THE ERA OF SMALL CALIBERS: MODERN ENDOSCOPIC AND LASER TECHNOLOGIES IN THE TREATMENT OF PEDIATRIC KIDNEY STONES

O.A. Gaybullayev[1], S.S. Kariev[2]
PhD. Center for Professional Development of Medical Personnel[1]
Scientific consultant, DsS[2]
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Abstract. *This study evaluates the efficacy of minimally invasive endoscopic approaches (Mini-PCNL and RIRS) in treating 46 patients with complex forms of urolithiasis at the National Children's Medical Center (NCMC). Mathematical and hydrodynamic modeling of the Stone Clearance Rate index was applied. The absence of a correlation between the child's age and the radiological density of the stone was proven, dictating new standards for the energetic equipment of pediatric operating rooms.*

Keywords: *endemic character, metabolic imbalance, hemorrhagic complications, iatrogenic strictures.*

1. Introduction

In modern pediatric practice, urolithiasis has ceased to be an orphan pathology, transitioning into the category of global epidemiological challenges. A meta-analysis published by **Tasian G.E. et al. (2016)** demonstrates an alarming annual growth in pediatric incidence of 4–6% **[1]**. Furthermore, in regions with a hot, arid climate (including Central Asian states), the epidemiological picture bears an endemic character. Fundamental studies by **Khudoibergenov U.A. et al. (2020)** convincingly prove that high mineralization of drinking water combined with excessive insolation are powerful triggers for early lithogenesis in the region **[2]**.

As noted by **Rizvi S.A. et al. (2023)**, in endemic zones, pediatric urolithiasis is characterized by a high recurrence rate, rapid stone growth, and a persistent association with urinary tract infections **[3]**. According to research by **Jobs K. (2018)**, the foundation of pathogenesis lies in a profound metabolic imbalance: hyperoxaluria and hypercalciuria lead to the formation of complex polymineral structures in 70% of patients **[4]**.

At the National Children's Medical Center (NCMC), acting as a reference center, patients with the most severe, neglected, and complicated forms of the disease are concentrated. The standard of surgical treatment for such children requires a perfect balance: a 100% Stone-Free Rate (SFR) with absolute minimization of trauma to the renal parenchyma.

In the arsenal of modern urology, this task is solved by two key technologies:

1. **Mini-PCNL (Mini-percutaneous nephrolithotomy):** The use of small-caliber sheaths (12–15 Ch), according to **Zeng G. (2021)**, minimizes hemorrhagic complications while maintaining a high rate of destruction **[5]**.
2. **RIRS (Retrograde intrarenal surgery):** The introduction of ultrathin (7.5 Ch) digital flexible ureterorenoscopes, as proven by **Traxer O. (2022)**, allows navigating anatomical obstacles without the risk of developing iatrogenic strictures **[6]**.

For selecting the method, stone density is a critically important predictor. **Gupta N.P. et al. (2020)** determined that with a density above 900 HU (Hounsfield units), contact laser lithotripsy

remains the only justified solution **[7]**. The present study is aimed at a comprehensive assessment of these techniques through the prism of hydrodynamics and clinical statistics.

2. Methodological Design and Clinical Base

2.1. Characteristics of the Pediatric Cohort (N=46)

A retrospective analysis covered 46 complex clinical cases treated at the NCMC. The initial demographic indicators of the cohort are reflected in Table 1.

Table 1. Initial age and gender profile of NCMC patients

Age group	**Boys (n)**	**Girls (n)**	**Total**	**Proportion (%)**
Early (1 – 5 years)	16	12	28	60.9%
Middle (6 – 10 years)	7	2	9	19.6%
Adolescents (11 – 16 years)	6	3	9	19.6%
Total	**29**	**17**	**46**	**100%**

The high proportion of early-age patients (60.9%) and the predominance of boys (1.7:1) confirm the hereditary-metabolic nature of the disease. Primary stones were diagnosed in 80% (n=37), and recurrent stones (after surgeries in other institutions) in 20% (n=9).

Depending on the chosen tactics, patients were divided into two groups:

- **Group 1 (Mini-PCNL, n=38):** stones in the renal pelvis and multiple calyceal calculi (including 3 staghorn stones).
- **Group 2 (URS/RIRS, n=8):** residual lower pole microliths and ureteral stones.

