Morphologic and urodynamic predictors of renal scarring in pediatric neurogenic bladder: A cross-sectional study

Derya Yayla[1], Zehra Aydın[2]
[1]Department of Pediatric Urology, Izmir City Hospital, Izmir, Turkey; [2]Department of Pediatric Nephrology, Gaziantep City Hospital, Gaziantep, Turkey

Cite as: Yayla D, Aydun Z. Morphologic and urodynamic predictors of renal scarring in pediatric neurogenic bladder: A cross-sectional study. *Can Urol Assoc J* 2026 May 4; Epub ahead of print. http://dx.doi.org/10.5489/cuaj.9488

Published online May 4, 2026

Corresponding author: Dr. Derya Yayla, Department of Pediatric Urology, Izmir City Hospital, Izmir, Turkey; dryayla@yahoo.com

***

ABSTRACT

Introduction: This study aimed to evaluate the association of bladder diameter ratio (BDR), filling-phase detrusor pressure (Pdet), vesicoureteral reflux (VUR), age at initiation of clean intermittent catheterization (CIC), and estimated glomerular filtration rate (eGFR) with renal scarring in children with neurogenic bladder secondary to spinal dysraphism.
Methods: A retrospective review was conducted, including 133 patients followed between October 2023 and January 2025. Urodynamic studies and voiding cystourethrography (VCUG) were performed within a short interval of dimercaptosuccinic acid (DMSA) scintigraphy. BDR was measured on standardized anteroposterior VCUG images as the mean of two independent measurements. Correlation analyses, receiver operating characteristic (ROC) curves, and multivariable logistic regression were performed. Internal validation was conducted using bootstrap resampling, and model calibration and decision curve analysis were also assessed.
Results: Renal scarring was identified in 55.6% of patients. Children with scarring had significantly higher BDR values (1.51±0.27 vs. 1.27±0.27, $p<0.001$). BDR demonstrated the strongest discrimination (area under the curve [AUC] 0.74, 95% confidence interval [CI] 0.64–0.83) and remained the variable most strongly associated with renal scarring in multivariable analysis (adjusted odds ratio [OR] 1.027, $p=0.002$). Although Pdet >32 cmH_2O and high-grade VUR were associated with scarring, their effects were attenuated after adjustment. eGFR was lower in scarred patients (117.3 vs. 130.4 mL/min/1.73 m², $p=0.003$), although its early discriminatory performance was limited.
Conclusions: BDR showed the strongest association with renal scarring among the evaluated morphologic and urodynamic parameters. Pdet and VUR provided supportive but overlapping risk information, whereas eGFR reflected later functional decline. Because the BDR and Pdet thresholds in this study were derived from the present dataset, they should be interpreted as exploratory and require external validation before being used clinically. Given its availability from routine VCUG imaging, BDR may assist in identifying higher-risk patients pending confirmation in independent cohorts.

INTRODUCTION

Neurogenic lower urinary tract dysfunction in childhood is most commonly associated with spinal dysraphism and leads to significant abnormalities in bladder storage and emptying (1,2). Elevated detrusor pressures, reduced compliance, and increased post-void residual volumes contribute to vesicoureteral reflux (VUR), recurrent urinary tract infections, and progressive renal scarring. Long-term studies indicate that renal deterioration in children with neurogenic bladder often develops silently, with unrecognized high-pressure filling patterns being among the strongest determinants of upper tract damage (3).

Classic urodynamic research demonstrates that filling-phase detrusor pressures (Pdet) exceeding 30–40 cmH_2O markedly increase the risk of renal scarring and hydronephrosis (4,5). Current international guidelines therefore emphasize maintaining storage pressures below 30 cmH_2O as a cornerstone of renal preservation (6). However, routine urodynamic monitoring is not always feasible, and repeated invasive testing in children may be limited, increasing clinical interest in radiological markers that can complement or approximate urodynamic findings.

The bladder diameter ratio (BDR), derived from standard anteroposterior VCUG images, has emerged as a simple morphological indicator of low-compliance, high-pressure tower bladder configuration. Several studies have reported significant associations between elevated BDR, high-grade VUR, and renal scarring (7,8).

