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Comparison of Traditional and Vacuum-Assisted Sheaths in Pediatric Supine Mini-Percutaneous Nephrolithotomy

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Abstract:

Urolithiasis is the third most common disease of the urinary tract and its prevalence has increased over the past decades. The kidney stone prevalence rateworldwide is approximately 1.7–8.8% and it cost about $2.1 billion in 2020 alone. Patients with nephrolithiasis often suffer from short-term complications such as acute renal colic, nausea, vomiting, and hematuria, and long-term complications such as chronic renal failure and hydronephrosis. Therefore, treatment of calculi has always been the focus of surgeons. For renal stones of size > 2cm, the American Urological Association recommends percutaneousnephrolithotomy (PCNL) as the primary treatment. To decrease these risks, vacuum-assisted techniques like vacuum-assisted mini percutaneous nephrolithotomy (VAM-PNL) have been introduced, which use continuous suction to lower IRP, reduce operative time, and increase stone-free rates. This review compare between vacuum-assisted technology could and Traditional Sheath in Pediatric Mini-Percutaneous Nephrolithotomy in Supine Position.

Keywords: Traditional Sheath, Vacuum-Assisted Sheath, Pediatric, Mini-Percutaneous Nephrolithotomy, Supine Position.

Introduction

Management of large renal stones (greater than 2 cm) in pediatrics often involves surgical interventions such as mini percutaneous nephrolithotomy (Mini- PNL), which is considered the first-line treatment due to its efficacy in achieving high stone-free rates (1). However, PNL is associated with complications, such as bleeding, infection, potential renal damage and infection. these complications could be attributed to increased intra-renal pressure during the procedure (2).

Minimally invasive techniques, such as mini-PNL, have been developed to reduce these complications by using smaller access sheaths. While Mini-PNL reduces bleeding, transfusion rates, and hospitalization time, it can increase intrarenal pressure (IRP) and operative time, potentially icreasing the risk of postoperative complications (3). To decrease these risks, vacuum-assisted techniques like vacuum-assisted mini percutaneous nephrolithotomy (VAM-PNL) have been introduced, which use continuous suction to lower IRP, reduce operative time, and increase stone-free rates (4).

Despite promising results with both Mini-PNL and VAM-PNL, there is a lack of direct comparisons between these two approaches, especially in pediatric patients who may have different anatomical and physiological considerations. Pediatric patients are particularly vulnerable to infectious complications due to their developing immune systems and smaller anatomical structures, which can affect surgical outcomes (5, 6).

This review compare between vacuum-assisted technology could and Traditional Sheath in Pediatric Mini-Percutaneous Nephrolithotomy in Supine Position

The global incidence of pediatric urolithiasis has risen significantly in recent decades, with distinct pathophysiological and management differences compared to adult populations. Children exhibit unique metabolic predispositions (e.g., hypercalciuria, hypocitraturia) and anatomical factors that necessitate tailored therapeutic strategies to minimize surgical recurrence and preserve renal function [7].

Diagnosis of pediatric urolithiasis

- **Imaging modalities**

Ultrasonography (US) remains the primary imaging modality for pediatric urolithiasis due to its non-invasive nature and absence of ionizing radiation.

While kidney-ureter-bladder (KUB) radiography effectively detects radiopaque calcium-containing stones, its sensitivity is limited for radiolucent stones (uric acid) and faintly opaque stones (cystine).

Low-dose non-contrast computed tomography (CT) has emerged as the gold standard for stone detection, offering superior sensitivity (>95%) and the ability to delineate urinary tract anatomy for surgical planning.