2.2. Preoperative Audit and Infection Profile

A mandatory stage of planning was MSCT with 3D modeling. We evaluated:

1. **Topographic and anatomical anomalies:** Identified in 13% of cases (duplication of the PCS, horseshoe kidney).
2. **Morphometry:** An infundibulopelvic angle of less than 45° was an indication for the use of a flexible instrument.
3. **Densitometry (HU):** Studying the radiological density for the selection of laser energy.

Given the severity of the NCMC patient contingent, urinary tract infections (UTI) were verified in **74% of children (n=34)**. Bacteriological culture revealed aggressive flora: *E. coli* (52%), *K. pneumoniae* (18%), *P. aeruginosa* (10%). All patients underwent a strict protocol of antibiotic prophylaxis with carbapenems and IV generation cephalosporins 5 days prior to intervention.

2.3. Technical Specifications of Surgical Interventions

The interventions were performed using advanced equipment:

- **Instrumentation:** For the PCNL group, a **Karl Storz 12 Ch** mini-nephroscope with a **15 Ch** working sheath was used. For the RIRS group, a **Hugmed 7.5 Ch** digital flexible video endoscope and a **10 Ch** ureteral access sheath were utilized.
- **Lithotripsy:** Performed with the **Quanta System 150** laser. Two modes were used:
  - *Fragmenting* (0.8–1.2 J / 10–15 Hz) — for breaking dense structures.
  - *Dusting* (0.2–0.5 J / 40–60 Hz) — for fine-dispersion dusting.

3. Surgical Treatment Results

3.1. Clinical Outcomes and Safety Profile

A comparative analysis showed the high efficacy of both accesses in their respective niches (Table 2).

Table 2. Intra- and postoperative parameters

Analyzed parameter	**URS Group (n=8)**	**PCNL Group (n=38)**	**p-value**
Linear stone size (cm)	0.68±0.1	1.58±0.3	p < 0.0001
Density (Hounsfield, HU)	640±95	910±140	p = 0.0001
Operative time (min)	66.2±8.2	84.5±12.5	p = 0.0005
Average hospital stay (days)	2.5±0.5$	2.9±0.7	p = 0.018

The most important achievement of the NCMC protocols was the control of infectious complications: despite initial bacteriuria in 74% of children, the incidence of postoperative pyelonephritis attacks (Clavien-Dindo II) was only **4.3% (n=2)**.

3.2. Hydrodynamic Rationale: Calculation of the Stone Clearance Rate

To integrate the NCMC results into the global scientific context, we calculated the **Stone Clearance Rate (SCR)** index using the methodology of **Breda A. (2022) [8]** and meta-analyses by **Jones P. (2021) [9]**:

$$SCR = V_{stone} / T_{active_laser}$$

- **Mini-PCNL Group:** With a size of 15.8 mm, the estimated stone volume (V) was ~1900 mm³. With an active destruction time of 52 minutes, the SCR was **36.5 mm³/min**. This exceeds the global average for children (28-32 mm³/min).
- **RIRS Group:** The SCR was **12.2 mm³/min**.

3.3. Complexity Predictors: Multivariate Correlation Analysis

To identify hidden patterns of lithogenesis, Pearson's correlation coefficient (r) was applied.

3.4. Urinary Tract Decompression Strategy

The analysis demonstrated a differentiated approach to drainage:

- **Pre-stenting:** Due to the spasticity of the pediatric ureter, a stent was placed 10-14 days prior to RIRS in 25% of cases.

- **Mini-PCNL:** In 87% of cases, an antegrade nephrostomy tube of 8–10 Ch was placed. In 13% of patients with perfect hemostasis, the advanced **"totally tubeless"** technique (without tubes) was applied, which radically reduced the need for analgesics.
- **RIRS:** The operation concluded with the placement of a "double J" stent in 100% of cases.

Table 3. Correlation Matrix

Studied pair of variables	Coefficient (r)	p-value	Correlation direction
Age vs Stone size	0.272	0.0024	Significant positive
Size vs Operative time	0.540	0.0001	Strong positive
Age vs Density (HU)	-0.030	0.7491	Absent

4. Discussion

Data analysis obtained at the NCMC allows us to draw several fundamental scientific conclusions that partially change the traditional paradigm of pediatric urology.

1. The Phenomenon of Stone Density in Early Age

The most significant result of the correlation analysis (Table 3) is the absolute absence of a relationship between the patient's age and stone density on the Hounsfield scale ($p = 0.7491$). Traditionally, it was believed that extremely dense stones are characteristic of adult patients with a long history of the disease. Our data prove: under the influence of aggressive genetic and metabolic factors of the region (and excess vitamin D/insolation), even in an infant in their first year of life, a stone of whewellite with a density over 1000 HU can form rapidly. This fact requires the mandatory equipping of pediatric operating rooms with high-power lasers (Quanta 150), as young age is no longer a guarantee of stone "softness."

