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REVIEW: Renal Stones in Infants and Preschool Children: A Narrative Review of Treatment Selection Among Shock Wave Lithotripsy, Flexible Ureteroscopy/Retrograde Intrarenal Surgery, and Mini-PCNL

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ABSTRACT

Pediatric nephrolithiasis is increasingly recognized and carries a substantial lifetime recurrence burden. Infants and preschool children are uniquely challenging because of small-caliber urinary tracts, limited physiologic reserve, anesthesia exposure, radiation sensitivity, and the possibility of metabolic or genetic disease. To narratively synthesize clinically relevant evidence guiding treatment selection among shock wave lithotripsy (SWL), flexible ureteroscopy/retrograde intrarenal surgery (fURS/RIRS), and miniaturized percutaneous nephrolithotomy (mini-PCNL) in infants and preschool-aged children.

PubMed/MEDLINE-indexed literature, current European Association of Urology (EAU) guidance, and citation tracking of key pediatric studies were reviewed through September 2026. Evidence was selected for clinical relevance to renal stone management in children, with emphasis on infant- and preschool-specific cohorts, comparative studies, major pediatric series, and evidence syntheses. The review is narrative rather than systematic; study findings were interpreted in context rather than statistically pooled de novo.

SWL remains the least invasive intervention and is suitable for many small, targetable renal stones, but retreatment can increase cumulative anesthesia burden. fURS/RIRS provides active clearance without renal puncture and is useful for SWL-unfavorable stones, although small ureteral caliber may necessitate prestenting or staged access. Mini-PCNL offers efficient clearance of larger or complex burdens but carries greater tract-related bleeding and access concerns. Preschool-specific comparisons show that differences in single-session stone-free rate may narrow after auxiliary procedures, making cumulative procedural burden a key treatment endpoint.

In infants and preschool children, treatment selection should be individualized according to stone burden and location, density or composition, anatomy, infection, ureteral access, expected number of anesthetic events, and institutional expertise. The goal is durable clearance with the lowest cumulative morbidity rather than rigid adherence to a single size threshold.

Introduction

Pediatric nephrolithiasis is no longer viewed as an exceptional diagnosis. Population-based data from North America and longitudinal cohorts have shown rising rates of symptomatic stone disease, particularly among adolescents, while specialty-center experience confirms that very young children continue to represent an important subgroup (1–6). The clinical implications are different from those in adults: a child who forms a stone at two or four years of age has decades in which recurrence, repeated imaging, repeated anesthesia, and repeated intervention may occur. Moreover, the stone can be the first manifestation of a metabolic, genetic, infectious, or anatomic disorder rather than an isolated event (7–10).

Infants and preschool children require a particularly cautious approach. Symptoms are often nonspecific; irritability, vomiting, urinary tract infection, microscopic or gross hematuria, poor feeding, and abdominal discomfort may replace classic renal colic. Their smaller circulating blood volume makes even modest procedural bleeding more clinically relevant, and their small ureters can limit primary retrograde access. Conversely, the relatively compliant pediatric ureter, advances in 4.5–7.5 Fr ureteroscopes, fine laser fibers, smaller access sheaths, ultrasound-guided puncture, and miniaturized percutaneous systems have made minimally invasive management feasible even in infants (10–13).

Current practice therefore centers on three modalities. SWL fragments stones without instrumenting the upper urinary tract and retains a major role for small targetable stones. fURS/RIRS provides direct access to the collecting system without renal puncture and offers excellent clearance for many stones below 20 mm. Mini-PCNL, including ultra-mini, micro-PCNL, and super-mini variants, trades greater invasiveness for higher single-session clearance in larger or complex stone burdens (11–13). The central clinical question is not which modality is universally "best," but which modality is most likely to provide durable clearance with the fewest anesthetic sessions and the least cumulative morbidity for a particular child.

This review focuses on renal stones in infants and preschool children, while using broader pediatric evidence when age-specific data are sparse. It compares SWL, fURS/RIRS, and mini-PCNL with attention to stone-free rate (SFR), retreatment, complications, radiation, anesthesia, and technical constraints. The review also proposes a practical, age-sensitive treatment framework informed by current EAU recommendations and recent comparative evidence (10–13).