VUR in neurogenic bladder typically reflects elevated intravesical pressure and abnormal bladder dynamics. Higher reflux grades are associated with greater scarring risk, and outcomes of anti-reflux surgery remain suboptimal unless bladder pressures are adequately controlled (9,10). Accordingly, VUR should always be interpreted in the context of both pressure and morphology.

Estimated glomerular filtration rate (eGFR) reflects renal function; however, reductions in eGFR typically occur later than radiological evidence of parenchymal injury (11), limiting its utility as an early indicator.

Clean intermittent catheterization (CIC) remains central to management. While older studies suggested benefits of earlier initiation (12), more recent evidence indicates that outcomes depend more on adherence and effective pressure control than on the precise age at initiation (13,14).

Despite the relevance of these parameters, few studies have assessed morphological (BDR), urodynamic (Pdet), functional (eGFR), and reflux-related (VUR) markers concurrently within the same cohort. Clarifying how these variables relate to renal scarring in children with neurogenic bladder may help identify those at higher risk for early upper tract deterioration and allow more targeted surveillance and intervention.

METHODS

Study design

This study employed a cross-sectional design in which predictor variables and DMSA findings were obtained within the same clinical period. Accordingly, the analyses describe concurrent associations rather than true prognostic performance. The dataset consisted of children with neurogenic bladder secondary to spinal dysraphism who were followed between October 2023 and January 2025.

Ethics approval

Ethical approval was granted by the Izmir City Hospital Ethics Committee on August 13, 2025 (Decision No. 339/2025). In accordance with institutional policy, the committee provides general authorization for retrospective access to clinical records and PACS archives;

therefore, all data extraction occurred after ethics approval. No patient contact was required, and no identifiable personal information was collected.

Measurement characteristics and rationale for modeling choices
BDR measurements were obtained by a single observer; interobserver reliability could not be assessed and is acknowledged as a study limitation. VUR showed substantial collinearity with both BDR and Pdet, and high-grade cases contributed to coefficient instability in multivariable models. For this reason, VUR was not included as an independent predictor in adjusted analyses but was reported comprehensively in descriptive and subgroup analyses.

Multivariable modeling adhered to the events-per-variable (EPV) principle. To evaluate the risk of overfitting, ridge penalization and bootstrap resampling with 1000 iterations were applied. Model performance indicators—including AUC, Brier score, and calibration measures—are presented in the Results.

Study population
Children with spinal dysraphism (myelomeningocele, lipomyelomeningocele, tethered cord) were eligible if they had:

1. at least one complete urodynamic study,
2. VCUG images of adequate diagnostic quality, and
3. DMSA scintigraphy performed for renal scar assessment.

Patients with prior major urinary tract reconstruction or missing key clinical/urodynamic data were excluded. A total of 133 children met inclusion criteria and were included in the final analysis.

Timing of predictor and outcome variables
Urodynamic studies, VCUG, and eGFR measurements were obtained within 0–6 months of the DMSA scan, consistent with institutional clinical protocols. Because predictors and outcomes were measured in the same window, the models characterize cross-sectional associations rather than longitudinal prognostic performance.

Clinical data
Demographic characteristics, ambulatory status, urinary tract infection history, anticholinergic medication use, and CIC practices were extracted from patient files. The age at CIC initiation was recorded; however, CIC frequency and adherence could not be reliably quantified and were not included in analyses.

Urodynamic evaluation
All studies were performed according to ICCS standards (3). A 6 Fr or 7 Fr double-lumen catheter was used, with a filling rate of 10% of expected bladder capacity per minute. Studies were conducted in the supine position using 37°C saline. Pdet was defined as the maximum detrusor pressure during filling. Leakage was confirmed by urethral flow sensors and direct observation.

A threshold of 32 cmH_2O was used as the reference value for high-pressure storage, consistent with commonly applied cutoffs in contemporary pediatric neurogenic bladder studies (4,5). Although McGuire originally proposed 40 cmH_2O as a classic risk threshold (6), current ICCS guidance emphasizes maintaining storage pressures <30 cmH_2O (7).

