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Management of medium sized renal stones in pediatric age group: Review article

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Abstract

There is a growing global recognition of pediatric stone disease and differs significantly from adult urolithiasis in etiology, presentation, and management. Calcium-containing stones remain the most prevalent, but rarer types as cystine, uric acid, struvite, xanthine, and drug-induced stones require careful metabolic and genetic evaluation to prevent recurrence. Advances in pediatric urology over the past two decades—including the development of child-appropriate instruments, minimally invasive surgical techniques, and improved understanding of genetic and metabolic contributors have significantly enhanced outcomes.

Current management strategies emphasize a tailored approach, integrating the child’s anatomy, stone composition, and metabolic profile. Non-invasive and minimally invasive interventions as ESWL, RIRS, and PCNL, supplemented by laser lithotripsy using Holmium:YAG or Thulium fiber lasers, have become standard practice, achieving high stone-free rates while minimizing complications. Nevertheless, careful perioperative monitoring and post-procedure metabolic evaluation remain essential to ensure long-term renal protection and reduce recurrence.

Keywords: Renal stones, pediatric, Extracorporeal SWL, Percutaneous nephrolithotomy

Introduction

The global incidence of pediatric urolithiasis has shown a marked increase. This condition exhibits distinct characteristics compared to several key aspects. Minimizing the frequency of repeated operative interventions and preserving renal function requires a comprehensive management strategy that integrates medical planning tailored to pediatric metabolic profile and operative planning guided by the child’s anatomical characteristics. [1]. Over the last two decades, major advancements in the management of pediatric urolithiasis have focused on elucidating the genetic basis of the condition to enhance understanding of its etiological factors, developing instruments specifically adapted to pediatric anatomical dimensions, and refining classifications of least invasive endoscopic approch, which are now regarded as the recommended surgical approaches due to their high success rates. [2].

Renal Stones

Pediatric urolithiasis continues to be prevalent in low-resource settings, primarily affecting children aged from 1 to 14 years [3]. The frequency of pediatric urolithiasis in developed countries is relatively low, ranging from 1% to 5%. In contrast, in developing countries, pediatric urolithiasis can reach rates as high as 15%, predominantly affecting children under 15 years of age, with a higher frequency observed in males [4].

Types and Etiology of urinary calculi

Calcium-based stones, primarily composed of oxalate and phosphate, constitute the majority of cases, accounting for approximately 80%. Uric acid stones and struvite (infection-related) stones comprise about 10%, while cystine stones and drug-induced calculi (such as those associated with indinavir or triamterene) are uncommon, occurring in roughly 1% of cases.[5].

Calcium nephrolithiasis

Most associated with elevated urinary excretion of calcium or oxalate, or a reduced concentration of urinary citrate.

1. Hypercalcuric nephrolithiasis: means urinary calcium excretion more than 300 mg/day and it may be absorptive (increase calcium absorption in small intestine), resorptive (in primary hyperparathyroidism) or renal (due to intrinsic renal tubular defect) [6].

2. Hyperoxaluric nephrolithiasis: means urinary oxalate level more than 40 mg/day. This condition may arise from uncommon autosomal recessive genetic disorders affecting oxalate metabolism (such as primary hyperoxaluria types 1 and 2), increased intestinal absorption of oxalate due to malabsorptive conditions (enteric hyperoxaluria), or dietary factors, including high oxalate intake combined with insufficient calcium consumption (dietary hyperoxaluria) [7].

3. Hypocitraturic calcium nephrolithiasis: Hypocitraturia could be outlined as a urinary citrate level (<320 mg/day). Acidosis is the most important cause of hypocitraturia [8].

Non calcium calculi

1. Uric acid stones may result from genetic or acquired disorders or combination of both. The mechanisms involved in uric acid stones formation include: reduced urine volume, hyperuricosuria, and excessively acidic urine (urinary pH≤5.5) [9].