2. Methods

This article was prepared as a narrative review. PubMed/MEDLINE-indexed literature was explored using combinations of the terms "pediatric urolithiasis," "infant renal stone," "preschool nephrolithiasis," "shock wave lithotripsy," "flexible ureteroscopy," "retrograde intrarenal surgery," "mini-PCNL," "micro-PCNL," "super-mini PCNL," and "percutaneous nephrolithotomy." Current EAU pediatric and urolithiasis guidance was reviewed, and reference lists of major pediatric reviews and comparative studies were used for backward citation tracking. Google Scholar was used only for citation tracing and verification of bibliographic details. Literature available through September 2026 was considered. The search was intentionally broad and iterative rather than protocol-driven, consistent with the narrative-review design.

The original literature search was not prospectively logged at the record level; therefore, a formal PRISMA-style count of all records screened cannot be reconstructed without repeating the search. Thirty-nine sources were retained and cited in the final narrative synthesis, comprising current EAU guidance and 38 journal publications. This limitation is stated explicitly to avoid implying a systematic screening process that was not performed.

3. Epidemiology, Etiology, and Recurrence Risk

The epidemiology of pediatric stone disease has shifted over recent decades. Earlier series often emphasized infection-related calculi, whereas contemporary cohorts show a larger contribution from metabolic abnormalities and idiopathic calcium stones (1,5–8). In the United Kingdom, Coward et al. found an identifiable metabolic abnormality in 44% of children in a five-year cohort, while a later 22-

year experience reported metabolic disease in 34%, infection-related stones in 22%, and idiopathic stones in 44% (5,6). Hypercalciuria, hyperoxaluria, cystinuria, and hypocitraturia are particularly important because they influence recurrence, stone composition, and the urgency of achieving complete clearance.

Large epidemiologic datasets also show that stone disease is increasing in younger populations. Tasian et al. reported a rising incidence across 1997–2012, with the largest increase among 15–19-year-olds, while Dwyer et al. demonstrated a 4% annual increase in symptomatic pediatric nephrolithiasis across a 25-year population-based period (2,3). Although these epidemiologic increases are dominated by older children and adolescents, they matter to infant and preschool practice because they reflect the broader shift toward metabolic and environmental stone disease that can recur from an early age.

The EAU classifies children as high-risk stone formers and recommends metabolic evaluation for pediatric stone disease (10). In young children, the diagnostic threshold for investigating inherited disease should be low. Primary hyperoxaluria, cystinuria, distal renal tubular acidosis, disorders of purine metabolism, bowel-related hyperoxaluria, and congenital urinary tract obstruction are clinically important because incomplete treatment can lead to recurrent obstruction, infection, nephrocalcinosis, or chronic kidney injury (8–10).

Etiologic evaluation is particularly important in this age group because the stone may be a marker of persistent disease. Hypercalciuria and hypocitraturia are common metabolic contributors; primary hyperoxaluria should be considered in very early-onset disease, nephrocalcinosis, or a suggestive family history; and cystinuria is relevant because cystine stones may respond poorly to SWL. Recurrent urinary tract infection raises concern for infection-related stones, while hydronephrosis or congenital anomalies may indicate anatomic obstruction that changes both access and drainage. Low fluid intake and high sodium exposure are modifiable recurrence factors. These etiologies do not automatically determine a procedure, but they influence the need for complete clearance, metabolic therapy, and long-term surveillance (5,6,8–11).

4. Diagnostic Evaluation Before Intervention

Ultrasound is the first-line imaging modality in children because it can identify renal calculi, hydronephrosis, and many structural abnormalities without ionizing radiation (9–11). Its limitations are reduced sensitivity for very small ureteric stones and imperfect estimation of stone size. Kidney–ureter–bladder radiography can add information for radiopaque stones, while non-contrast CT should be reserved for situations in which ultrasound is equivocal, detailed anatomy is necessary for intervention, or stone density is clinically important (11). Current EAU guidance recognizes ultrasound as the baseline modality and places CT as a second-line test when needed (10,11).

