greater than 10 mm and covering over half the bladder surface.

Statistical analysis

Demographic data such as sex and age are presented as the mean ± standard deviation. To compare clinical information according to bladder trabeculation grade, the data were analyzed using one-way analysis of variance if the data satisfied the Shapiro–Wilk test of normality, and the Kruskal–Wallis test if they did not. To identify any relationships with bladder trabeculation grade, correlation analyses were performed. To analyze correlations between the neurological level of injury (NLI) of the spinal cord and trabeculation grade among voiding-related parameters, the NLI was used as a continuous variable by converting the eight cervical, 12 thoracic, and five lumbar vertebrae into continuous variable numbers. If the variable to be compared was on an ordinal scale, the Spearman correlation coefficient was used; if it was on an interval or ratio scale, a polyserial correlation coefficient was used; and it was if on a nominal scale, a polychoric correlation coefficient was used. Analyses were performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY, USA) and RStudio, version 1.1.456 (RStudio, Boston, MA, USA).

Results

Subject demographics

There were 337 subjects with a mean age of 55.3 ± 14.3 years, ranging from 11 to 84 years. The subjects included 252 male patients (74.8%) and 85 female patients (25.2%), and there were 578 datasets when repeated-measure data were collected. Two hundred four patients underwent UDS once, 68 twice, 35 thrice, 19 four times, 10 five times, and 1 seven times. The average interval between injury and UDS was 57.5 months. Medical comorbidities are described in Table 1, and included diabetes mellitus, hypertension, renal failure, heart failure, and arrhythmia. Of the injuries, 16.4% were AIS A (complete SCI), 10.6% were AIS B, 23.4% were AIS C, and 49.7%

Table 1. Demographic information of subjects.

Variables	Numbers
Subjects (male/female)	337 (252/85)
Collected data (male/female)	578 (440/138)
Age (years)	55.28 ± 14.28
Disease duration from onset to UDS (months)	57.52 ± 87.64
Medical comorbidities	
Diabetes mellitus	76
Hypertension	15
Other (renal failure, heart failure, arrhythmia, etc.)	17
Neurological level of injury	
Cervical	320 (55.4%)
(AIS A:B:C:D)	(30:40:82:168)
Thoracic	204 (35.3%)
(AIS A:B:C:D)	(61:19:36:88)
Lumbar	54 (9.3%)
(AIS A:B:C:D)	(4:2:17:31)
AIS	
A	95 (16.4%)
B	61 (10.6%)
C	135 (23.4%)
D	287 (49.7%)
Total	578 (100%)
Injury vector	
Falls	280 (48.4%)
Traffic accidents	160 (27.7%)
Iatrogenic	23 (4.0%)
Violence	1 (0.2%)
Sports	1 (0.2%)
Other	113 (19.6%)
Voiding methods	
Clean intermittent catheterization	235 (40.7%)
Self voiding	151 (26.1%)
Credé voiding	17 (2.9%)
Valsalva voiding	124 (21.5%)
Percussion voiding	5 (0.9%)
Indwelling catheter	46 (8.0%)

Values are presented as the mean ± standard deviation or numbers (%).
AIS, American Spinal Injury Association Impairment Scale; UDS, urodynamic study.

were AIS D, meaning that more patients with incomplete injuries were included. Approximately 80% of the injury vectors were related to traumatic causes, and 19.6% were spontaneous, such as transverse myelitis and spondylotic myelopathy (Table 1).