VCUG and BDR
BDR was calculated from anteroposterior VCUG images obtained at full bladder capacity as:

BDR = vertical bladder length / horizontal bladder width

Measurements were performed twice by a single observer, and the mean value was used. No interobserver assessment was available. Measurements were conducted independently of DMSA results.

VUR
VUR was graded according to the International Reflux Classification (I–V). High-grade VUR was defined as grades IV–V. Although present in 48 children, VUR showed strong collinearity with BDR and Pdet and produced unstable coefficients in multivariable regression. Therefore, it was excluded from adjusted models but fully reported descriptively.

Renal function (eGFR)
eGFR was calculated using the age-adjusted Schwartz formula:

eGFR = (k × height [cm]) / serum creatinine [mg/dL]

with k = 0.55 for children and 0.70 for adolescent males (8).

Renal scar assessment
Renal scarring was assessed using 99mTc-DMSA scintigraphy (9). Scars were defined as cortical defects, parenchymal thinning, or asymmetric uptake. A semi-quantitative score was assigned (0–4). Analyses considered both the binary and continuous forms of the outcome.

Statistical analysis
Continuous variables were summarized as mean ± SD; categorical variables as counts and percentages. Student's t-tests, Mann–Whitney U tests, and chi-square tests were used as appropriate. Spearman correlation coefficients assessed relationships among BDR, Pdet, eGFR, and VUR. Variance inflation factors (VIF ≤ 2.5) indicated no concerning multicollinearity in the final model.

ROC curves were created for BDR, Pdet, eGFR, and age at CIC initiation. Cut-off points were derived using the Youden index but interpreted cautiously due to their data-driven nature. A multivariable logistic regression model was constructed for the binary outcome. Ridge penalization and sensitivity analyses were applied. Given the modest number of events and predictor collinearity, multivariable estimates were considered exploratory.

Internal validation was conducted using 1000 bootstrap replications. Performance measures included apparent and optimism-adjusted AUC, Brier score, calibration slope and intercept, and LOESS-based calibration curves. Decision curve analysis (DCA) evaluated the net clinical benefit of individual and combined models. Statistical significance was defined as $p < 0.05$.

RESULTS
A total of 133 children were included in the analysis, with a mean age of 7.4 ± 4.6 years; 51.9% were male. CIC was used by 77.4% of participants, and the mean age at CIC initiation was 5.0 ± 4.7 years. The mean BDR was 1.39 ± 0.32, the mean maximum filling-phase Pdet was 28.5 ± 12.3 cmH_2O, and the mean eGFR was 123.2 ± 27.6 mL/min/1.73 m^2. Renal scarring was detected in 74 children (55.6%) on DMSA scintigraphy (Table 1).

Bladder morphology and renal scarring
Children with renal scarring demonstrated significantly higher BDR values than those without scarring (1.51 ± 0.27 vs. 1.27 ± 0.27; $p < 0.001$).

BDR showed the strongest discriminatory performance on ROC analysis (AUC 0.74; 95% CI 0.64–0.83). A Youden-derived threshold of 1.28 yielded 82.4% sensitivity and 57.9% specificity.

In exploratory multivariable analysis, BDR remained independently associated with renal scarring (adjusted OR 1.027; 95% CI 1.010–1.044; $p = 0.002$; Supplementary Table S1). Each 0.01-unit increase in BDR was associated with an estimated 3–4% relative increase in scarring risk.

Urodynamic parameters
Renal scarring was more common in children with Pdet values >32 cmH_2O than in those with lower pressures (69.4% vs. 39.3%; $p < 0.001$).

However, after adjusting for BDR and other variables, Pdet did not retain independent significance ($p = 0.12$) (Table 2), suggesting overlap between bladder morphology and elevated storage pressures. Higher Pdet values were also more frequently observed in children with high-grade VUR (Table 3).

Vesicoureteral reflux
High-grade VUR (grades IV–V) was present in 48 children, while 12 had low-grade reflux and 73 had no reflux.

Mean DMSA scar scores were highest in the high-grade VUR group (2.06 ± 1.42), significantly exceeding scores in both the non-reflux and low-grade groups ($p < 0.001$).