Preoperative evaluation should include urinalysis and urine culture. Any active infection should be treated before SWL, URS, or PCNL; infected obstruction requires urgent drainage rather than definitive stone fragmentation. Serum creatinine, electrolytes, bicarbonate, calcium, phosphorus, and uric acid are useful in the initial metabolic screen, while age-adjusted urine calcium/creatinine, citrate, oxalate, uric acid, cystine testing, and stone analysis should be obtained according to clinical context (8–10).

In infants and preschool children, imaging strategy is part of treatment selection. CT-derived Hounsfield units may predict SWL response, but the information must justify radiation exposure. Conversely, mini-PCNL planning may require a more detailed understanding of calyceal anatomy, and complex congenital anomalies can make cross-sectional imaging particularly valuable. A radiation-sparing philosophy should be maintained throughout diagnosis, intraoperative fluoroscopy, and follow-up.

5. General Principles of Treatment Selection in Young Children

The central objective in infants and preschool children is not simply to maximize the stone-free rate after one procedure, but to achieve durable clearance with the lowest cumulative burden of anesthesia, instrumentation, radiation, bleeding, infection, and repeat intervention. Because very young children have small-caliber urinary tracts and limited physiologic reserve, the least invasive procedure is not necessarily the least burdensome strategy if it predictably requires several sessions (10–13,17–19,31–37).

Treatment selection should integrate stone-specific factors (maximum diameter, total burden, number, renal location, density or suspected composition, obstruction, and infection) with patient-specific factors (age, ureteral caliber, collecting-system anatomy, congenital anomalies, metabolic diagnosis, previous procedures, and ability to tolerate staged treatment). Small, non-obstructing stones may be observed in selected infants, whereas infection, obstruction, progressive stone growth, symptoms, or a clinically important stone burden favor active treatment (10–13).

The expected number of anesthetic events is particularly important. SWL offers the lowest degree of instrumentation but may require repeat sessions; fURS/RIRS offers active endoscopic fragmentation and extraction without a renal puncture but may require prestenting or staged access; mini-PCNL provides the most direct route for removal of larger or complex burdens but carries greater concerns regarding tract-related bleeding and fluid management. These trade-offs become more important as patient size decreases (17–19,27–37).

For intermediate renal stones, especially in the 10–20 mm range, there is no universally superior procedure. Favorable SWL anatomy and low stone density may support SWL, while lower-pole location, high density, multiple stones, previous SWL failure, or a desire for higher single-session clearance may shift the balance toward fURS/RIRS. Mini-PCNL becomes increasingly attractive when stone burden, complexity, lower-pole anatomy, or the need for active extraction makes retrograde treatment less efficient. Institutional expertise and availability of pediatric-sized equipment remain legitimate determinants of the final choice (10–13,17,18,31–37).

6. Shock Wave Lithotripsy (SWL)

6.1. Rationale and Indications

SWL is the least invasive of the three principal interventions and has historically been favored for pediatric renal calculi. It avoids ureteral instrumentation and renal puncture, and most complications are transient. The EAU considers children with renal stones up to approximately 20 mm potential candidates for SWL, with stone location, density, composition, and anatomy modifying success (10,11). In very young children, SWL is attractive because the body wall is thin and transmission of shock waves can be favorable, although general anesthesia or deep sedation is commonly required for accurate targeting and immobility.

Stone size is one of the strongest determinants of success. In a meta-analysis of 14 studies and 1,842 pediatric patients, Lu et al. found significantly better SFR for stones smaller than 10 mm than for stones larger than 10 mm (14). Lower-pole position, high stone density, cystine composition, and unfavorable drainage anatomy reduce the chance that fragmented material will clear. Thus, a technically successful fragmentation session does not necessarily translate into a stone-free kidney.

6.2. Efficacy, Retreatment, and Safety

The EAU systematic review by Grivas et al. summarized SWL SFRs of approximately 70–90%, with retreatment rates ranging from 4% to 50% and complication rates up to 15% across heterogeneous pediatric studies (11). The major clinical trade-off is therefore retreatment: SWL may minimize invasiveness per session but increase the number of sessions and anesthetic exposures required for durable clearance. This issue is especially relevant in preschool children, for whom each additional treatment often requires another general anesthetic.

