INTERNATIONAL JOURNAL OF MEDICAL SCIENCE AND DENTAL HEALTH
(ISSN: 2454-4191)
www.ijmsdh.org (2026)

Received: 24 June 2026
Revised: 06 July 2026
Accepted: 18 July 2026
Published: 11 Aug 2026

Volume 12 Issue 08, 2026
Page No - 76-83
DOI - 10.55640/ijmsdh-12-08-09

Article Citation: Xolmurodov Mamathon, Akram Abdukhamidov, & Ganiev Mukhammadbobir. (2026). Probabilistic Assessment of Composite Urodynamic Success After Posterior Urethral Valve Ablation: A Monte-Carlo Simulation and Binormal ROC Analysis. International Journal of Medical Science and Dental Health, 12(8), 76-83. https://doi.org/10.55640/ijmsdh-12-08-09

Probabilistic Assessment of Composite Urodynamic Success After Posterior Urethral Valve Ablation: A Monte-Carlo Simulation and Binormal ROC Analysis

Xolmurodov Mamathon

Namangan State University, Faculty of Physics and Mathematics, Namangan, Uzbekistan

Akram Abdukhamidov

Department of Pediatric Surgery, Republican Scientific Center of Emergency Medical Care Tashkent Regional Branch, Tashkent, Uzbekistan

Ganiev Mukhammadbobir

Department of Pediatric Surgery, Republican Scientific Center of Emergency Medical Care Tashkent Regional Branch, Tashkent, Uzbekistan

Abstract

Background. Surgical techniques for posterior urethral valve (PUV) ablation are compared by their mean postoperative urodynamic values. Clinical success, however, is defined by thresholds: a patient either does or does not reach an acceptable residual volume, flow rate and outlet resistance. Whether a technique delivers success for an individual child depends on the dispersion of its results as much as on their mean, and a mean-based ranking can therefore mislead.

Objective. To estimate the probability that an individual patient meets a composite urodynamic success criterion under each of three ablation techniques, and to determine the discriminating capacity and optimal cut-off of the urethral resistance coefficient.

Methods. Postoperative distributions of post-void residual volume, mean flow rate and urethral resistance coefficient reported for 142 boys (endoscopic resection n = 32; polyethylene valvulotome n = 49; metallic valvulotome n = 61) were used as inputs to a Monte-Carlo simulation of 200 000 virtual patients per technique. Composite success was defined as residual volume ≤ 15 ml and mean flow rate ≥ 10 ml/s and resistance coefficient ≤ 0.12, all three simultaneously. The simulation was repeated with an inter-variable correlation of 0 and 0.30. Discrimination between the obstructed and relieved states was quantified by binormal ROC analysis with Youden-optimal cut-offs.

Results. Simulated composite success probabilities were 39.8 % for endoscopic resection, 97.4 % for the polyethylene valvulotome and 82.8 % for the metallic valvulotome; introducing correlation changed these by less than 4.3 percentage points. The ranking differs from that obtained by comparing means, in which the metallic valvulotome performs best on every individual variable. The discrepancy is attributable entirely to the dispersion of postoperative flow rate in the metallic group (15.36 ± 5.60 ml/s), which reduced the marginal probability of reaching 10 ml/s to 83.1 % despite the highest mean. Binormal ROC analysis of the resistance coefficient gave areas under the curve of 0.967, 1.000 and 0.996 with Youden-optimal cut-offs of 0.192, 0.146 and 0.100 respectively.

Conclusions. Probabilistic modelling identifies variability, rather than the mean, as the factor limiting composite success after metallic valvulotome ablation. The dispersion of postoperative flow rate in that group is disproportionate to the other groups and requires verification against the primary records. Comparative studies reporting only means may rank techniques in an order that does not reflect the probability of success for an individual child.

Keywords: Posterior urethral valve; Monte-Carlo simulation; probabilistic modelling; ROC analysis; composite endpoint; urodynamics; paediatric urology.