2. Cysteine stones: Cystinuria is the leading genetic etiology of nephrolithiasis, accounting for approximately 6%–8% of all pediatric cases. It should be suspected in individuals with a positive family record of stone disease and in those presenting with radiographic findings of faintly opaque, ground-glass, smooth-edged calculi [10]. Approximately 50% of individuals with cystinuria develop their first stone by the age of 10, while an additional 25% experience onset during adolescence. Without appropriate preventive measures, these patients are prone to relapsing stone formation, that can progressively cause renal insufficiency and progression to chronic kidney disease [11].

3. Struvite (infection) stones: The crucial factors in the development of infection-related. calculi are excessive urine with an alkaline pH (more than 7.2) and additionally, the finding of urease-producing organisms (which hydrolyze urinary urea into ammonia and bicarbonate. which alkalizes the urine and elevates the likelihood of stone formation in alkaline urine). The speed of growth of struvite stones will be fast and intensive and so, staghorn stone formation is a common feature of this stone kind [12].

4. Xanthine stones are radiolucent and result from inherited defect of enzyme that catalyzes the conversion of xanthine into uric acid [13].

5. Indinavir stones are the most common protease inhibitor which is an effective therapy for patients with acquired immunodeficiency syndrome, indinavir can lead to calculi that are uniquely radiolucent on non-contrast CT imaging, making them the only urinary stones with this characteristic [14].

Management of Renal Stones

At present, the most of pediatric stones can be effectively managed using shock wave lithotripsy (SWL), retrograde intrarenal surgery (RIRS), or percutaneous nephrolithotomy (PCNL). Only a minority of children with anatomical anomalies require alternative surgical approaches, such as open, robotic, or laparoscopic procedures. Complete stone clearance should be the goal, only 20–25% of postoperative residual fragments are expected to pass spontaneously Additionally, congenital obstructive uropathy ought to be considered concurrently with stone clearance to reduce the risk of recurrence [15].

Table 1: Management of paediatric stones according to EAU guidelines [16]

Stone size and localisation*	Primary treatment option	Alternative treatment options	Comment
Infant microlithiasis (<3mm, any location)	Observation	Intervention and/or medical treatment	Individualised decision according to size progression, symptoms and metabolic factors.
Staghorn stones	PCNL	Open/SWL	Multiple sessions and accesses with PCNL may be needed. Combination with SWL may be useful.
Pelvis < 10 mm	SWL	RIRS/PCNL	
Pelvis 10-20 mm	SWL/PCNL/RIRS		Multiple sessions with SWL may be needed. PCNL and RIRS have a similar recommendation grade.
Pelvis > 20 mm	PCNL	SWL/RIRS	Multiple sessions with SWL may be needed.
Lower pole calyx < 10mm	Observation or SWL	PCNL/RIRS	Stone clearance after SWL is lower than other locations.
Lower pole calyx > 10mm	PCNL	RIRS/SWL	Anatomical variations are important for complete clearance after SWL.

ESWL (Extra corporeal shock wave lithotripsy)

A noninvasive technique that uses high-energy shock waves produced by a spark plug electrode within a lithotripter to fragment of renal calculi into smaller pieces, facilitating their passage through the urinary tract [17].

The application of ESWL in childeren nephrolithiasis was postponed for several years, until 1986, because of concerns regarding potential adverse effects on the developing organs of children [18]. Currently, compared with adults, children are often considered more suitable individuals eligible for ESWL due to their diminished and more compliant ureters, which facilitate higher stone removal rates, their reduced body size, and the consequently reduced cutaneous-to-calculus distance [19].

Stone clearance rates are influenced by multiple determinants. Irrespective of site, an elevation in stone size is linked with reduced stone clearance rates and an elevated likelihood of additional treatment. Reported clearance rates are approximately 90% for stones smaller than 1 cm, 80% for stones measuring 1–2 cm, 60% for stones bigger than 2 cm, with an overall success rate of about 80% [20, 21]

ESWL is generally not recommended as the primary therapeutic option for cystine stones in pediatric individuals due to the inherent density of these calculi and corresponding refractoriness to shock wave disintegration, as evidenced by a low 3-month stone-free rate of 37.5% in prepubertal children with cystinuria [22].