Demographics and clinical parameters according to bladder trabeculation grade

Subject demographic characteristics and voiding-related parameters were divided into four categories according to bladder trabeculation grade[6] (Table 2). The time from injury to testing (injury duration) was 23.9 months for trabeculation grade 0 and exceeded 120 months for patients with grade 3. This overall increase was significant ($p < 0.001$) and post hoc test results revealed significant differences in injury duration between each grade, except between grades 1 and 2 and grades 2 and 3. When the NLI and AIS were categorized by trabeculation grade, no clear pattern was observed; the largest proportion comprised grades 0 and 1. Voiding volumes were significantly different according to trabeculation grade ($p = 0.008$). However, post hoc test results showed significant differences between grades 0 and 3, 1 and 3, and 2 and 3 only, indicating a decrease in voiding volume only when the trabeculation was grade 3. The difference in trabeculation according to CIC and indwelling catheterization of voiding methods was analyzed using the Pearson chi-squared test. In patients with CIC, trabeculation occurred as grades 0:1:2:3 in 72 (30.6%):100 (42.6%):46 (19.6%):17 (7.2%) cases. In patients with indwelling catheterization, trabeculation occurred as grades 0:1:2:3 in 17 (37.0%):26 (56.5%):3 (6.5%):0 (0%) cases. The difference in trabeculation occurrence was significant ($p = 0.026$) and patients with CIC showed more severe trabeculation. Among the UDS parameters, IDC occurred in 152 (26.3%) of all 578 cases, while DSD occurred in 263 (45.5%) cases, most of which were grade 1.

Table 2. Demographic data and voiding-related parameters according to trabeculation grade in patients with spinal cord injury.

	Bladder trabeculation				
	Grade 0 (206)	Grade 1 (251)	Grade 2 (84)	Grade 3 (37)	Total (578)
Disease duration from onset to VCUG (mo.)	23.9 ± 45.3	67.2 ± 91.5	83.5 ± 95.8	120.1 ± 139.3	<0.001
Neurological level of injury					
Cervical	119 (37.2%)	152 (47.5%)	34 (10.6%)	15 (4.7%)	320 (100%)
(AIS A:B:C:D)	(9:11:25:74)	(19:19:36:78)	(2:7:14:11)	(0:3:7:5)	
Thoracic	64 (31.4%)	82 (40.2%)	45 (22.1%)	13 (6.4%)	204 (100%)
(AIS A:B:C:D)	(12:4:9:39)	(27:8:18:29)	(14:6:8:17)	(8:1:1:3)	
Lumbar	23 (42.6%)	17 (31.5%)	5 (9.3%)	9 (16.7%)	54 (100%)
(AIS A:B:C:D)	(2:0:8:13)	(0:1:6:10)	(1:1:0:3)	(1:0:3:5)	
AIS					
A	23 (24.2%)	46 (48.4%)	17 (17.9%)	9 (9.5%)	95 (16.4%)
B	15 (24.6%)	28 (45.9%)	14 (23.0%)	4 (6.6%)	61 (10.6%)
C	42 (31.1%)	60 (44.4%)	22 (16.3%)	11 (8.1%)	135 (23.4%)
D	126 (43.9%)	117 (40.8%)	31 (10.8%)	13 (4.5%)	287 (49.7%)
Voiding diary					
Voiding volume (mL)	354.0 ± 141.4	358.0 ± 138.1	347.0 ± 148.6	262.6 ± 173.4	0.008
Voiding methods					
Clean intermittent catheterization	72 (30.6%)	100 (42.6%)	46 (19.6%)	17 (7.2%)	235 (100%)
Indwelling catheter	17 (37.0%)	26 (56.5%)	3 (6.5%)	0 (0%)	46 (100%)
Urodynamic parameters					
UDS filling volume (mL)	449.8 ± 89.7	398.4 ± 136.3	364.1 ± 146.7	295.2 ± 158.1	<0.001
Detrusor pressure compliance (cmH_2O)	9.0 ± 10.9	10.7 ± 13.5	16.7 ± 14.0	18.8 ± 17.0	<0.001
Compliance (mL/cmH_2O)	120.0 ± 126.2	100.3 ± 117.9	54.1 ± 74.5	29.4 ± 26.8	<0.001
PdetQmax (cmH_2O)	30.8 ± 21.6	38.5 ± 36.4	36.8 ± 20.8	43.4 ± 29.9	0.002
IDC (no. [%])	27 (4.7%)	69 (11.9%)	37 (6.4%)	19 (3.3%)	152 (26.3%)
IDC reflex volume (mL)	270.4 ± 122.2	227.2 ± 108.0	206.0 ± 90.1	172.6 ± 92.0	0.014[1)]
DSD (no. [%])	92 (15.9%)	115 (19.9%)	36 (6.2%)	20 (3.5%)	263 (45.5%)
DSD type 1	31 (5.4%)	40 (6.9%)	5 (0.9%)	3 (0.5%)	79 (13.7%)
DSD type 2	3 (0.5%)	8 (1.4%)	2 (0.3%)	1 (0.2%)	14 (2.4%)
DSD type 3	51 (8.8%)	63 (10.9%)	28 (4.8%)	16 (2.8%)	158 (27.3%)
DSD type undetermined	7 (1.2%)	4 (0.7%)	1 (0.2%)	0	12 (2.1%)
VUR (no.)	1 (0.2%)	9 (1.6%)	4 (0.7%)	6 (1.0%)	20 (3.5%)
Medication					
None	125	94	24	12	255
A-blocker	14	27	13	3	57
Anticholinergics	13	48	17	5	83
Cholinergics	4	5	5	1	15
A-blocker with anticholinergics	24	46	20	14	104
A-blocker with cholinergics	25	31	5	2	63