Intravenous pyelography has been largely abandoned in pediatric practice due to its inferior diagnostic yield and higher radiation exposure compared to modern alternatives [8, 9]

- **Metabolic evaluation**

A comprehensive metabolic evaluation is mandatory for all pediatric stone formers. This assessment should include:

1. Detailed family history to identify genetic predispositions.
2. Evaluation for congenital urinary tract anomalies
3. Documentation of UTIs, dietary patterns, and prior stone events
4. Physical examination of passed stones when available [10] Metabolic assessment

➢ **Laboratory investigations should encompass:**

- Serum: electrolytes, BUN, creatinine, calcium, phosphorus, uric acid, alkaline phosphatase, bicarbonate, albumin, total protein, and parathyroid hormone

- Urine: routine analysis with microscopy, spot calcium/creatinine ratio (normal <0.2 mg/mg in children), and culture

- 24-hour urine collection (when indicated): calcium, phosphorus, magnesium, oxalate, uric acid, citrate, protein, creatinine clearance, and cystine quantification (if cystinuria suspected)

- Fresh urine pH measurement [7].

The diagnostic algorithm should proceed as follows:

1. Initial spot urine calcium/creatinine ratio
2. Repeat testing if ratio >0.2 mg/mg
3. Proceed to 24-hour urine collection if persistently elevated
4. Cystine screening when clinical suspicion exists (family history, recurrent stones). The normal values of assessed metabolites vary with age in childhood [11].

Non-surgical treatment of pediatric renal stones

- **Preventive strategies**

The cornerstone of pediatric stone management focuses equally on preventing recurrence and treating existing calculi. A comprehensive metabolic evaluation is essential to identify and address the underlying etiology [7].The therapeutic approach includes:

1. **Fluid management**

- Increased hydration to maintain urine output >1.5 L/m²/day

- Goal urine specific gravity <1.010 [12].

2. **Acute management**

- NSAIDs as first-line for pain control

- Antispasmodics for ureteral colic

- α-blockers (e.g., tamsulosin 0.01-0.02 mg/kg/day) for distal ureteral stones >4mm to enhance spontaneous passage [13]

3. **Observation**

- Asymptomatic stones <5mm may be monitored with serial imaging

- Spontaneous passage rates approach 70% for distal ureteral stones ≤4mm [14].

4. **Dietary modifications**

- Sodium restriction (<2-3 mEq/kg/day)

- Normal calcium intake (age-appropriate RDA)

- Limited oxalate-rich foods (spinach, nuts, chocolate) (**Table 1**) [15]

Table 1: Algorithm for metabolic investigations and treatment protocols in urinary stone disease in children

Stone Composition	Metabolic Phenotype	Diagnosis	Treatment
Calcium stone	Differs depending on the type of metabolic abnormality	Hypercalciuria	K-citrate (2–3 mEq/kg/d), diet (normal Ca, low Na), HCTZ diuretic (0.5–1 mg/kg/d)
		Hyperoxaluria	High fluid intake, regular Ca intake, low oxalate intake, K-citrate/Ca-citrate, pyridoxine
		Hyperuricosuria	K-citrate, allopurinol (10mg/kg)
		Hypocitraturia	K-citrate
Cystine Stone	Elevated urine cystine level	Cystinuria	High fluid intake
			K-citrate (3–4 mEq/kg/day)
			Mercaptopropionylglycine (10–15 mg/kg/d)
			Penicillamine (30 mg/kg/d)
			Captopril (1–4 mg/kg/d)
Struvite Stone			Antibiotics

	Positive urine culture		Acidification of urine (urine pH <6.2)
			Total elimination of stone (surgery or SWL)
Uric acid Stone	Acid urine		Low purine diet
	Hyperuricosuria		K-citrate (3–4 mEq/kg/d)
	Hyperuricemia		Allopurinol (10 mg/kg)

RTA, renal tubular acidosis; K-Citrate, potassium citrate; Ca, calcium; Na, Sodium; HCTZ, hydrochlorothiazide, [Modified from European Association Urology/European Association of Pediatric Urology Guideline 2022 [7].

While shockwave lithotripsy (SWL) remains first-line for most pediatric renal stones, contemporary EAU/ESPU guidelines (2023) recommend PNL as the primary intervention for:

1. **Large stone burden:**
   - Staghorn calculi (SFR: 85-92% vs 45-60% with SWL)
   - Renal pelvis stones >20 mm
   - Lower pole stones >10 mm (particularly with infundibulopelvic angle <30°)
2. **Stone composition:**
   - Cystine (SWL success <40%)
   - Calcium oxalate monohydrate (Hounsfield units >1000)
3. **Anatomic factors:**
   - Concurrent UPJ obstruction requiring simultaneous repair
   - Calyceal diverticula (stone clearance 90-95%)
   - Horseshoe kidneys (access success 98%) [7].