High-grade VUR was also associated with lower mean eGFR values (113.9 ± 34.3 mL/min/1.73 m^2) (Table 3).

The relatively high prevalence of VUR in this cohort reinforces its close relationship with neurogenic bladder pathophysiology. However, variability across VUR subgroups and collinearity with other predictors limited its performance as an independent predictor in multivariable analyses; therefore, VUR was considered a clinically relevant risk-augmenting feature rather than a primary determinant in adjusted models.

Renal function
Children with renal scarring had significantly lower eGFR values compared with those without scarring (117.3 ± 33.7 vs. 130.4 ± 14.6 mL/min/1.73 m^2; $p = 0.003$).

BDR demonstrated a weak-to-moderate negative correlation with eGFR ($r = –0.262$; $p = 0.0023$).

Despite these associations, eGFR showed limited discriminatory ability in ROC analysis (AUC 0.57), supporting its role as an indicator of later functional decline rather than early structural injury.

Age at initiation of CIC
ROC analysis suggested an optimal CIC initiation threshold of 5 years (AUC 0.56), but age at CIC initiation did not remain independently associated with scarring in multivariable models ($p = 0.23$). These findings indicate that long-term protection is likely influenced by adherence and pressure control rather than the timing of CIC onset.

Correlation analyses
VUR grade showed a moderate positive correlation with DMSA scar score ($r = 0.372$; $p < 0.001$).

BDR and VUR demonstrated a weak-to-moderate correlation ($r = 0.228$; $p = 0.017$). The correlation between VUR and eGFR was weak and not statistically significant ($r = –0.127$; $p = 0.187$) (Table 5).

Multivariable model performance
The exploratory multivariable logistic regression model is presented in Supplementary Table S1.

Given the limited events-per-variable and collinearity among predictors, adjusted estimates should be interpreted cautiously.

Bootstrap validation demonstrated good calibration, with minimal deviation in calibration slope or intercept.

Brier scores indicated acceptable overall accuracy.

Decision curve analysis showed that models incorporating both BDR and Pdet provided greater net clinical benefit than single-parameter models across a range of threshold probabilities.

DISCUSSION
This study evaluated the interplay between bladder morphology, storage-phase pressure, reflux severity, and renal function in a contemporary cohort of children with neurogenic bladder due to spinal dysraphism. Our findings highlight the BDR as the parameter most consistently associated with renal scarring, suggesting that disruptions in the morpho-urodynamic relationship may serve as early indicators of upper tract vulnerability. While elevated detrusor pressure and high-grade VUR were also associated with scarring, their effects appeared to converge within the morphological domain represented by BDR.

BDR as a morphological marker of risk
Among all variables examined, BDR showed the strongest and most stable association with renal scarring, both in descriptive analyses and in exploratory adjusted models. Even small increments in BDR were associated with meaningful increases in scarring probability. This observation is consistent with previous work describing the "tower bladder" configuration—characterized by a vertically elongated, low-compliance reservoir—as a marker of pressure-related risk, and with reports linking bladder shape and vertical–transverse ratios to both VUR and renal scarring (7,8).

A key advantage of BDR is its accessibility: it can be calculated from routine VCUG without the need for specialized equipment and may complement urodynamic evaluation in settings where repeated invasive testing is impractical. However, the absence of interobserver reliability assessment in our study underscores the need for standardized measurement protocols and reproducibility studies, ideally incorporating dual-observer measurements and intraclass correlation coefficient (ICC) analysis in future work.

The role of storage pressure
The relationship between elevated storage pressure and renal injury has been well described in the neurogenic bladder literature (4–6). Classic work by McGuire et al. identified filling pressures above 40 cmH_2O as high-risk, whereas more recent guidelines emphasize maintaining storage pressures below 30 cmH_2O to protect the upper tracts (6). Consistent with these data, children with Pdet >32 cmH_2O in our cohort had substantially higher rates of renal scarring. However, Pdet did not retain independent significance after adjustment for BDR, reflecting the considerable overlap between bladder configuration and storage-phase pressure and supporting prior observations that morphological deterioration may mediate the impact of pressure on renal outcomes (3). This does not diminish the clinical relevance of Pdet; rather, our findings suggest that BDR may function as a morphological surrogate—or downstream consequence—of chronically elevated filling pressures. Morphological and urodynamic markers should therefore be viewed as complementary, and neither should be interpreted in isolation.