Values are presented as the mean ± standard deviation. [1)]Analyzed using one-way analysis of variance; all other parameters were analyzed using the Kruskal–Wallis test.

AIS, American Spinal Injury Association Impairment Scale; DSD, detrusor sphincter dyssynergia; IDC, involuntary detrusor contraction; mo., months; no., number; PdetQmax, peak detrusor pressure values; UDS, urodynamic study; VCUG, voiding cystourethrography; VUR, vesicoureteral reflux.

DSD occurred in 84 (55%) of 152 IDC cases, which was a higher proportion than the DSD occurrence of 263 (45.5%) of all 578 cases (with or without IDC). Among the DSD data, 251 were classified as types 1, 2, and 3, and 12 were undetermined cases. Type 3 DSD accounted for >60% of the DSD cases, most of which showed grades 0 and 1 trabeculation. The DSD type was undetermined in 12 cases. UDS filling volume, PdetQmax, and compliance significantly decreased as trabeculation grade increased ($p < 0.001$, $p = 0.002$, and $p < 0.001$, respectively).

Moreover, detrusor pressure of compliance significantly increased as trabeculation grade increased ($p < 0.001$). The results of the post hoc test showed that UDS filling volume was significantly different between grades 0 and 1, 0 and 2, 0 and 3, and 1 and 3. In the case of PdetQmax, there was only a significant difference between grades 0 and 1. Compliance was significantly different between all grades except between grades 2 and 3. Detrusor pressure of compliance was significantly different between all grades except between grades 0 and 1 and grades 2 and 3. In the 152 datasets for IDC, reflex volume (the infused saline volume when reflexive detrusor contraction was noted) significantly decreased with increasing trabeculation grade ($p = 0.014$), but post hoc test results showed significant differences between grades 0 and 3 only. Filling volume significantly decreased with increased trabeculation grade ($p < 0.001$), and post hoc test results revealed significant differences between grades 0 and 2, 0 and 3, and 1 and 3 only. VUR occurred in 20 patients (3.5%), of whom two had hydronephrosis. VUR grade 1 was observed in 12 cases, VUR grade 2 in five cases, and VUR grade 3 in three cases. The medications administered to patients at the time of UDS are described in Table 2.

Association of bladder parameters with bladder trabeculation

When the correlations between various parameters and trabeculation were analyzed to identify their relationship with the occurrence and progression of trabeculation, VUR showed the strongest positive correlation, with a correlation coefficient of 0.433. For disease duration and IDC, correlation coefficients were between 0.3 and 0.4. For UDS filling volume and VCUG filling volume, the correlation coefficients with trabeculation grade were between −0.3 and −0.4 (Table 3). The NLI, post-void residual, detrusor pressure, PdetQmax, DSD, and DSD subtype showed positive correlations below 0.3, whereas completeness level, voiding volume based on the voiding diary, compliance based on the UDS, and reflex volume of the patients with IDC showed negative correlations greater than −0.3. Thus, their correlations with trabeculation grade were poor (Table 3).

Discussion

This study analyzed the relationships between clinical symptoms, voiding-related urodynamic parameters, and bladder trabeculation grades observed on VCUG in patients with neurogenic bladder caused by SCI. Factors such as disease duration, bladder capacity, detrusor pressure, PdetQmax, and compliance showed significant differences between different bladder trabeculation grades, while NLI, AIS score, and DSD did not. The correlation analysis revealed that a long duration from onset, small bladder volume, the presence of IDC, and VUR had moderate correlations with trabeculation grade. These results are similar to the results of a previous study that categorized bladder trabeculation into grades from 0 to 3 and reported significant correlations with UDS

Table 3. Correlation coefficients according to bladder trabeculation grade in patients with spinal cord injury.

