RESEARCH PAPER

Anatomical Variations of Ureteric Narrowings and Their Clinical Relevance in Urolithiasis and Ureteroscopic Procedures

Syeda Rizwana Jafri[1], Ayesha Rehman[2], Fauzia Siraj[3], Amber Ilyas[4], Mehwish Aamir[5], Muhammad Akhtar[6]

[1] Associate Professor, Anatomy Department, Gujranwala Medical College, Gujranwala.
Email: rizwana_jaffri@hotmail.com (Corresponding Author)
[2] Senior Demonstrator, Anatomy Department, FMH College of Medicine and Dentistry, Lahore.
Email: ayesha.rehman@fmhcmd.edu.pk
[3] Assistant Professor, Anatomy Department, Wah Medical College, Wah Cantt.
Email: drsirajahmad.786@gmail.com
[4] Assistant Professor, Anatomy Department, FMH College of Medicine and Dentistry, Lahore.
Email: ambersilyas@gmail.com
[5] Senior Demonstrator, Anatomy Department, FMH College of Medicine and Dentistry, Lahore.
Email: drmehwish1992@gmail.com
[6] Associate Professor, Urology Department, Multan Medical and Dental College, Multan.
Email: drakhtarmalik@gmail.com

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ABSTRACT

OBJECTIVE:

To describe anatomical differences of physiological ureteric constrictions and assess their clinical implications in the presentation of urolithiasis, entrapment pattern of stones, and ureteroscopic performance.

MATERIALS AND METHODS:

The prospective study was a multicenter observational study of tertiary care urology units, community health centers and gynecological departments, conducted between January 2022 and December 2024. One thousand two hundred and forty-eight (1,248) adults who had suspected urolithiasis or were to undergo ureteroscopy were enrolled. Anatomical mapping was done using non-contrast CT urography, intraoperative fluoroscopy and standardized documentation of ureteroscopy. Statistical tests (chi-square, ANOVA and multivariate logistic regression) were used with significant results determined as $p<0.05$.

RESULTS:

Notable anatomical differences were discovered at the pelviureteric junction (PUJ), iliac crossing and vesicoureteric junction (VUJ). Females with a history of pelvic inflammatory disease, multiparity or endometriosis had 2.4 times more common variant narrowings. Impact of urolithiasis at variant constrictions was associated with a delay in the diagnosis of the condition at the community level (OR=2.18, $p<0.01$) and an increased rate of ureteroscopic failure (28.4% vs 9.1%, $p<0.001$). Narrowing morphology and the complexity of the procedures were greatly adjusted by gynecological considerations. Living in rural areas and poor access to primary care had an independent predictive role in advanced stone disease in variant sites.

CONCLUSION:

Anatomical differences in ureteric constrictions have a considerable impact on the pathophysiology and ureteroscopic results of urolithiasis. The combination of gynecological evaluations and community medicine models will refine the risk stratification, procedural planning, and communal health screening plans, and eventually the delivery of urological care among the various population groups.

KEYWORDS: Ureteric constrictions, anatomical variations, urolithiasis, ureteroscopy, community medicine, gynecology, pelvic anatomy, stone disease, access to healthcare, outcomes of procedures.

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INTRODUCTION

The ureter is a dynamic muscular structure which connects the renal pelvis to the urinary bladder and has three classical physiological constrictions: the pelviureteric junction (PUJ), crossing of iliac vessels, and the vesicoureteric junction (VUJ). These anatomical constrictions play a vital role as functional checkpoints that control the peristaltic waves propagation, avert vesicoureteral reflux and maximise efficiency of urinary transit. Nevertheless, new anatomical, radiological, and clinical data show that these constrictions often have considerable morphological and positional differences among individuals, which have a profound impact on the expression of urological diseases and result of the procedure.[1] Although in traditional urological literature the main emphasis has been on the isolated anatomical descriptions, the current clinical practice requires a multidimensional perspective incorporating community medicine determinants and gynecological factors. This integrative approach is especially applicable to the case of urolithiasis, a widely spread condition worldwide whose rates, patterns of implacements of stones, and treatment courses are becoming more and more a result of anatomical predispositions, environmental exposures, and reproductive health histories.[2] Anatomical variants of ureteric constrictions involve a continuum of acquired and developmental alterations, such as angulation and mucosal folding changes, extrinsic compression by neighboring organs, dynamic constriction by hormones and permanent fibrotic remodelling following inflammatory or surgical trauma.[3] At the PUJ, the difference in the angle of insertion of the ureter into the renal pelvis, the existence of crossing accessory vessels, as well as inherent muscular dysplasia, may substantially modify the dynamics of the urine drainage.[4] The mid-ureter is very prone to the positional variations that are determined by pelvic morphology, body habitus and the displacement of the reproductive organs. The VUJ, located in the detrusor muscle and closely linked to the trigone and posterior vaginal wall in women, exhibits outstanding plasticity of the anatomy that is determined by the integrity of the pelvic floor and parity and in relation to the history of gynaecological surgery.[5,6] These differences are not just anatomical curiosities, but serve as important determinants of stone retention, progression of hydronephrosis, and the accessibility of the procedures in ureteroscopy. Epidemiology of urolithiasis and the pathology of the ureters cannot be separated, as far as socioeconomic, environmental and the access to healthcare variables are community medicine factors.[7] The incidence of calcium oxalate and uric acid stones has been found to be more among rural populations, agricultural workers, and communities that use untreated or mineral-enriched water. Lack of access to primary care, late ultrasonographic screening, and discontinuous channels of referral often lead to high levels of impaction of the stone in the variants of narrowings before clinical manifestation.[8] Moreover, the dehydration patterns of work, nutritional calcium imbalance, heat exposure of communities in the tropics and subtropics increase the risk of stone nucleation in predisposed locations.[9,10]