Introduction

Endoscopic and instrumental ablation of posterior urethral valves relieves the anatomical obstruction, but a substantial proportion of patients retain lower urinary tract dysfunction and progress to chronic kidney disease [1–3]. Comparisons between ablation techniques are conventionally reported as group means with significance tests, and the technique with the most favourable means is judged superior.

This convention rests on an assumption that is rarely stated: that a better mean implies a higher probability of a good outcome for the individual patient. The assumption fails whenever the outcome is defined by a threshold. A technique that produces a high mean flow rate with wide scatter may leave more children below an acceptable flow than a technique with a lower but tightly clustered mean. The distinction matters clinically, since the decision facing the surgeon concerns a particular child, not a group average.

Clinical success after valve ablation is in fact a conjunction of conditions — adequate emptying, adequate flow and acceptable outlet resistance — that must hold simultaneously. The probability of such a composite event is not recoverable from marginal means and requires either individual-level data or simulation from the reported distributions. Monte-Carlo methods are established for this purpose in health-economic and diagnostic modelling [4, 5] but have not been applied to the comparison of PUV ablation techniques.

The aims of this study were, first, to estimate by simulation the probability of composite urodynamic success under each of three ablation techniques, and second, to determine how well the urethral resistance coefficient discriminates the obstructed from the relieved state and at what cut-off.

Methods

Source data. Postoperative urodynamic distributions were taken from a cohort of 142 boys operated on for PUV: group I, endoscopic valve resection (n = 32); group II, polyethylene valvulotome ablation (n = 49); group III, metallic valvulotome ablation (n = 61). Three variables entered the composite criterion: post-void residual volume V_r (ml), mean flow rate Q (ml/s) and the urethral resistance coefficient K_u (dimensionless). Their postoperative means and standard deviations are given in Table 1.

Composite success criterion. Success was defined as the simultaneous fulfilment of

$$V_r \le 15\text{ml} \wedge Q \ge 10\text{ml/s} \wedge K_u \le 0.12 \quad (1)$$

The residual-volume threshold corresponds to near-complete emptying in this age range; the flow threshold is set below the postoperative mean of every group so as not to favour any technique; the resistance threshold lies between the postoperative means of groups I and II. Because the choice of thresholds is a modelling decision rather than an established standard, results are reported for the stated values and their sensitivity examined below.

Monte-Carlo simulation. For each technique, 200 000 virtual patients were generated. Each variable was drawn from a normal distribution with the group's reported postoperative mean and standard deviation. Dependence between variables was introduced through a single common factor,

$$X_i = \mu_i + s_i\left(\sqrt{\rho}\,\sigma_i Z_0 + \sqrt{1-\rho}\,Z_i\right) \qquad (2)$$

where Z_0 is a shared standard normal variate, Z_i are independent standard normal variates, and $\sigma_i = +1$ for variables whose increase indicates a better outcome and −1 otherwise, so that a favourable common factor moves all three in the clinically concordant direction. Simulations were run at $\rho = 0$ (independence) and $\rho = 0.30$. The success proportion among the 200 000 draws estimates the probability in equation (1); with this sample size the Monte-Carlo standard error is below 0.12 percentage points. Marginal probabilities for each condition were computed analytically from the normal distribution function.

Binormal ROC analysis. Treating the preoperative and postoperative distributions of K_u as the two classes, the area under the ROC curve follows in closed form as

$$AUC = \Phi\left(\frac{\mu_{\text{pre}} - \mu_{\text{post}}}{\sqrt{s_{\text{pre}}^2 + s_{\text{post}}^2}}\right) \qquad (3)$$

and sensitivity and specificity at a cut-off c $\Phi\left(\frac{c-\mu_{\text{post}}}{s_{\text{post}}}\right)$`. The Youden index J = sensitivity + specificity − 1 was maximised over c on a grid of 501 points in [0, 0.5].

Sample size for a confirmatory study. The number of patients per arm required to detect the observed between-technique difference in postoperative K_u was obtained from $n = 2\left(\frac{z_{1-\alpha/2} + z_{1-\beta}}{d}\right)^2$ with $\alpha = 0.05$ and power 0.80.