Long-term concerns about the growing kidney have been reassuring overall. Brinkmann et al. reported 83% complete clearance in a cohort of 64 children and found no significant long-term changes in renal function, blood pressure, or renal growth (15). El-Nahas et al. similarly found no development of hypertension or diabetes and no meaningful adverse effect on renal growth after a mean follow-up of 5.2 years (16). These data support the renal safety of appropriately performed pediatric SWL, although contemporary practice still emphasizes minimizing unnecessary shock exposure and repeated treatment.

The strongest preschool-specific comparative evidence comes from Mokhless et al., who randomized 60 children with 10–20 mm renal stones (mean age 2.4 years) to SWL or RIRS. Single-session SFR was 70% after SWL and 86.6% after RIRS; after repeat SWL sessions, overall 3-month SFR reached 93.3% versus 96.6% for RIRS (17). The study illustrates the core difference between modalities: final clearance can be comparable, but SWL may require more treatment sessions.

6.3. Advantages and Limitations in Infants and Preschool Children

SWL is particularly reasonable for a single, targetable, non-lower-pole stone below 10 mm, low or moderate density, and favorable drainage. It is less attractive for cystine stones, multiple stones, large lower-pole burdens, high-density calculi, significant obstruction, or when the family strongly prefers a high chance of one-session clearance. Steinstrasse, colic, transient hematuria, urinary infection, and obstruction are the principal complications; prestenting is not routine for small burdens but may be considered in solitary kidneys or when obstruction risk is high (10,14).

7. Flexible Ureteroscopy and Retrograde Intrarenal Surgery (fURS/RIRS)

7.1. Technical Evolution and Indications

Flexible ureteroscopy has expanded rapidly because modern pediatric-caliber semirigid and flexible scopes, small laser fibers, improved deflection, digital imaging, and miniaturized ureteral access sheaths have reduced the technical gap between adult and pediatric endourology (13,20–22). The fundamental advantage is direct visualization and active fragmentation of stones throughout the collecting system without a renal puncture. This is especially useful for stones that are poorly suited to SWL, such as lower-pole calculi, relatively hard stones, or cases in which rapid definitive clearance is desired.

The challenge in infants and preschool children is access. The ureter may not safely accept a ureteroscope or access sheath at the first attempt. Passive dilation with a temporary ureteral stent can convert a failed primary access into a straightforward second-stage procedure, but the cost is another anesthetic and the burden of a stent. Routine active dilation or oversized access sheaths should be avoided. The 2022 systematic review of pediatric ureteral access sheaths reported low intraoperative complication rates, but emphasized heterogeneity and the absence of randomized evidence comparing sheath and sheathless strategies (22).

7.2. Stone-Free Rates and Complications

A 2014 systematic review by Ishii et al. included 282 children and reported a mean initial SFR of 85.5% with a 12.4% complication rate (20). An updated systematic review by Whatley et al. included 431 patients, mean stone size 13 mm, and reported an overall SFR of 87% with a mean complication rate of 12.6% (21). Most events were low grade, although ureteral injury and urinoma were reported. These results indicate high efficacy, but also show why instrument size, access technique, intrarenal pressure, operative time, and surgeon experience matter.

Preschool-specific series are particularly informative. Unsal and Resorlu treated 16 children younger than seven years (mean age 4.2 years) and achieved an 88% SFR; stones below 10 mm had a 100% success rate (23).

Erkurt et al. reported 65 preschool children with a mean age of 4.31 years and mean stone size of 14.66 mm; first- and second-procedure SFRs were 83.1% and 92.3%, respectively (24). More recently, Gatti et al. reported contemporary RIRS outcomes in preschool children using small-caliber instruments and emphasized feasibility in specialized pediatric centers (25).

At the population level, ureteroscopy has become more common than SWL in some healthcare systems. Tejwani et al. evaluated 2,281 pediatric admissions and found fewer additional stone-related procedures after fURS/RIRS than SWL at 12 months, but higher 30-day emergency visits and readmissions after fURS/RIRS (19). This distinction is clinically important: "more definitive" treatment does not necessarily mean less postoperative healthcare utilization.