Parameters	Correlation coefficient
Disease duration from onset to VCUG	0.346[2)]
Neurologic level of injury	0.109[1)]
AIS	−0.217[3)]
Voiding diary	
Voiding volume	−0.116[2)]
PVR	0.101[2)]
Urodynamic parameters	
UDS filling volume	−0.348[2)]
Detrusor pressure	0.245[2)]
PdetQmax	0.124[2)]
Compliance	−0.256[2)]
IDC	0.392[3)]
IDC reflex volume	−0.278[2)]
DSD	0.030[3)]
DSD subtype	0.201[3)]
VCUG	
VCUG filling volume	−0.333[2)]
VUR	0.433[3)]

Data were analyzed using the [1)]Spearman correlation coefficient, [2)]polyserial correlation coefficient, and [3)]polychoric correlation coefficient.
AIS, American Spinal Injury Association Impairment Scale; DSD, detrusor sphincter dyssynergia; IDC, involuntary detrusor contraction; PdetQmax, peak detrusor pressure values; PVR, post-void residual; UDS, urodynamic study; VCUG, voiding cystourethrography; VUR, vesicoureteral reflux.

parameters in patients with neurogenic bladder.[6] However, our study differed in that IDC showed the second highest positive correlation, at a correlation coefficient of 0.392, after VUR—and in that the correlation with VUR was analyzed. Previous studies have reported that trabeculation is significantly correlated with UDS parameters in patients with BOO and voiding symptoms.[6,7,11,12,23] By contrast, the present study differed from previous studies because it included only patients with neurogenic bladder caused by suprasacral SCI, and the results should therefore be considered differently. Weld et al.[5] reported that 94.9% of patients with suprasacral SCI showed DSD and hyperreflexia, 12 out of 14 (85.7%) patients with sacral cord injuries showed areflexia, and both suprasacral and sacral lesions led to low bladder compliance and high detrusor leak point pressure.

We thus hypothesized that DSD, which has been described as a functional outlet obstruction during detrusor contraction caused by neurogenic lower urinary tract dysfunction,[24] would be the main factor resulting in trabeculation in patients with SCI—similar to BOO in patients with prostatism, which is thought to be the cause of trabeculation. However, the presence of DSD was not associated with trabeculation grade, and DSD subtype did not significantly correlate with trabeculation grade. Rather than functional obstruction, parameters such as DSD, small bladder capacity, the presence of detrusor overactivity, and VUR were more correlated with trabeculation. This result suggests that isolated outlet dysfunction cannot be considered as a sole risk factor of neurogenic trabeculation in SCI. Detrusor overactivity caused by dysfunction of the detrusor muscle itself from neurogenic changes in SCI can cause trabeculation in suprasacral SCI. The mechanism of trabeculated bladder in SCI is assumed to be the result of neurogenic changes with or without outlet obstruction.

Because SCI causes various types of neurogenic bladder dysfunction depending on the level or completeness of the injury, we assumed that NLI and AIS scores would be significantly correlated with the occurrence and progression of trabeculation. However, we found that NLI and AIS scores had little correlation with trabeculation in SCI (Table 3), and trabeculation progressed significantly with time after SCI onset (Tables 2 and 3). Although the correlation with NLI was very low, high-grade trabeculation (grades 2 and 3) occurred relatively frequently in patients with thoracic-level

injuries (28.3%) compared with those with cervical- (15.3%) and lumbar-level injuries (26%; Table 2). We speculate that this may be because the disease duration in thoracic injury was longer (mean, 66.7 months) than that of cervical- and lumbar-level injuries (mean, 54.8 and 39.3 months, respectively). Completeness of the injury was unlikely to be correlated to severity of trabeculation in the present study. However, it must be considered that more patients with incomplete than complete lesions were included in this analysis, which might have affected the results. There was also a significant difference in trabeculation severity between patients with CIC and those with indwelling catheterization. More severe trabeculation was observed in patients with CIC. However, patients with CIC showed higher compliance and bladder filling volume, fewer IDC occurrences, and a large difference in sample size between the two groups (there were 253 cases of CIC and 46 cases of indwelling catheterization), which might have affected the results of the current study. It is thus difficult to conclude whether more severe trabeculation occurs in patients with CIC; a future prospective study is needed in this regard.