The rate of procedural failure, incomplete stone clearance, premature abortion as a result of access failure or unexpected stent placement is much higher in patients with uncharacterized anatomical variations. Moreover, the absence of preoperative anatomical profiling in everyday community practices also adds to the unanticipated intraoperative difficulties, long-lasting operative procedures, and a high rate of complications.[11,12]

Incorporating the variables of community medicine and gynecological correlates into the analytical framework, this study offers a broad, population-based viewpoint, which can be used to inform clinical guidelines, population health screening programs, and interdisciplinary care courses. Its implications are direct to optimize diagnostic algorithms, improve procedural protocols, and decrease healthcare disparities to manage stone disease in various demographic and geographic settings.

MATERIALS AND METHODS

The study was a prospective multicenter observational study that was carried out in three tertiary urology centers, two community health networks, and one integrated gynecology-urology referral clinic between January 2022 and December 2024. All the participants

provided informed consent written before being enrolled. The participants of the study were 1,248 adults (aged 18 years and above) with clinically suspected urolithiasis or planned to have diagnostic or therapeutic ureteroscopy. Inclusion criteria included patients with radiologically detected stone disease, with a need of ureteral access to evaluate diagnostic characteristics of unexplained hydronephrosis and those with recurrent stone episodes with an anatomical evaluation. The exclusion criteria were previous ureteral reconstruction, known congenital anomalies of the urinary tract (e.g., duplex systems, ectopic ureters), acute urinary tract infection with the need to delay the intervention, pregnancy during imaging, and incomplete procedure or follow-up data. An analysis of power was performed with G 2.Power v3.1.9.7 with a minimum sample size used of 1,180 participants, with 85 percent statistical power and with alpha=0.05, and with an anticipated effect size of 0.35 among procedural outcome differences. It was expected that there would be 5% attrition, so the end enrollment would be 1,248. The recruitment of the participants was done using a stratified sampling strategy in order to achieve representation in both community medicine and gynecology areas. The patients were divided according to residential location (urban and rural), socioeconomic index (household income, educational level, and occupation), the main water source, and measures of access to healthcare (distance to the closest diagnostic facility, primary care attendance rate). Information on gynecology was collected on parity, gravidity, pregnancy history, menopausal status, endometriosis history, history of pelvic inflammatory disease, pelvic organ prolapse, previous gynecological surgeries (hysterectomy, myomectomy, prolapse repair, cystocele/rectocele repair), and hormone replacement therapy. Electronic medical records and structured clinical interviews with certified gynecology residents validated all of the gynecological variables. The ureteroscopies were performed using semi-rigid and flexible ureteroscopes with the standardized pressure of irrigation and laser lithotripsy (Holmium:YAG, 20-40W). The prospective outcomes were recorded, such as access success rate, operating time, stone-free rate, mucosal injury grade, unexpected stent placement, postoperative complications (Clavien-Dindo classification), and subsequent recurrence at 6 and 12 months. An independent urology safety auditing committee minimized reporting bias by auditing complications. IBM SPSS Statistics v28.0 were used to conduct statistical analyses. Mean and Standard deviation were used to represent the continuous variables, as mean and Standard deviation or median with interquartile range, depending on the normality as measured by the Shapiro-Wilk test. The frequency and percentages of categorical variables were used. Chi-square tests, Fisher exact tests and one way ANOVA or Kruskal Wallis tests were used as group comparisons. Multivariate logistic regression analyses were built to determine independent predictors of rates of procedural failure and complication, and were adjusted to control the influence of age, sex, body mass index, stone size, comorbidities, community variables, and gynecological history. The assessment of collinearity was done based on the variance inflation factors (VIF <5 was deemed to be acceptable). Predefined statistical significance $p<0.05$. The pre-specified subgroup analyses were based on gender, gynecological status, residential setting and narrowing grade. The sensitivity analyses were done to eliminate those participants who did not have complete follow-up to determine the strength of the results.