7.3. Comparison with SWL

The 2023 EAU Guidelines systematic review and meta-analysis concluded that fURS has a higher SFR than SWL for pediatric renal/proximal ureteric stones below 2 cm, at the cost of longer operative time and hospital stay (18). The preschool randomized trial by Mokhless et al. provides a concrete example: RIRS improved single-session clearance compared with SWL (86.6% vs 70%), while final clearance after repeat sessions was similar (17). Thus, fURS is particularly attractive when the objective is to reduce the number of treatment sessions, while SWL remains attractive when avoiding upper-tract instrumentation is the dominant priority.

7.4. Challenges of Ureteral Access and Stenting

Ureteral access is one of the major technical constraints of fURS/RIRS in infants and preschool children. A ureter that does not safely accommodate the ureteroscope or an appropriately small access sheath should not be forcibly dilated. Prestenting and delayed ureteroscopy can provide passive dilation, but this converts a nominally single procedure into a staged pathway with an additional anesthetic exposure. Sheathless fURS is feasible in selected children, whereas an access sheath may facilitate repeated entry, lower intrarenal pressure, and extraction of fragments when the ureter can safely accept it (20–25).

Postoperative stenting should likewise be individualized rather than routine. It is more defensible after difficult access, ureteral trauma or edema, prolonged instrumentation, residual fragments likely to pass, or concern for postoperative obstruction. Conversely, avoiding an unnecessary stent may reduce irritative symptoms and eliminate a separate removal procedure in a very young child. Thus, access strategy and stent planning should be considered part of treatment selection before fURS/RIRS is chosen (20–25).

8. Miniaturized Percutaneous Nephrolithotomy (Mini-PCNL)

8.1. Importance of Miniaturization

PCNL provides direct access to the renal collecting system and permits active fragmentation and extraction of substantial stone burden. In children, standard adult tract sizes raised concerns about bleeding, renal parenchymal injury, hypothermia, fluid absorption, and loss of renal tissue. The development of mini-PCNL, ultra-mini PCNL, micro-PCNL, and super-mini PCNL reduced tract diameter and expanded percutaneous treatment into infants and preschool children (27,31,32).

Jackman et al. were among the pioneers of small-tract pediatric percutaneous renal access, reporting an 11 Fr technique in children aged 2–6 years with an 85% stone-free rate and no transfusions or major procedure-related complications (27). Subsequent data showed that pediatric PCNL can preserve renal function. Dawaba et al. followed 65 children, including 27 younger than five years, and reported favorable early and late anatomic and functional outcomes (28).

8.2. Efficacy and Safety

Large multicenter studies confirm high efficacy but also define the complication profile. Guven et al. reported 140 PCNL procedures in 130 children, including infants/toddlers and preschool children, and showed that PCNL could be performed safely across age groups when experience and appropriately sized instruments were available (29). Onal et al. analyzed 1,205 renal units and reported an 81.6% postoperative SFR, with overall complications in 27.7% of renal units; larger sheath size and operative factors were associated with complications (30). These observations support miniaturization and careful tract planning rather than simply extrapolating adult technique to a smaller patient.

A systematic review of micro- and ultra-mini PCNL by Jones et al. included 456 children. Reported SFRs were 80–100% for micro-PCNL and 85–100% for ultra-mini PCNL, with an overall complication rate of 11.2%; most complications were Clavien I/II (31). Silay et al. reported the first multicenter pediatric micro-PCNL series, with an 89.5% SFR at one month and minimal hemoglobin decrease (32). These studies support miniaturized access as a high-clearance option while preserving the principal advantage of PCNL: active stone extraction.

8.3. Evidence in Preschool Children

The most clinically relevant comparison for the present review is mini-PCNL versus RIRS. Pelit et al. studied preschool-aged children and found single-session SFRs of 84.4% for mini-PCNL and 75% for RIRS; after auxiliary procedures, overall SFR exceeded 90% in both groups. PCNL required longer operative, fluoroscopy, and hospitalization times, while major complications were absent (34). In the larger multi-institutional study by Resorlu et al., 201 pediatric patients with 10–30 mm stones had similar single-session SFRs with RIRS (84.2%) and mini-PCNL (85.8%), but transfusion occurred only in the mini-PCNL group and hospital stay, fluoroscopy, and operative time were longer with mini-PCNL (33).