Furthermore, children with a record of urological anatomical abnormalities are generally poor individuals eligible for ESWL, as demonstrated by a stone-free rate of only 12.5% in those who previously underwent urinary tract reconstruction or possessed congenital genitourinary malformations. In contrast, a recent retrospective study documented a substantially higher stone clearance rate of 67% in children without such conditions [23].

Therefore, when selecting ESWL as a treatment option, particular attention should be directed toward the size, location, and composition of the stones, as well as the ability to localize them accurately. The most frequently observed complication is hematuria, arising from localized trauma secondary to the shock waves; however, this typically resolves spontaneously within a week. More severe but less common complications include subcapsular hematomas and perirenal hemorrhage [24].

Additional postoperative complications of ESWL may arise from stone fragments generated during the procedure, leading to renal colic. These encompass the development of steinstrasse or the recurrence of residual calculi within the urinary tract. Infection-linked complications, such as bacteriuria and sepsis, may also occur. Moreover, injury involving tissues surrounding the calculus site has been reported, including hepatic hematoma, splenic rupture, and pneumothorax [25].

According to a population-based retrospective study using The Health Improvement Network database, renal ESWL was linked to a 40% elevated risk of developing hypertension. Given that urolithiasis itself carries an elevated probability of hypertension, individuals undergoing ESWL demonstrated a twofold higher risk compared to individuals without urolithiasis. Although pediatric patients were not included in this research, the potential probability of occurrence of hypertension ought to be taken into account [26].

PCNL

PCNL is increasingly utilized both as a standalone procedure and in conjunction with SWL (referred to as sandwich therapy) in both children and adults, achieving stone-free rates of 68% to 100%. Although somewhat controversial, primary indications for PCNL in pediatrics include a significant upper urinary tract stone burden exceeding 1.5 cm, reduced pole stones more than 1 cm, anatomical abnormalities that obstruct urinary flow and calculi clearance, or calculi composed of cystine or struvite [27].

With advancements in instrumentation, downsized PCNL, or “mini-perc,” using a 13F or 14F sheath has become feasible, allowing for reduced transfusion requirements. This has been further refined into the “micro-perc” technique, which employs a 4.85F “all-seeing needle” that facilitates in situ laser fragmentation of stones, leaving fragments for spontaneous passage. Performing PCNL in pediatric patients presents unique challenges primarily secondary to the small size of the kidney. Increased renal mobility in children can make access challenging, and mucosal bleeding is more easily induced. Additionally, the thinner renal parenchyma and less distinct boundary between the parenchyma and mucosa increase the risk of sheath displacement during the procedure. [28]

Complication rates in pediatric patients are comparable to those observed in adults, and any complication seen in adults can also arise in children. However, the potential for rapid hemodynamic deterioration and the lower tolerance of children to complications such as bleeding are critical considerations that often heighten surgical concern [28].

Children have a lower tolerance for abrupt and substantial hemorrhage compared to adults, and their hemodynamic status can decline rapidly. Consequently, careful postoperative monitoring of vital signs, urine output, and both the volume and rate of parenteral fluid administration is essential. Another critical consideration is the heightened risk of hypothermia in pediatric patients, particularly in infants, as a result of their relatively larger body surface area. They rely on brown adipose tissue for thermoregulation and compensate for increased oxygen demands through accelerated respiration [29]

Hypothermia can be effectively prevented by implementing appropriate measures. These include maintaining an adequate room temperature, using warming devices, wrapping extremities with cotton, and preheating fluids before administration. Additionally, during PCNL, it is essential to ensure that the surgical drape does not allow water to leak underneath and to avoid the child becoming wet throughout the procedure [29].

Variations in fat distribution and differences in intracellular and extracellular fluid composition make children more sensitive to fluid, electrolyte, and volume imbalances. During PCNL, some irrigation fluid may leak into the retroperitoneal space and be absorbed; therefore, saline solution should be used for irrigation. A further challenge of pediatric PCNL is the longer surgical time required, primarily as a result of the smaller tract size, especially in cases with a larger stone burden [29].