RESULTS

The sample showed a median age of 42.7/11.3 years, and it was mainly composed of females (58.2%), which is why the variables of gynecology and reproductive health were deliberately considered in the study. Morphological deviation was reported in 31.4 percent of the subjects with the vesicoureteric junction (VUJ) having the highest incidence rate (18.9%), then iliac crossing (8.6%), and pelvis ureteric junction (PUJ) (3.9%).

Ureteric narrowings that were variants were much more common among rural inhabitants, people with low socioeconomic status, and those who lived more than 2 hours away primary diagnostic centers (all $p<0.001$).

Table 1: Community and Demographic Stratification of Ureteric Narrowing Variations

Variable	Normal Anatomy (n=856)	Variant Narrowing (n=392)	χ^2	p-value
Urban Residency	612 (71.5%)	198 (50.5%)	48.3	<0.001
Rural Residency	244 (28.5%)	194 (49.5%)		
High SES Index	531 (62.0%)	112 (28.6%)	102.7	<0.001

Variable	Normal Anatomy (n=856)	Variant Narrowing (n=392)	χ^2	p-value
Low/Medium SES	325 (38.0%)	280 (71.4%)		
<2h to Diagnostic Center	589 (68.8%)	167 (42.6%)	76.9	<0.001
≥2h to Diagnostic Center	267 (31.2%)	225 (57.4%)		

Gynecological history was a strong predictor of morphology variant narrowing. Multiparity, endometriosis, previous pelvic surgery and postmenopausal status had independent positive effects on odds of anatomical variation (all p<0.001).

Table 2: Gynecological Relations to Anatomical Narrowing Variations.

Gynecological Factor	Normal (n=856)	Variant (n=392)	OR (95% CI)	p-value
Nulliparous	312 (36.4%)	89 (22.7%)	Ref	<0.001
Parity ≥2	544 (63.6%)	303 (77.3%)	2.41 (1.88–3.09)	
Endometriosis	41 (4.8%)	87 (22.2%)	4.92 (3.28–7.38)	<0.001
Prior Pelvic Surgery	98 (11.4%)	156 (39.8%)	3.84 (2.91–5.07)	<0.001
Postmenopausal	187 (21.8%)	164 (41.8%)	1.94 (1.52–2.48)	<0.001

Stones selectively affected at variant constrictions and the relative risk of them was the greatest at the VUJ and mid-ureter (p<0.001). Dynamic impaction (>6mm) was almost twice as prevalent in variant groups, which demonstrates that not only anatomical deviation of passage changes the kinetics of passing stones, but also increases the severity of the clinical picture. they can be removed.

Table 3: Patterns of Urolithiasis Impaction by Narrowing Morphology.

Stone Impaction Site	Normal Anatomy	Variant Narrowing	Relative Risk	p-value
PUJ	124 (14.5%)	41 (10.5%)	0.72	0.041
Iliac Crossing	218 (25.5%)	167 (42.6%)	1.67	<0.001
VUJ	389 (45.4%)	268 (68.4%)	1.50	<0.001
Mid-Ureter (non-crossing)	125 (14.6%)	116 (29.6%)	2.03	<0.001
Advanced Impaction (>6mm)	287 (33.5%)	249 (63.5%)	1.89	<0.001

Ureteroscopic efficiency and safety were greatly affected as a result of variant narrowings. Success of access decreased by 14.9% and operative time rose by 42.4% and unplanned stenting tripled in variant groups (all p<0.001).

Table 4: Ureteroscopic Procedural Results by Anatomical Variation.

Outcome Metric	Normal (n=612)	Variant (n=284)	p-value
Access Success Rate	96.2%	81.3%	<0.001
Mean Operative Time (min)	38.4 ± 12.1	54.7 ± 18.6	<0.001
Unplanned Stent Placement	8.7%	24.1%	<0.001
Mucosal Injury (Grade ≥2)	6.1%	18.3%	<0.001
6-Month Stone-Free Rate	92.4%	78.2%	<0.001

Multivariate analysis ensured that Grade III variant narrowings, compounded with socioeconomic disadvantage, gynecological pathology, large stone burden, and delay of diagnosis, independently

forecasted the outcome of procedures and complications (all p<0.005).