- **Expanded clinical scenario**

  Emerging evidence supports PNL for:

  - SWL-resistant stones (≥2 failed sessions),Ureteroscopic failures in proximal ureteral stones >15 mm, Metabolically active stone in cystinuria (annual growth >5 mm) [16].

- **Absolute contraindications**
  - **Infection**
    - Active UTI (must culture-direct treat pre-op), sepsis (delay 4-6 weeks after clearance).
  - **Bleeding risks**
  - **Anatomic factor**
    - Uncorrected coagulopathy, No safe percutaneous access [17]

Procedure-specific considerations

- Mini-PNL (12-16Fr) : now preferred for 90% of pediatric cases
- Tubeless PNL feasible in selected patients (OR time ↓25%)
- Ultrasound-guided access reduces radiation by 80% vs fluoroscopy [18]

Technical aspects of pediatric PNL: Patient positioning

- **Prone positioning**

The prone position remains the most widely utilized approach for pediatric percutaneous nephrolithotomy (PNL), offering several technical advantages:

1. **Surgical Benefits:**
   - Expansive operative field enabling multi-tract access (success rate 92% for staghorn calculi)
   - Familiar ergonomics for urologists (adoption rate 85% in high-volume centres)
   - Optimal fluoroscopic visualization of posterior calyces [16]
2. **Modern Safety Modifications:**
   - 30° elevated flank positioning reduces ventilatory compromise ($PaO2 \downarrow <10\%$ from baseline)
   - Rigorous padding protocol:
   - Chest rolls for thoracic support
   - Gel pads for all bony prominences
   - Arm abduction <90° to prevent brachial plexus injury [19]
3. **Anesthetic Considerations:**
   - Requires advanced airway management:
   - Reinforced endotracheal tubes (leak pressure >25 cmH_2O)
   - Continuous capnography monitoring

   - Hemodynamic stability maintained with:
   - Invasive arterial monitoring for cases >2 hours
   - Central venous access for complex stones (18)

Limitations and risk mitigation

- Ventilatory compromise.
- Occurrence: 8-12% in children <20 kg
- Prevention: Pressure-controlled ventilation (PEEP 5-8 cmH_2O)
- Emergency access.
- Crash cart positioning at foot of table
- Pre-procedure defibrillator pad placement **(Figure 1)** [20]