Few studies of trabeculation in neurogenic bladder caused by SCI have been conducted.[17–19,25] A previous study reported that 70% of patients with acute SCI with reflex voiding showed bladder trabeculation at 24 months, and the urodynamic pressure/flow measurements of patients with trabeculation were significantly different from those of patients with no trabeculation on X-ray.[17] Hoffberg and Cardenas[18] also reported that trabeculation was significantly correlated with age, male sex, upper motor lesion, diverticula, VUR, external collection device in male patients, CIC, and upper tract radiographic abnormality in female patients. However, while duration of injury had a trend toward an increase of trabeculation, this was not reported as conclusive. Ogawa et al. reported that high-grade bladder deformities with trabeculation occur more frequently in complete injuries and with low bladder compliance in patients with traumatic SCI.[19] Moreover, neonates with myelodysplasia in the first month after birth show VUR or trabeculation related to DSD or elevated leak point pressure, which suggests that neurogenic bladder changes may lead to structural abnormalities.[25] The difference between our study and previous studies was that disease duration affected the trabeculation progression of neurogenic bladders, while completeness according to AIS score and the NLI had little correlation with trabeculation occurrence. Additionally, many parameters were analyzed separately according to trabeculation grade in the patients with SCI in the current study.

The power of the present study is that only data from suprasacral neurogenic bladders with SCI were included, in contrast to previous studies that included unclassified neurogenic bladder and BOO. In addition, the current study showed the objective results of correlation coefficients of trabeculation grade in relation to clinical and urodynamic parameters in patients with neurogenic bladder in SCI, and showed the importance of clinical factors such as disease duration, rather than NLI or AIS score, in the occurrence of trabeculation. However, a limitation of the present study is that all repeated measurements of data were included; thus, initial data (obtained before taking bladder medications) and follow-up data (obtained after taking bladder medications) were mixed. The effects of medication on trabeculation were therefore unable to be analyzed. Another limitation of our study was the accuracy of bladder trabeculation diagnoses, which were based on the fluoroscopic trabeculation grading system by Cho et al.[6] The diagnosis of trabeculation by cystography alone is inferior to that by cystoscopy,

which looks directly at the bladder wall. It has previously been reported that the accuracy of fluoroscopic-based trabeculation diagnoses may be lower than that of cystoscopic-based diagnoses because of overlapping bladder contours and observational errors in measuring depths.[7,26] However, because cystoscopy is an invasive procedure, and is not recommended as a routine evaluation for patients with neurogenic bladder, cystoscopy was not performed in all patients who underwent UDS in the present study. Fluoroscopic bladder trabeculation was not compared with or confirmed by cystoscopy, which may also be a limitation of the current study.

Conclusion

The present study classified bladder trabeculation into grades in patients with neurogenic bladder caused by suprasacral SCI. Differences and correlations among the clinical factors and bladder-related parameters were then analyzed. Although disease duration was significantly correlated with bladder trabeculation grade, NLI and AIS of the SCI were not. Bladder volume, peak detrusor pressure, compliance, reflex volume, and VUR also showed significant differences according to trabeculation grade. VUR was moderately correlated with bladder trabeculation. Disease duration, IDC, and bladder filling volume had a weak linear correlation with bladder trabeculation.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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References