VUR as a secondary phenomenon rather than an independent predictor
The association between VUR and renal scarring is well established (9,10), and this pattern was evident in our cohort, particularly among children with high-grade reflux. However, VUR showed strong overlap with bladder morphology (BDR) and storage pressure (Pdet), leading to collinearity and unstable coefficients in multivariable models. This behaviour is consistent with the pathophysiological notion that VUR often arises as a consequence of impaired compliance and elevated intravesical pressure rather than acting as an independent driver of renal injury. For this reason, VUR was not retained as an independent predictor in adjusted analyses. Nevertheless, it remains clinically meaningful and was interpreted as a risk-augmenting marker that should be considered alongside bladder configuration and pressure, rather than as a standalone determinant in risk stratification.

Renal function as a late indicator
The lower eGFR values observed in children with renal scarring were expected, as eGFR typically reflects functional decline at a later stage of the disease process (11). Consistent with this, eGFR demonstrated limited discriminatory ability and only weak correlations with other predictors, indicating that it cannot be relied upon for early risk identification, even though it remains essential for monitoring long-term renal function. The absence of a clear non-linear inflection in spline analyses further suggests that eGFR in pediatric patients may be influenced by age-related variations such as hypertrophic or hyperfiltration phases, underscoring the need for cautious interpretation and reinforcing the importance of morphological and urodynamic markers for early detection.

Clinical relevance of age at CIC initiation
Historically, earlier initiation of CIC has been linked to better renal outcomes in children with neurogenic bladder (12). More recent evidence, however, suggests that long-term preservation of renal function depends less on the chronological age at which CIC is started and more on sustained pressure control, appropriate pharmacotherapy, and adherence to catheterization regimens (13,14). Our findings are consistent with this view: age at CIC initiation was not independently associated with renal scarring. The relatively older initiation age observed in this cohort likely reflects contextual factors rather than deficiencies in clinical decision-making. In particular, delays in routine neuro-urological follow-up during the COVID-19 pandemic, changes in health-seeking behaviour among families, and the temporary disruption of regional healthcare infrastructure following the 2023 earthquake may all have contributed to later assessment and initiation of CIC. These observations support the interpretation that effective CIC practice—combined with stable detrusor pressure control and ongoing morphological surveillance—is more critical for renal protection than the exact age at which CIC is begun.

Model performance and clinical interpretation
Bootstrap validation and calibration analyses indicated acceptable internal performance and a limited risk of overfitting. Decision curve analysis further showed that models incorporating both BDR and Pdet provided greater net clinical benefit across a broader range of threshold probabilities, suggesting practical value in considering these parameters jointly. Nevertheless, all thresholds examined in this study were derived from a single cross-sectional cohort and should be regarded as exploratory rather than definitive. In particular, the BDR value of 1.28 represents a statistically optimal cut-off within this dataset, not a clinically validated decision point. Since predictors and DMSA findings were collected within the same timeframe, the models characterize cross-sectional associations rather than future risk prediction. Clinical adoption of any proposed thresholds should therefore await external validation in

independent, ideally longitudinal, cohorts, and current findings are best viewed as hypothesis-generating.

Strengths and limitations

This study is among the relatively few investigations to evaluate morphological, urodynamic, and functional parameters concurrently within a single pediatric neurogenic bladder cohort. The integration of VCUG-based bladder morphology with standardized urodynamic measures provides a comprehensive view of factors associated with renal scarring. In addition, the use of both SPSS (v26) and R (v4.3.2) contributed to methodological robustness and allowed complementary statistical validation.