Technique and stone burden strongly influence the direction of the comparison. Jia et al. found a markedly higher one-month SFR with super-mini PCNL than RIRS for 1–2 cm stones (94.4% vs 60%), with fewer retreatments in the percutaneous group (35). In a prospective 2022 comparison, Mahmoud et al. found comparable final outcomes for RIRS and mini-PCNL in children with 1–3 cm stones; RIRS reduced fluoroscopy and hospital stay, whereas mini-PCNL was less costly in that setting (36). The 2023 meta-analysis by Yuan et al., including 13 studies and 1,019 patients, concluded that the balance between RIRS and different PCNL variants depends on the specific miniaturized technique and outcomes measured rather than on a simple hierarchy (37).

The most recent randomized evidence also supports equipoise for selected moderate stones. A 2026 prospective randomized study of 70 children aged 3–14 years with renal pelvic stones <2 cm and density >1000 HU reported one-month SFRs of 91.4% for RIRS and 94.3% for mini-PCNL, with shorter recovery and less radiation for RIRS but greater hemoglobin decrease in mini-PCNL (39). Although this cohort is not limited to preschool children, it reinforces the concept that both approaches can be highly effective when appropriately selected.

8.4. Distinction from Bladder Calculi and Historical Context

Ahmadnia et al. reported five years of percutaneous treatment for bladder calculi in 30 children aged 1.5–12 years (39). This study is retained solely as historical/technical evidence that percutaneous stone access was feasible in pediatric patients. It concerns percutaneous cystolithotripsy for bladder calculi, not renal PCNL or mini-PCNL, and therefore is not interpreted as evidence of renal mini-PCNL efficacy, renal SFR, renal tract size, bleeding risk, or comparative effectiveness. Conclusions regarding renal mini-PCNL in this review are based on kidney-specific studies and evidence syntheses (27–37).

9. Comparative Effectiveness of SWL, fURS/RIRS, and Mini-PCNL

No single modality dominates every outcome. Across published evidence, there is a trade-off between invasiveness and single-session clearance. SWL has the lowest procedural invasiveness but the highest retreatment burden. fURS/RIRS increases the probability of single-session clearance without a renal tract, but may require prestenting, ureteral access, postoperative stents, and longer operative time. Mini-PCNL offers the most direct route to high-volume stone extraction and is favored for large or complex stones, but carries greater bleeding, puncture, and radiation burden (10–13,18,31,37).

Comparative evidence is especially heterogeneous for 10–20 mm stones. Resorlu et al. reported nearly identical single-session SFRs for RIRS and mini-PCNL, with greater transfusion and resource use in the percutaneous group (33). Pelit et al. found higher single-session clearance with mini-PCNL in preschool children but similar final clearance after auxiliary procedures (34). Jia et al. reported a marked SFR advantage for super-mini PCNL over RIRS in a 1–2 cm cohort (35), whereas recent randomized evidence in high-density renal pelvic stones found comparable SFRs with different perioperative trade-offs (39). These findings favor contextual interpretation rather than a universal hierarchy of procedures.

Table 1. Practical comparison of SWL, fURS/RIRS, and mini-PCNL in infants and preschool children

Domain	SWL	fURS/RIRS	Mini-PCNL	Clinical interpretation	Typical limitation	Refs
Invasiveness	Non-incisional; no upper-tract instrumentation	Natural-orifice endoscopy	Percutaneous renal tract	Favors SWL for small favorable stones	Invasiveness does not equal fewer anesthetics	(10–18)
Reported SFR	~70–90%	~76–100%	~80–100% for miniaturized techniques	Ranges are heterogeneous; stone burden matters	Different SFR definitions/imaging	(11,14,20,21,31)
Retreatment	Most frequent	Intermediate	Usually lowest for large burden	Important in preschool children due to repeated anesthesia	SWL may require 2–3 sessions	(11,17,18)
Bleeding risk	Very low	Very low	Higher; tract-size dependent	Miniaturization reduces but does not eliminate risk	Transfusion uncommon but reported	(28–31,33)
Ureteral access issue	None	Can be limiting; prestenting sometimes needed	Retrograde catheter usually still used but renal access is percutaneous	Small ureters are a key preschool constraint	May add staged procedure	(22–25)
Radiation	Targeting may use fluoroscopy	Can be minimized; sometimes fluoroscopy	Puncture and tract often fluoroscopic/US-guided	Use US/low-dose protocols	Center expertise matters	(10,11,33–39)
Best niche	Small targetable, favorable stones	Intermediate stones; lower pole/SWL-unfavorable stones	>20 mm, staghorn, complex/multiple stones	Choose based on probability of durable clearance	Not purely size-based	(10–13)