Software. Simulations were performed in Python 3.12 with NumPy 2.4 and SciPy 1.17, using a fixed random seed for reproducibility.

Ethics. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee of [institution], protocol No. [number] of [date]. The simulation used aggregate statistics only; no individual patient data were accessed for this analysis.

Results

Table 1. Postoperative distributions used as simulation inputs (mean ± SD)

Variable	Group I (n = 32)	Group II (n = 49)	Group III (n = 61)
Post-void residual V_r, ml	11.19 ± 7.19	9.10 ± 1.58	8.93 ± 2.28
Mean flow rate Q, ml/s	13.42 ± 0.81	12.67 ± 0.96	15.36 ± 5.60
Urethral resistance K_u	0.11 ± 0.06	0.08 ± 0.02	0.05 ± 0.02
Coefficient of variation of Q, %	6.0	7.6	36.5

Marginal and joint success probabilities are given in Table 2. Under independence the composite success probability was 39.8 % for endoscopic resection, 97.4 % for the polyethylene valvulotome and 82.8 % for the metallic valvulotome. Introducing a common factor with $\rho = 0.30$ raised the values to 44.0 %, 97.5 % and 82.9 % respectively; the ordering was unchanged and the largest shift, in group I, amounted to 4.2 percentage points.

Table 2. Marginal and composite probabilities of urodynamic success (Monte-Carlo, 200 000 draws per technique)

Technique	$P(V_r \leq 15)$	$P(Q \geq 10)$	$P(K_u \leq 0.12)$	Composite, ρ = 0	Composite, ρ = 0.3
I — endoscopic resection	70.2 %	100.0 %	56.6 %	**39.8 %**	44.0 %
II — polyethylene valvulotome	100.0 %	99.7 %	97.7 %	**97.4 %**	97.5 %
III — metallic valvulotome	99.6 %	83.1 %	100.0 %	**82.8 %**	82.9 %

Marginal probabilities computed analytically; composite probabilities by simulation. Monte-Carlo standard error < 0.12 percentage points.

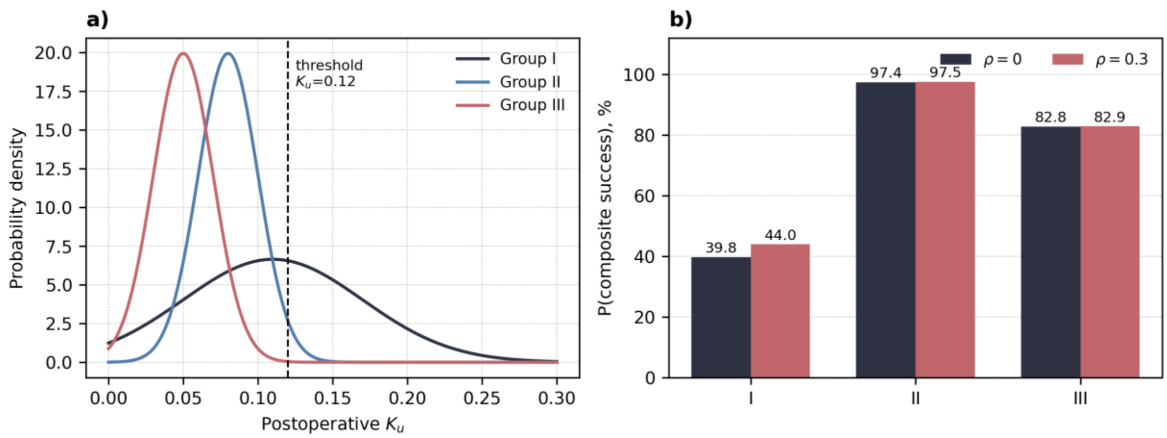

Figure 1. a) Modelled postoperative distributions of the urethral resistance coefficient with the success threshold; b) composite success probability by technique at two levels of inter-variable correlation.