Several limitations should also be acknowledged. The retrospective, cross-sectional design limits causal inference and precludes assessment of temporal relationships between predictors and renal outcomes. BDR measurements were performed by a single observer; although duplicate assessments enhanced intra-observer consistency, the absence of inter-observer reliability testing restricts generalizability across centers. Future studies should incorporate multi-observer evaluation with intraclass correlation coefficient (ICC) analysis to address this issue. Variability in VUR grading represents another potential source of measurement bias, as interpretation may differ among clinicians and institutions. Moreover, objective data on CIC adherence were not available, preventing evaluation of this key aspect of long-term management. Despite these limitations, the present findings provide a useful foundation for future prospective studies aimed at validating BDR-based risk stratification and refining combined morphological–urodynamic models for early detection of renal injury.

CONCLUSIONS

This study provides an integrated evaluation of bladder morphology, urodynamic parameters, reflux severity, and renal function in children with neurogenic bladder secondary to spinal dysraphism. Among all variables examined, the BDR showed the strongest and most consistent association with renal scarring. Increasing BDR values reflect a vertically elongated, low-compliance, high-pressure bladder configuration and may serve as a practical morphological marker for identifying children at increased risk of upper tract injury.

Although filling-phase Pdet and high-grade VUR remained clinically meaningful findings, their effects overlapped substantially with BDR in adjusted analyses, suggesting that pressure- and reflux-related renal injury may be mediated, at least in part, through underlying morphological changes. eGFR was lower in children with scarring but showed limited discriminatory capacity for early detection, and age at initiation of CIC was not independently associated with scarring, reinforcing that long-term protection of renal function depends more on sustained pressure control and treatment adherence than on the timing of CIC onset.

Because BDR can be obtained easily and non-invasively from routine VCUG imaging, it may contribute to early risk stratification in pediatric neurogenic bladder. However, the BDR- and Pdet-related thresholds identified in this study are exploratory and cohort-specific; they should not be used as clinical decision points without external validation. Given the cross-sectional design, the associations reported here should not be interpreted as causal or as evidence of validated prognostic performance. Prospective, multi-center studies are needed to confirm these findings and refine combined morphological–urodynamic risk models aimed at preserving long-term renal function.

REFERENCES

1. Bauer SB. The management of the neuropathic bladder in children. *J Urol* 1984;132:240-4. https://doi.org/10.1016/S0022-5347(17)49729-1
2. Routh JC, Joseph DB, Cheng EY, et al. Long-term renal outcomes in children with neurogenic bladder: A multicenter review. J *Pediatr Urol*. 2021;17:511-20.
3. Silva JM, Lopes RI, Macedo A Jr. Urodynamic and imaging predictors of upper urinary tract deterioration in children with neurogenic bladder. *Neurourol Urodyn* 2020;39:960-8.
4. McGuire EJ, Woodside JR, Borden TA, et al. Prognostic value of urodynamic testing in myelodysplastic patients. *J Urol* 1981;126:205-9. https://doi.org/10.1016/S0022-5347(17)54449-3
5. Koff SA. Estimating bladder storage pressure by end-filling detrusor pressure. *J Urol* 1983;129:317-9.
6. Austin PF, Bauer SB, Bower W, et al. The standardization of terminology of lower urinary tract function in children and adolescents: Update report from the ICCS. *J Urol* 2020;203:112-20.
7. Kajbafzadeh AM, Sharifi-Rad L, Ahmadi H, et al. Bladder shape and compliance in children with neurogenic bladder: Urodynamic and imaging correlation. *Urology* 2013;82:1041-7.
8. Dicuio M, Pomara G, Menchini Fabris F, et al. Morphologic changes of the bladder in children with neurogenic dysfunction and their clinical implications. *Pediatr Nephrol* 2016;31:1329-38.
9. Sillén U, Hansson S, Hermansson G, et al. Bladder function and renal damage in children with neurogenic bladder dysfunction. *J Urol* 2015;194:758-64.
10. Stohrer M, Castro-Diaz D, Chartier-Kastler E, et al. EAU guidelines on neurogenic lower urinary tract dysfunction. *Eur Urol* 2009;56:81-8. https://doi.org/10.1016/j.eururo.2009.04.028
11. Piepsz A, Colarinha P, Gordon I, et al. Guidelines for 99mTc-DMSA scintigraphy in children. *Eur J Nucl Med Mol Imaging* 2014;41:1025-33.
12. Dik P, Klijn AJ, van Gool JD, et al. Early start to clean intermittent catheterization in newborns with spina bifida reduces renal deterioration. *J Urol* 2006;176:1106-11.
13. Verpoorten C, Buyse GM. The neurogenic bladder: Medical treatment. *Eur Urol* 2008;54:891-900. https://doi.org/10.1007/s00467-007-0691-z
14. Sager C, Lopes RI, Macedo A Jr. Management of neurogenic bladder dysfunction in children: Current concepts and future directions. *Int Braz J Urol* 2022;48:31-51. https://doi.org/10.1590/s1677-5538.ibju.2020.0989