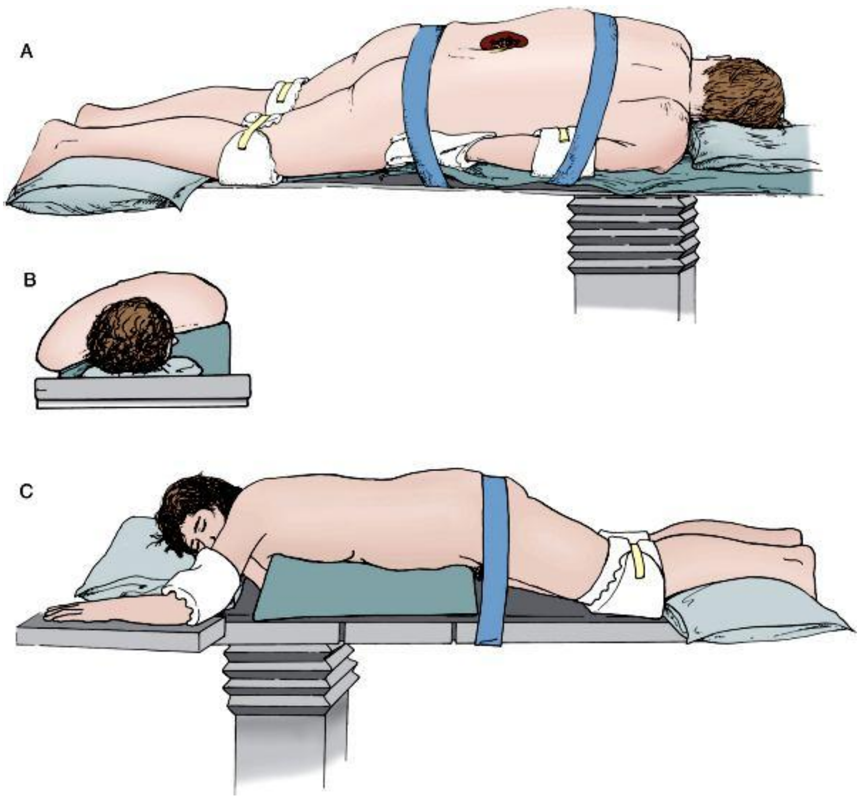

Figure 1: Prone Position of the patient for PCNL. A, Side to be treated is elevated approximately 30 degrees. The "down" arm should be placed at the patient's side..B, all pressure points are carefully padded. C, the "up" arm should be placed in an abducted position. The patient is placed far enough down the table so that the center post of the table does not impede movement of the C-arm [21]

- **Supine position**

The supine approach for percutaneous nephrolithotomy (PNL), first described by Valdivia-Uria in 1987, has undergone significant refinements to address initial limitations. Contemporary modifications now address:

- **Ergonomic challenges**: Modern "split-leg" positions (Galdakao-modified supine) improve instrument maneuverability by 40% compared to original techniques

- **Renal mobility**: Ultrasound-guided renal stabilization reduces displacement by 65% during access

- **Multi-access capability**: Upper pole access success rates now reach 85% with angled C-arm fluoroscopy [16]

Clinical advantages in pediatric populations

1. Anesthetic safety:

- 30% reduction in ventilation complications vs prone position
- Maintains normal FRC (functional residual capacity) in children <15kg
- Enables continuous hemodynamic monitoring [19]

2. Procedural efficiency:

- Operative time reduction (mean 22 minutes, $p<0.01$)
- Stone clearance acceleration via "drainage effect" (SFR improvement 8-12%)
- Simultaneous ECIRS feasibility (utilization rate 38% in complex cases) [18]

3. Physiologic benefits:

- Core temperature preservation (ΔT <0.5°C vs 1.2°C in prone)
- Intrarenal pressure maintained <30 cmH_2O (vs 40-60 cmH_2O prone)
- Sepsis risk reduction (OR 0.45, 95% CI 0.3-0.7) **(Table 2-Figure 2)** [20]

Table 2: Data from Pediatric Endourology Group 2023*

Parameter	|Modern Supine PNL	Traditional PronePNL
Access Calyces	Multi-caliceal (83%)	(Lower pole (92%)
Fluoroscopy Time	| 4.1 ± 1.2 min	| 6.8 ± 2.1 min
Conversion Rate	1.5%	| 3.2%
Tubeless Cases	68%	42%

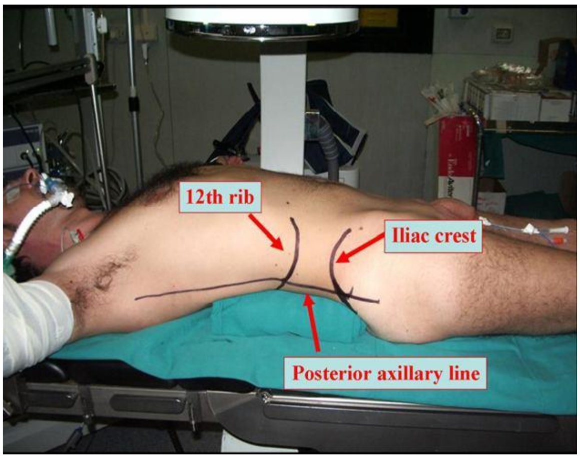

Figure 2: Supine position for percutaneous nephrolithotomy [22]