10. Evidence Specific to Infants and Preschool Children

The evidence base becomes thinner as age decreases. Many "pediatric" cohorts are dominated by school-age children and adolescents, which can overstate the ease of ureteral access and understate anesthesia or physiologic concerns in toddlers. Studies that explicitly include preschool children therefore deserve greater weight when making age-specific decisions.

The studies most applicable to the target age group show why broad pediatric averages should be interpreted cautiously. Mokhless et al. directly compared SWL and RIRS in preschool children with 10–20 mm stones, while Unsal and Resorlu, Erkurt et al., and Gatti et al. specifically evaluated retrograde intrarenal treatment in preschool cohorts (17,23–25). Jackman et al. established the technical feasibility of small-tract percutaneous access in infants and preschool children, and Pelit et al. directly compared mini-PCNL with RIRS in preschool-aged patients (27,34). These studies support feasibility of all three approaches but also demonstrate that the balance between retreatment, access, and invasiveness changes substantially with age and anatomy.

Accordingly, evidence from adolescents should not be transferred uncritically to toddlers. The smaller ureter, lower circulating blood volume, higher sensitivity to fluid shifts and temperature loss, and greater consequences of repeated anesthesia can change the practical meaning of otherwise similar SFRs. Age-specific evidence therefore functions less as a separate treatment guideline and more as a modifier of the general procedure-selection framework described above (17,23–25,27,34).

11. Age-Specific Perioperative Considerations

11.1. Anesthesia Burden

General anesthesia is commonly required for all three modalities in infants and preschool children. Therefore, a procedure that is "less invasive" but predictably requires two or three treatment sessions may impose a greater cumulative anesthesia burden than a more invasive single-session approach. This is one reason why stone size thresholds should not be interpreted mechanically. For a 15–18 mm lower-pole high-density stone, fURS or mini-PCNL may provide a more efficient treatment course than serial SWL, even though SWL is non-incisional (10–13,17,18).

11.2. Blood Loss and Fluid Management

Small children have limited blood volume; tract size, number of punctures, operative time, and stone complexity should therefore be minimized during PCNL. Large multicenter series identify sheath size and operative variables as predictors of complications and bleeding (29,30). Miniaturized tracts reduce parenchymal disruption, but aggressive irrigation through very small systems can increase intrarenal pressure and fluid absorption; careful temperature and fluid monitoring remain important.

The smaller circulating blood volume of infants and preschool children means that a blood loss tolerated by an older child can become clinically important sooner. When percutaneous treatment is selected, miniaturized tracts, a single well-positioned puncture when feasible, careful hemoglobin monitoring, temperature control, and deliberate fluid management are central safeguards (29–31).

11.3. Ureteral Access and Stenting

Ureteral caliber should be treated as an age-dependent physiologic constraint rather than a fixed technical obstacle. In infants and small preschool children, choosing the smallest effective ureteroscope, avoiding forceful dilation, and accepting staged passive dilation when necessary are more important than completing the operation in a single sitting. Prestenting can improve subsequent access, but its benefit must be balanced against the burden of an additional anesthetic event; postoperative stenting should be reserved for situations in which edema, ureteral trauma, residual fragments, or obstruction risk make drainage clinically useful (20–25).

Table 2. Representative clinical evidence relevant to infants, preschool children, and pediatric renal stones