FIGURES AND TABLES

Table 1. Baseline demographic and clinical characteristics	
Variable	**Value**
Number of patients, n	133
Age (years), mean ± SD	7.4±4.6
Sex (male/female)	69 (51.9%)/64 (48.1%)
Patients performing CIC	103 (77.4%)
Age at CIC initiation (years)	5.0±4.7
Mean BDR	1.39±0.32
Mean Pdet (cmH_2O)	28.5±12.3
Mean eGFR (mL/min/1.73 m^2)	123.2±27.6
Renal scarring present	74 (55.6%)

BDR: bladder diameter ratio; CIC: clean intermittent catheterization; eGFR: estimated glomerular filtration rate; Pdet: detrusor pressure; SD: standard deviation.

Table 2. Diagnostic performance of candidate parameters based on ROC analysis					
Parameter	**AUC**	**Cutoff**	**Sensitivity (%)**	**Specificity (%)**	**p**
BDR	**0.74**	1.28	82.4	57.9	**0.002**
Pdet	0.63	32 cmH_2O	71.6	62.7	0.12
eGFR	0.57	122	91.2	29.7	0.056
Age at CIC initiation	0.56	5 years	50.8	64.1	0.23

p-values refer to the null hypothesis AUC=0.5. AUC: area under the curve; BDR: bladder diameter ratio; CIC: clean intermittent catheterization; eGFR: estimated glomerular filtration rate; Pdet: filling-phase detrusor pressure.

Table 3. Clinical parameters and renal damage according to VUR grade				
VUR group	**Patients (n)**	**DMSA score (mean ± SD)**	**eGFR (mean ± SD)**	**Pdet (mean ± SD)**
No VUR	73	0.79±1.26	128.2±22.5	35.2±22.9
Low grade (I–III)	12	0.75±0.97	129.7±15.0	47.1±22.4
High grade (IV–V)	48	2.06±1.42	113.9±34.3	47.6±23.8

DMSA: dimercaptosuccinic acid; eGFR: estimated glomerular filtration rate; Pdet: filling-phase detrusor pressure; SD: standard deviation; VUR: vesicoureteral reflux.

Table 4. eGFR distribution across combined BDR-Pdet groups					
Group	**Definition**	**Patients (n)**	**Mean eGFR**	**SD**	**Median eGFR**
1	BDR <1.28 & Pdet <32	36	133.1	11.2	136
2	BDR <1.28 & Pdet ≥32	12	118.8	18.6	125
3	BDR ≥1.28 & Pdet <32	22	130.8	14.9	133
4	BDR ≥1.28 & Pdet ≥32	63	115.7	35.8	132

Group 4 demonstrated the lowest mean eGFR, reflecting combined morphologic deterioration and elevated storage pressure. ; BDR: bladder diameter ratio; eGFR: estimated glomerular filtration rate; Pdet: filling-phase detrusor pressure; SD: standard deviation.

Table 5. Correlation analysis between clinical and radiologic variables		
Variable pair	**Correlation (r)**	**p**
VUR ↔ DMSA scarring	0.372	**<0.001**
BDR ↔ VUR	0.228	**0.017**
VUR ↔ eGFR	-0.127	0.187
BDR ↔ eGFR	-0.262	**0.0023**

Bolded values indicate statistical significance. DMSA: dimercaptosuccinic acid; eGFR: estimated glomerular filtration rate; VUR: vesicoureteral reflux.