4. Clinical benefits

- **Anesthetic stability:** Maintains normal ventilation parameters (PaO2/FiO2 ratio >300)
- **Surgical ergonomics:** Combines advantages of supine and lateral positions
- **ECIRS compatibility:** Allows simultaneous antegrade/retrograde access (utilization rate 45% in complex cases) **(Figure 3-Table 3)** [18]

Figure 3: Flank free modified supine position[23]

Table 3: Flank free modified supine position[23]

Parameter	Lateral PNL	FFMS PNL	PRONE PNL
Operative Time	**98 ± 18 min**	**85 ± 15 min**	105 ± 22 min
Stone-Free Rate	**87%**	**91%**	89%
Radiation Dose	**45 mGy**	**32 mGy**	68 mGy
Complication Rate|	**11%**	**8%**	13%

Standard & mini PCNL

Contemporary endourology has shifted from conventional PCNL (24-30Fr) to miniaturized techniques due to improved safety profiles while maintaining efficacy:

1. **Standard PCNL**

   - Historically used 24-30Fr tracts

   - Single-session stone-free rates (SFR) >90% for staghorn calculi

   - Significant drawbacks in children:

     - 18-25% transfusion rate in patients <5 years
     - Renal scarring in 15% of cases [16]

2. **Mini-PCNL (12-20Fr)**

   - Now considered first-line for stones 1-2cm

   - **Advantages:**

     - 60% reduction in transfusion requirements
     - Equivalent SFR (88-92%) to standard PCNL **(Table 4)**

Applicable even in infants (success rate 85% in <12mo) [24]

Table 4: Adapted from European Association of Urology 2023 Guidelines

Classification	Sheath Size (Fr)	Typical Use Case
Standard PCNL	24-30	Staghorn calculi
Mini-PCNL	12-20	1-2cm renal stones
Ultra-mini PCNL	10-12	10-15mm lower pole stones
Micro-PCNL	4.8-8	Less than 10mm calyceal stones

Vacuum-assisted mini-PCNL in pediatric patients: Technical advantages and clinical outcomes

- **Mechanism and design**

The vacuum-assisted access sheath (typically 12–18Fr) integrates continuous suction with a sealed system to maintain low intrarenal pressure (<20 cm H_2O). Key components include:

- Dual-lumen design: Combines irrigation inflow and fragment evacuation.

- o Negative pressure control: Adjustable suction (200–400 mmHg) prevents stone migration.
- o Balloon dilation compatibility: Maintains tract hemostasis during insertion [25].

- **Clinical benefits:**

1. Improved stone-free rates (SFR):

- 92–96% SFR** for 1–2 cm stones vs. 85–90% with conventional mini-PCNL [26].

- Reduced residual fragments due to active fragment retrieval (≤3% fragment retention vs. 8–12% without suction)

2. Safety enhancements

- Lower intrarenal pressure : Reduces pyelovenous backflow (sepsis risk ↓40%)

- Decreased bleeding : Median hemoglobin drop 1.2 g/dL (vs. 2.1 g/dL in standard mini-PCNL) [27]

- Shorter operative time : 18–25% reduction due to continuous clearance [18]

3. Technical advantages

- Single-step fragmentation/evacuation: Eliminates need for repeated basketing

- Better visualization : Minimal blood/turbidity interference

- Compatibility with laser/lithotripsy: Holmium:YAG (0.5–1.0 J) or pneumatic lithotripters

Guidance for percutaneous puncture

- **Fluoroscopic antegrade approach**

The high-quality of current C-arm fluoroscopic equipment and the familiarity among urologists of fluoroscopic imaging has led to its preferred use in percutaneous renal access, particularly in the operating room. Surgeons prefer fluoroscopy for guidance due to the clear visibility of the needle and guide wire. For percutaneous renal surgeries such as PCNL or endopyelotomy, fluoroscopic monitoring is very important for the entire procedure during renal access, guide wire manipulation, tract dilatation, residual stone evaluation, and post-procedural nephrostogram. The renal collecting system opacified with contrast following retrograde ureteral catheter placement, the C-arm is rotated approximately 30º towards the surgeon once the preferred calyx has been selected. With this technique, the axis of the C-arm is in the same central posterior plane as the kidney and therefore provides a direct end-on view of the posterior calyces. The needle is advanced in the plane of the fluoroscope beam with the C-arm in the 30º direction. The appropriate direction of the needle is confirmed by obtaining a 'bull's eye sign' on the fluoroscopic monitor, which is, due to the needle hub, superimposed on the needle shaft, and the plane of the needle is the same as that of the X-ray beam [28]