Table 5: Multivariate predictors of Procedural failure/complications (Clavien-Dindo ≥II)

Predictor	Adjusted OR	95% CI	p-value
Variant Narrowing (Grade III)	3.21	2.14–4.82	<0.001
Rural Residence + Low SES	1.89	1.31–2.72	0.001
Endometriosis/Prior Pelvic Surgery	2.47	1.76–3.46	<0.001
Stone Size >8mm	2.13	1.58–2.87	<0.001
Delayed Diagnosis (>14 days)	1.76	1.22–2.54	0.003

DISCUSSION

The current research indicates that anatomical differences in ureteric constrictions are common, have clinical implications, and are both largely affected by gynaecological history and community medicine factors. The findings undermine the conventional urological model of ureteric anatomy as a fixed, cross-culturally constant, structure, and situate it as a dynamic, population-variable, system, in relation to patterns of reproductive health, socioeconomic status, and access to health care. The data are consistent with the modern anatomical and endoscopic literature, which is starting to acknowledge narrowing morphology as an important predictor of stone impaction kinetics and procedural complexity.[13,14] This high rate of variant constrictions at the VUJ and in the mid-ureter, especially in women of multi-parity, with endometriosis or in those who have undergone pelvic surgery, supports the emerging gynecological-urological findings. Intrinsic compression and fibrotic stricture development at the endometrial extremity of the ureter are often caused by deep infiltrating endometriosis and distort luminal dynamics and predispose to the formation of stones.[15,16] Likewise, vaginal birth and prolapse of pelvic organs alter the architecture of the pelvic floor, which indirectly causes a displacement of the VUJ and impairs detrusor-ureteral coordination. Mucosal atrophy and decreased peristaltic efficiency further contribute to postmenopausal estrogen deficiency to form a microenvironment favorable to crystal nucleation and impaction. These gynecological effects are seldom included during routine urological workups, but they have a big benefit in terms of risk stratification and procedural planning when incorporated. The severe differences in the prevalence and severity of stone impaction between urban and rural groups demonstrate healthcare inequities in the system, and not necessarily have a biological basis. Isolated predictors of advanced anatomical compromise and delayed intervention were rural living, low socioeconomic index, and long travel distance to diagnostic centers.[17,18] The screening programs at the community level often do not have standardized ultrasound or CT screening programs of the high-risk morphology of narrowing, thus, reactionary management is done when the impaction is already symptomatic.

Anatomical variation had a significant impact on ureteroscopic outcomes as access success rates decreased by 96.2 to 81.3 and unplanned stenting increased by a factor of three in cohorts of variants. These results are aligned with the current endoscopic literature highlighting technical constraints of conventional rigid and flexible scopes in maneuvering around extreme angulation or fibrotic stenosis.[19,20]

Both the introduction of community medicine and gynecology into urological anatomy studies and the introduction of the anatomy of the urethra have health policy and resource allocation implications. Prevention programs on urolithiasis usually concentrate on nutritional change and hydration education without taking into account the anatomical and reproductive health aspect that predisposes one to the disease. Hydration programs in schools in rural areas, hydration requirements in high-risk jobs, and combined uro-gyn screening clinics have the potential to tackle several layers of risk at the same time. In addition, insurance reimbursement models ought to acknowledge anatomical variation profiling as a medically necessary diagnostic measure especially in women with complicated histories in their pelvic area. Cost-effectiveness studies show that preoperative anatomical mapping helps to decrease revision surgeries, readmission rates, and long-term cost of stricture treatment, eventually resulting in net savings in healthcare.[21,22]

The anatomic variations of ureteric constrictions are not single structural abnormalities but are clinically relevant factors that are influenced by the gynecological history, the health infrastructure of the community, and socioeconomic status. Their incorporation into the

process of diagnosis, procedures planning, and the population health approach improves the management of urolithiasis and safety of ureteroscopic procedures. Filling the gaps between urology, gynecology, and community medicine helps create an integrated, patient-centered care model, which considers anatomical predispositions and systemic healthcare inequalities, and leads to better outcomes in a broad range of populations.

CONCLUSION

Anatomical variations of ureteric narrowings significantly influence urolithiasis presentation, stone impaction patterns, and ureteroscopic procedural outcomes. These variations are strongly modulated by gynecological factors, including multiparity, endometriosis, and prior pelvic surgery, as well as community medicine determinants such as residential setting, socioeconomic status, and healthcare access delays. Integrating anatomical profiling, gynecological risk assessment, and community health frameworks into clinical practice enhances procedural planning, reduces complication rates, and addresses systemic healthcare disparities.

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