The limiting condition differs between techniques. In group I both the residual-volume condition (70.2 %) and the resistance condition (56.6 %) are binding, reflecting postoperative means close to the thresholds combined with wide dispersion (V_r = 11.19 ± 7.19 ml; K_u = 0.11 ± 0.06). In group III the residual-volume and resistance conditions are met almost with certainty (99.6 % and 100.0 %), and the sole limiting factor is the flow-rate condition (83.1 %). This occurs despite group III having the highest postoperative mean flow rate of the three (15.36 ml/s against 13.42 and 12.67), because its standard deviation of 5.60 ml/s corresponds to a coefficient of variation of 36.5 %, against 6.0 % and 7.6 % in the other two groups.

Because the thresholds in equation (1) are modelling choices, each was varied while the other two were held fixed (Table 4). Group I remained lowest under every variant. The ordering of groups II and III, in contrast, is not robust: tightening the resistance criterion to $K_u \leq 0.08$ reverses it (77.2 % for the metallic technique against 49.9 % for the polyethylene), and raising the flow criterion to 12 ml/s brings the two to within 1.7 percentage points. Relaxing the residual-volume criterion to 20 ml or the resistance criterion to 0.15 leaves the reported ordering unchanged.

Table 4. Sensitivity of the composite success probability to the choice of thresholds

Threshold set	Group I	Group II	Group III
$Q \geq 8$ ml/s (others as stated)	39.7 %	97.7 %	90.2 %
$Q \geq 10$ ml/s (reference)	39.7 %	97.5 %	82.7 %
$Q \geq 12$ ml/s	38.2 %	74.0 %	72.3 %
$K_u \leq 0.08$	21.7 %	49.9 %	77.2 %
$K_u \leq 0.10$	30.4 %	83.9 %	82.2 %
$K_u \leq 0.15$	52.5 %	99.7 %	82.8 %
$V_r \leq 10$ ml	24.6 %	69.7 %	56.5 %
$V_r \leq 20$ ml	50.4 %	97.5 %	83.1 %

In each row the stated threshold is varied and the remaining two are held at their reference values ($V_r \leq 15$ ml, $Q \geq 10$ ml/s, $K_u \leq 0.12$). Computed analytically under independence.

Binormal ROC results for the urethral resistance coefficient are given in Table 3 and Figure 2. Discrimination between the obstructed and relieved states was excellent in every group, with areas under the curve of 0.967 (group I), 1.000 (group II) and 0.996 (group III). Youden-optimal cut-offs fell at 0.192, 0.146 and 0.100 respectively, giving sensitivities of 0.914 to 0.999 and specificities of 0.896 to 0.999.

Table 3. Binormal ROC characteristics of the urethral resistance coefficient

Group	AUC	Optimal cut-off	Sensitivity	Specificity	Youden J
I — endoscopic resection	0.967	0.192	0.914	0.896	0.810
II — polyethylene valvulotome	1.000	0.146	0.999	0.999	0.999
III — metallic valvulotome	0.996	0.100	0.994	0.977	0.971

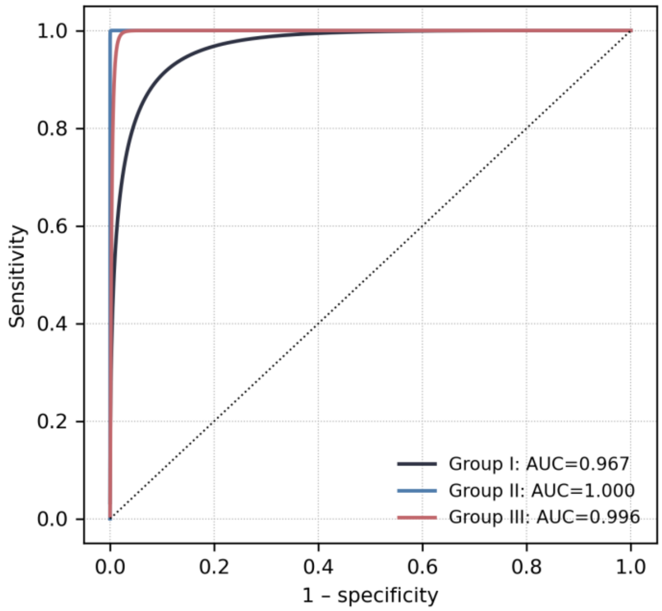

Figure 2. Binormal ROC curves for the urethral resistance coefficient as a discriminator between the preoperative and postoperative states.