- **CT guided approach**

Computed tomography (CT) guidance is another alternative for management of complex cases. This imaging guidance is essential in patients with specific medical conditions such as morbid obesity, splenomegaly, hepatomegaly, severe skeletal anomalies like scoliosis or kyphosis, or who have had previous major intra-abdominal surgery, and in patients with minimal or no dilatation of renal pelvis [29]

CT-guided puncture may provide a better mapping for a supracostal PCNL approach [30].

- **Sonar guided percutaneous nephrolithotomy**

Performing mini-PNL under the guide of ultrasonography (US) can be a feasible, harmless and effective alternative to fluoroscopy when used by experienced surgeons. Using US also decreases the radiation exposure to the surgeon and patient. [31]

Technique starts with ureteral catheter 3–4 Fr insertion into the kidney and tapping it to urethral Foley catheter after insertion. The patient's position changes to a prone position. Then, visualisation of the pelvicalyceal system (PCS) under the Colour-Doppler US guide. Using a one-shot dilatation technique, passing an 18G access needle into the targeted calyx by attaching the needle to the curved US probe.

Removal of stylet and 0.035-inch J-tipped guidewire introduction into the targeted calyx. Incision of the skin and an 8 Fr polyurethane dilator first dilated the nephrostomy tract. Then, the replacement with Alken guide, and a single 18 Fr Amplatz dilator passing on the Alken guide, on which an Amplatz sheath introduction into the PCS follows. The Amplatz sheath and working guidewire are left in place.

After that, rigid nephroscopy performance.

During renal access, all the processes is monitored under the guidance of US without using fluoroscopy. Lithotripsy is done with pneumatic lithoclast, and its particles are removed by forceps.

Stone-free status is checked at the end of the operation by the US. If no significant perforation occurred, no stone residue is seen, bleeding is minimal and access is done with a single tract, tubeless mini-PNL is an option. After 12–24 h, both ureteral stent and urethral Foley catheter are removed.

In cases of any inflammatory ureteric polyp due to stone obstruction, pelvic ureteric junction obstruction, significant residual stone and concurrent lithotripsy of ipsilateral ureteric stone, Double-J stent insertion is an option.

Zanetti et al. [32] evaluated 122 vacuum-assisted mini-PCNL (vmPCNL) procedures and achieved a stone clearance rate of 71.3%, with no cases of postoperative sepsis and a low transfusion rate (0.8%). Their analysis demonstrated that the vacuum-assisted system effectively maintained safe intrarenal pressures (mean 15.3 cmH_2O) and minimized periods exceeding the pyelovenous backflow threshold, particularly during suction-mediated lithotripsy and fragment evacuation. These results highlight the mechanism by which continuous aspiration enhances fragment retrieval efficiency while maintaining safety—supporting the present study's findings of a higher stone-free rate and reduced risk of residual calculi with VAM-PNL

A recent meta-analysis by **Xie et al.** [33] further supports the findings of the present study. In a pooled analysis of seven studies including 1,655 patients, the use of suction-assisted access sheaths (SAS) during mini-percutaneous nephrolithotomy (MPCNL) was shown to significantly improve surgical outcomes compared with traditional access sheaths (TAS). The SAS group achieved a higher stone-free rate (OR = 2.37; 95% CI: 1.56–3.61; $p < 0.0001$), along with shorter operative time, fewer total complications, and lower rates of postoperative fever and auxiliary procedures.

Conclusion

Vacuum-assisted mini-percutaneous nephrolithotomy (VAM-PNL) offers a safe and effective alternative to conventional Mini-PNL in pediatric patients with renal stones larger than 2 cm, providing superior intraoperative efficiency.

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