1. Sullivan M and Yalla S. Spinal cord injury and other forms of myeloneuropathies. *Probl Urol* 1992; 6: 643–643.
2. Jeong SJ, Cho SY and Oh SJ. Spinal cord/brain injury and the neurogenic bladder. *Uro Clin North Am* 2010; 37: 537–546.
3. Maynard FM Jr, Bracken MB, Creasey G, et al. International standards for neurological and functional classification of spinal cord injury. *Spinal cord* 1997; 35: 266.
4. Fam B and Yalla SV. Vesicourethral dysfunction in spinal cord injury and its management. *Semin Neurol* 1988; 8: 150–155.
5. Weld KJ and Dmochowski RR. Association of level of injury and bladder behavior in patients with post-traumatic spinal cord injury. *Urology* 2000; 55: 490–494.
6. Cho SY, Bae J, Yoo C, et al. Establishment of a grading system for bladder trabeculation. *Urology* 2013; 81: 503–507.
7. Jung JH, Cho SY, Yoo C, et al. Establishment of the novel cystoscopic classification for bladder trabeculation of neurogenic bladder. *Urology* 2014; 84: 515–519.
8. Gilpin S, Gosling J and Barnard R. Morphological and morphometric studies of the human obstructed, trabeculated urinary bladder. *Br J Urol* 1985; 57: 525–529.
9. Hongoh Y, Sakanaka M, Kitagawa Y, et al. Morphologic changes in detrusor muscles of patients with chronic obstruction of lower urinary tract electron microscopic and immunohistochemical findings. *Urology* 1991; 37: 584–589.
10. Gosling JA and Dixon JS. Structure of trabeculated detrusor smooth muscle in cases of prostatic hypertrophy. *Urol Int* 1980; 35: 351–355.
11. Bai SW, Park SH, Chung DJ, et al. The significance of bladder trabeculation in the female lower urinary system: an objective

evaluation by urodynamic studies. *Yonsei Med J* 2005; 46: 673–678.
12. El Din KE, De Wildt M, Rosier P, et al. The correlation between urodynamic and cystoscopic findings in elderly men with voiding complaints. *J Urol* 1996; 155: 1018–1022.
13. Lee YJ, Kim SR, Kim SK, et al. The significance and factors related to bladder outlet obstruction in pelvic floor dysfunction in preoperative urodynamic studies: a retrospective cohort study. *Obstet Gynecol Sci* 2014; 57: 59–65.
14. Liang CC, Chang YL, Lin YH, et al. Significance of bladder trabeculation in postmenopausal women with severe pelvic organ prolapse: clinical and urodynamic assessments. *Menopause* 2013; 20: 813–817.
15. Khoury AE, Dave S, Peralta-Del Valle MH, et al. Severe bladder trabeculation obviates the need for bladder outlet procedures during augmentation cystoplasty in incontinent patients with neurogenic bladder. *BJU Int* 2008; 101: 223–226.
16. Gowda M, Danford JM, Hu Y, et al. Clinical findings associated with bladder trabeculations in women. *Int Urogynecol J* 2013; 24: 1167–1171.
17. Anderson RU. Urodynamic patterns after acute spinal cord injury: association with bladder trabeculation in male patients. *J Urol* 1983; 129: 777–779.
18. Hoffberg HJ and Cardenas DD. Bladder trabeculation in spinal cord injury. *Arch Phys Med Rehabil* 1986; 67: 750–753.
19. Ogawa T, Yoshida T and Fujinaga T. Bladder deformity in traumatic spinal cord injury patients. *Hinyokika Kiyo* 1988; 34: 1173–1178.
20. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007; 370: 1453–1457.
21. Abrams P, Cardozo L, Fall M, et al. The standardisation of terminology in lower urinary tract function: report from the standardisation sub-committee of the International Continence Society. *Urology* 2003; 61: 37–49.
22. Blaivas J, Sinha H, Zayed A, et al. Detrusor-external sphincter dyssynergia: a detailed electromyographic study. *J Urol* 1981; 125: 545–548.
23. Güzel Ö, Aslan Y, Balcı M, et al. Can bladder wall thickness measurement be used for detecting bladder outlet obstruction? *Urology* 2015; 86: 439–444.
24. Amarenco G, Sheikh SI, Chesnel C, et al. Diagnosis and clinical evaluation of neurogenic bladder. *Eur J Phys Rehabil Med* 2017; 53: 975–980.
25. Kopp C and Greenfield S. Effects of neurogenic bladder dysfunction in utero seen in neonates with myelodysplasia. *Br J Urol* 1993; 71: 739–742.
26. Wyndaele JJ, Wyndaele M, Rapidi C-A, et al. What do X-ray images of the bladder during video urodynamics show us in patients with spinal cord injury? *Spinal Cord* 2022: 1–6.