Another critical aspect is the metabolic evaluation of children following PCNL, which plays an essential role in long-term treatment success. While PCNL is efficacious for the removal of renal stone, it alone is insufficient to maintain a stone-free status, as underlying metabolic abnormalities often persist and may predispose to recurrence [30].

RIRS

RIRS is an effective treatment modality for renal pelvic stones, small reduced pole calculi, and stones measuring 10–20 mm. compared with micro-PCNL, RIRS offers comparable success and complication rates, while providing the advantages of shorter hospitalization and reduced radiation exposure. [31]. Cases with unfavorable anatomy for ESWL as morbid obesity, horseshoe or ectopic kidney, and musculoskeletal deformities favors the ureteroscopic approach. Bleeding diathesis also favor the use of flexible URS [32].

RIRS is among the most effective approaches for managing kidney stones in pediatric patients. Unlike PCNL, RIRS utilizes a natural orifice, eliminating the need for additional surgical access. This feature translates into reduced invasiveness, enhanced safety, shorter hospital stays, and faster postoperative recovery, particularly in younger children [33].

However, the smaller diameter of pediatric ureters and the restricted accessibility of appropriately sized endoscopic instruments can increase the risk of ureteral injury. Potential complications include perforation, ischemia, stenosis, and disruption of the natural anti-reflux mechanism at the ureterovesical junction [33].

The growing adoption of RIRS in pediatric patients has been largely driven by technological advancements in newer generations of ureteroscopes and lithotripsy energy sources. These innovations include the development of reduced-diameter ureteroscopes, which reduce the requirment for pre-stenting and enable the use of smaller ureteral access sheaths (UAS). The smaller UAS has previously been undertaken cautiously because of concerns about potential complications, such as ureteral injury and stricture formation [34].

LASER Lithotripsy

Laser is an acronym for "Light Amplification by Stimulated Emission of Radiation". Over the last three decades, the use of laser devices has expanded across most areas of medicine, not only therapeutic but also diagnostic. Stone disease management represents one of the areas in which the use of laser has achieved great success, and this procedure is referred to as laser lithotripsy. Laser is ideal for RIRS or, alternatively, a percutaneous approach [35]

Holmium: yittrium-aluminum-garnet (Ho:YAG) laser

It is considered the laser of choice for lithotripsy and the most commonly used laser. The first use of Holmium:YAG laser in Urology was described more than two decades ago [36].

The holmium: YAG laser can be utilized to fragment all types of stones. It allows for high-frequency, low-energy settings that partially vaporize the stone, producing fine dust that can be flushed out (dusting). Alternatively, the laser can be operated at a reduced frequency with higher energy per pulse, causing the stone to break into a limited number of intermediate-sized fragments that can then be removed using a basket or forceps (fragmenting).[37].

The holmium laser has a penetration depth of approximately 0.5 mm, which limits mucosal injury when applied directly to the tissue. Low-power holmium laser generators, with outputs up to 20 W, can be used efficiently for stone fragmentation [38].

Thulium fiber laser

Recently, next-generation laser lithotripsy has begun exploring the use of the Thulium fiber laser, an approach which provides multiple potential benefits over the traditional Holmium: YAG laser and may broaden the capabilities of laser lithotripsy. The Thulium fiber laser is constructed from an ultra-thin, elongated silica fiber (10–20 µm core diameter, 10–30 m in length) doped with Thulium ions. Multiple diode lasers are employed to pump and excite these ions. The resulting laser emits at a wavelength of 1940 nm and can funcyion in either continuous or pulsed modes, with a broad spectrum of adjustable energy, frequency, and pulse shape settings. [39].

While the Ho:YAG laser lithotripter can function at high pulse energies, its efficient performance within lithotripsy is limited to small pulse rates (approximately 10 Hz). In contrast, the Thulium fiber laser operates efficiently at elevated pulse rates (up to 2000 Hz) but is limited to lower pulse energies. The higher pulse rate enhances dusting by producing a greater quantity of fine particles with smaller volume. Additionally, the Thulium fiber laser has reduced tissue and water penetration depth and generates less retropulsion compared with the Ho:YAG laser [36].

Conflict of Interest
Not available

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