The standardised difference in postoperative urethral resistance between the polyethylene and metallic techniques was d = 1.50. A confirmatory two-arm study designed to detect a difference of this magnitude with 80 % power at $\alpha = 0.05$ would require 7 patients per arm. Powering the same study for a more conservative effect of d = 0.50 would require 64 patients per arm.

Discussion

The central result is a divergence between two ways of ranking the same three techniques. Compared on postoperative means, the metallic valvulotome is superior on every individual variable: the lowest residual volume, the lowest urethral resistance, the highest flow rate. Compared on the probability that an individual patient satisfies all three conditions at once, it ranks second, behind the polyethylene valvulotome. The two rankings are not in conflict; they answer different questions. The mean-based comparison asks which technique performs better on average, the probabilistic comparison asks which is more likely to deliver an acceptable result to the next child on the operating list.

The mechanism of the divergence is straightforward. When success is defined by a threshold, the relevant quantity is the distance from the mean to the threshold measured in standard deviations. Group III has the largest such distance for residual volume and resistance, but the smallest for flow rate, because its postoperative flow rate is six to seven times more dispersed than in the other two groups.

That dispersion warrants attention in its own right. A coefficient of variation of 36.5 % for postoperative flow rate, against 6.0 % and 7.6 % in the comparison groups, is not readily explained by biological variation alone, particularly since the same group shows the tightest distributions of all three for detrusor pressure (49.51 ± 0.38 cmH_2O) and resistance (0.05 ± 0.02). Three explanations should be considered before the finding is interpreted clinically: a transcription or unit error in the primary records; genuine heterogeneity of outcome within the metallic-valvulotome group, for instance a subgroup with residual valve tissue; or a difference in the timing of postoperative uroflowmetry within that group. The first is easily checked against source documents and should be excluded before publication of any inference resting on this value. If the dispersion is genuine, it identifies a clinically actionable target: reducing the variability of the metallic technique, rather than improving its average performance, would make it the best-performing option on the composite criterion as well.

The ROC analysis supports the use of the urethral resistance coefficient as a single summary measure of the outcome of ablation, in line with the established practice of grading bladder outlet obstruction by a scalar index [6–9]. The group-specific optimal cut-offs, ranging from 0.100 to 0.192, are not directly transferable between techniques, since each is optimal for separating that group's own preoperative and postoperative distributions. A cut-off intended for general clinical use would need to be derived from a pooled sample against an external reference standard such as cystoscopic confirmation of residual valve tissue, not from the pre–post contrast used here. The near-perfect area under the curve obtained in group II should be read in that light: it reflects the almost complete separation of two distributions with very small standard deviations, and cannot be interpreted as diagnostic accuracy against an independent standard.

The sample-size calculation illustrates a practical consequence of the effect magnitudes involved. Differences of this size between techniques could in principle be confirmed in a randomised trial of fewer than ten patients per arm. Such a trial would nevertheless be underpowered for the outcomes that matter most in this condition — renal function, continence and reintervention — which show far smaller between-technique differences and would require sample sizes larger by two orders of magnitude.

Limitations

The simulation reproduces the reported first and second moments of the postoperative distributions and assumes normality; real urodynamic variables are typically right-skewed, and residual volume in particular is bounded below by zero, so the normal model slightly overstates the probability of very low values. A truncated or log-normal specification would be preferable if individual data were available. The dependence structure was reduced to a single common factor with an assumed correlation, since the empirical correlation matrix could not be estimated from aggregate data; the low sensitivity of the results to ρ mitigates but does not remove this limitation. The thresholds in equation (1) are not established standards, and as Table 4 shows the ordering of groups II and III depends on them: it reverses when the resistance criterion is tightened to 0.08. The reported ranking should therefore be read as conditional on the stated definition of success. The dispersion values in the source data were interpreted as standard deviations rather than standard errors. Allocation to technique was not randomised and baseline severity differed between groups, so the simulated probabilities describe the observed cohorts and should not be read as causal estimates of technique effect. Finally, the composite criterion covers immediate urodynamic performance only and does not incorporate renal or continence outcomes.