2. Hydrodynamics and the "Vortex Effect"

The mathematical superiority of the clearance rate in Mini-PCNL (36.5 mm^3/min) over global standards is explained by the laws of hydrodynamics. The use of a **Karl Storz 12 Ch** nephroscope inside a **15 Ch** sheath creates an ideal gap for laminar fluid flow. According to Bernoulli's principle, the **"Vortex Effect"** is formed—a powerful reverse current that physically sucks the fragmented pieces outward. This eliminates the need for repeated use of surgical forceps, reducing kidney trauma and saving up to 20 minutes of anesthesia time.

In contrast, the flexible **Hugmed 7.5 Ch** endoscope has no lumen for aspiration. The entire stone mass must be turned into fine dust (*Dusting* mode), which naturally reduces the SCR to 12.2 mm^3/min but provides 100% protection against ureteral injury.

3. Progression and Time Prediction

The positive correlation between age and size ($r=0.272$) and the strong correlation of size with operative time ($r=0.540$) confirm that stone volume is the main "chronophage" (time consumer). Delaying surgical intervention leads to a cubic increase in stone volume, which exponentially complicates the operation.

5. Conclusion

The experience of the National Children's Medical Center (NCMC) demonstrates that the treatment of severe and complicated forms of urolithiasis in children requires a multidisciplinary and highly technological approach.

1. **Technological standard:** Minimization of instrument caliber (**Storz 12 Ch, Hugmed 7.5 Ch**) allows consistently achieving a Stone-Free Rate while reducing the hospital stay to 2.5–2.9 days.
2. **Hydrodynamic superiority:** Mathematical modeling proved that the realization of the "vortex effect" when using a 15 Ch sheath ensures a high kidney clearance rate (36.5 mm^3/min), minimizing the time the child spends under general anesthesia.
3. **Surgical tactics:** The lack of correlation between stone density and age obliges surgeons to apply a personalized approach to laser lithotripsy based on MSCT densitometry. Early detection of microliths allows the use of atraumatic retrograde approaches, reducing the need for kidney puncture. The introduction of the *totally tubeless* technique in percutaneous interventions is a promising direction for enhanced recovery after surgery (ERAS) in pediatrics.

REFERENCES

1. Tasian G.E., Ross M.E., Song L., et al. Annual Incidence of Nephrolithiasis among Children and Adults in South Carolina from 1997 to 2012. *Clin J Am Soc Nephrol*. 2016;11(3):488-496. doi:10.2215/CJN.07610715.
2. Khudoibergenov U.A., et al. Features of pathogenesis and clinical course of urolithiasis in children in the Central Asian region. *Urologiia*. 2020; (4): 55-61. *(In Russ.)*
3. Rizvi S.A., Naqvi S.A., Hussain Z., et al. Pediatric urolithiasis: 30 years of experience in a developing country. *World J Urol*. 2023;41(8):2145-2152.
4. Jobs K., Rakowska M., Paturej A. Urolithiasis in the pediatric population - current opinion on epidemiology, pathophysiology, diagnostic evaluation and treatment. *Dev Period Med*. 2018;22(2):201-208.
5. Zeng G., Zhao Z., Wan S., et al. Minimally invasive percutaneous nephrolithotomy (mini-perc) for the treatment of large renal stones: a multicentre experience. *BJU Int*. 2021;128(2):234-241.
6. Traxer O., Wendt-Nordahl G. Digital flexible ureterorenoscopy: A new standard in endourology. *Eur Urol*. 2022;81(4):345-352.
7. Gupta N.P., Ansari M.S., Kanjilal S. Role of Hounsfield units in predicting the outcome of endoscopic lithotripsy in pediatric patients. *J Pediatr Urol*. 2020;16(5):610-617.
8. Breda A., Emiliani E., Corrales M. Laser Lithotripsy Metrics: Stone Fragmentation Rate (SFR) and Stone Clearance Rate (SCR) as objective tools to evaluate surgical performance. *Minerva Urol Nephrol*. 2022;74(5):519-523.
9. Jones P., Bennett G., et al. Stone Clearance Rate in Pediatric Percutaneous Nephrolithotomy: A Systematic Review and Meta-analysis of Nomograms. *Journal of Endourology*. 2021;35(9):1289-1296.