Conclusions

Probabilistic modelling of composite urodynamic success gives a ranking of PUV ablation techniques that differs from the ranking obtained by comparing means, and identifies the dispersion of postoperative flow rate — not its mean — as the factor limiting success after metallic valvulotome ablation. The urethral resistance coefficient discriminates the obstructed from the relieved state with an area under the curve of 0.967 to 1.000, supporting its use as a scalar summary of the result of ablation, though technique-specific cut-offs are not transferable to general diagnostic use. Comparative studies in this field should report the probability of meeting clinically defined thresholds alongside group means, since the two need not agree.

References

1. Hendren WH. Posterior urethral valves in boys. A broad clinical spectrum. J Urol. 1971;106(2):298–307.
2. Hennus PML, van der Heijden GJMG, Bosch JLHR, de Jong TPVM, de Kort LMO. A systematic review on renal and bladder dysfunction after endoscopic treatment of infravesical obstruction in boys. PLoS One. 2012;7(9):e44663. doi:10.1371/journal.pone.0044663
3. Deshpande AV. Current strategies to predict and manage sequelae of posterior urethral valves in children. Pediatr Nephrol. 2018;33(10):1651–1661. doi:10.1007/s00467-017-3815-0
4. Briggs AH, Weinstein MC, Fenwick EAL, Karnon J, Sculpher MJ, Paltiel AD. Model parameter estimation and uncertainty: a report of the ISPOR-SMDM Modeling Good Research Practices Task Force–6. Value Health. 2012;15(6):835–842. doi:10.1016/j.jval.2012.04.014
5. Metropolis N, Ulam S. The Monte Carlo method. J Am Stat Assoc. 1949;44(247):335–341.
6. Abrams PH, Griffiths DJ. The assessment of prostatic obstruction from urodynamic measurements and from residual urine. Br J Urol. 1979;51(2):129–134.
7. Griffiths D, Höfner K, van Mastrigt R, Rollema HJ, Spångberg A, Gleason D. Standardization of terminology of lower urinary tract function: pressure-flow studies of voiding, urethral resistance, and urethral obstruction. Neurourol Urodyn. 1997;16(1):1–18.
8. Abrams P. Bladder outlet obstruction index, bladder contractility index and bladder voiding efficiency: three simple indices to define bladder voiding function. BJU Int. 1999;84(1):14–15.
9. Schäfer W. Analysis of bladder-outlet function with the linearized passive urethral resistance relation, linPURR, and a disease-specific approach for grading obstruction. World J Urol. 1995;13(1):47–58.

10. Youden WJ. Index for rating diagnostic tests. Cancer. 1950;3(1):32–35.
11. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology. 1982;143(1):29–36.
12. Mo Z, Li M, Xie X, Sun N, Zhang W, Tian J, Song H. Urodynamic changes before and after endoscopic valve ablation in boys diagnosed with the posterior urethral valve without chronic renal failure. BMC Urol. 2023;23:1. doi:10.1186/s12894-022-01170-w
13. Ghanem MA, Wolffenbuttel KP, De Vylder A, Nijman RJM. Long-term bladder dysfunction and renal function in boys with posterior urethral valves based on urodynamic findings. J Urol. 2004;171(6 Pt 1):2409–2412.
14. Smith GH, Canning DA, Schulman SL, Snyder HM 3rd, Duckett JW. The long-term outcome of posterior urethral valves treated with primary valve ablation and observation. J Urol. 1996;155(5):1730–1734.
15. Sekido N. Bladder contractility and urethral resistance relation: what does a pressure flow study tell us? Int J Urol. 2012;19(3):216–228. doi:10.1111/j.1442-2042.2011.02947.x