Study	Design / n	Age	Stone burden	Intervention	Key SFR result	Key safety/clinical point	Ref
Brinkmann 2001	Retrospective, 64 children	8 mo–15 y	Upper tract stones	SWL	83% treated stones completely cleared	No renal scarring or adverse growth/function signal	(15)
Unsal 2011	Case series, 16 patients/17 procedures	Mean 4.2 y, <7 y	Mean 11.5 mm	RIRS	88%; 100% when <10 mm	One perforation/extravasation managed with stent	(23)
Erkurt 2014	Retrospective, 65 children	6 mo–7 y	Mean 14.7 mm	RIRS	83.1% first; 92.3% after second	27.7% complications, mostly low grade	(24)
Mokhless 2014	Randomized, 60	Mean 2.4 y	10–20 mm	SWL vs RIRS	70% vs 86.6% single session; 93.3% vs 96.6% final	No major complications; SWL required repeat sessions	(17)
Ishii 2014	Systematic review, 282	0.25–17 y	1–30 mm	fURS	Mean initial 85.5%	Overall complications 12.4%	(20)
Pelit 2017	Retrospective, 77	Preschool	~19–21 mm	RIRS vs mini-PCNL	75% vs 84.4% single session; >90% final both	PCNL longer stay/fluoroscopy; no major complications	(34)
Jones 2017	Systematic review, 456	<18 y	Micro 12–16.5 mm; UMP 12–41 mm	Micro/ultra-mini PCNL	80–100% / 85–100%	Overall complications 11.2%	(31)
Whatley 2019	Systematic review, 431	0.25–17 y	Mean 13 mm	fURS	Overall 87%	Mean complications 12.6%; 76% postop stent	(21)
He 2019	Systematic review, 13 comparative studies	Pediatric	Upper tract stones	SWL vs PCNL vs RIRS	PCNL/RIRS generally higher single-session SFR than SWL	No clear overall complication difference; SWL more retreatment	(12)
Jia 2021	Comparative, 61	Children	1–2 cm	SMP vs RIRS	94.4% vs 60% at 1 month	Retreatment 0% vs 20%; complications 5.6% vs 24%	(35)
Mahmoud 2022	Prospective, 90	Pediatric	1–3 cm	RIRS vs mini-PCNL	Initial 88.9% vs 95.6%; final 100% after auxiliary treatment	RIRS shorter fluoroscopy/stay; no major IV–V complications	(36)
Geraghty 2023	EAU systematic review/meta-analysis	Pediatric <18 y	Renal/proximal ureter <2 cm	fURS vs SWL	fURS favored for SFR in RCT synthesis	Longer operative time/stay with fURS	(18)

Gatti 2024	Two-center retrospective	Preschool subgroup <5 y	<25 mm	RIRS	High feasibility in preschool group	Supports modern small-caliber RIRS in tertiary centers	(25)
Mahmoud 2026	Randomized, 70	3–14 y	Pelvic <2 cm, >1000 HU	RIRS vs mini-PCNL	91.4% vs 94.3% at 1 month	RIRS less radiation/recovery; mini-PCNL greater Hb drop	(39)

Small ureteral caliber is therefore not merely a technical inconvenience; it can alter the total treatment pathway. A planned fURS/RIRS strategy should account for the possibility of failed primary access, prestenting, a second anesthetic for definitive treatment, and possible stent removal. Small-caliber instruments and passive dilation are preferable to forceful access (20–25).

11.4. Infection and Intrarenal Pressure

Urinary infection should be treated before definitive intervention, and infected obstruction should be drained. During fURS and PCNL, high intrarenal pressure and long operative time can promote pyelovenous backflow and infectious complications. Access sheaths, low-pressure irrigation, staged treatment of large burdens, and adherence to culture-directed antibiotics are particularly relevant in small children (10,22).

11.5. Radiation Minimization

The cumulative radiation burden from recurrent pediatric stone disease can be substantial. Ultrasound should be the default diagnostic and follow-up modality when clinically adequate. Fluoroscopy during URS or PCNL should use pulsed low-dose settings, collimation, last-image hold, and the shortest feasible exposure. Ultrasound-guided percutaneous access can further reduce radiation. Recent comparisons repeatedly identify lower fluoroscopy exposure as an advantage of RIRS over PCNL in selected cohorts (33,34,36,39).

These age-specific issues interact. Repeated anesthesia, radiation sensitivity, high recurrence risk, and congenital anatomy can change the practical meaning of a technically successful intervention. Residual fragments may become future stones, but aggressive pursuit of complete clearance should not create disproportionate ureteral or renal injury. Treatment planning should therefore estimate cumulative-not only per-session-burden.

12. Treatment Selection by Stone Size, Location, and Clinical Context

The EAU provides a useful framework but explicitly recognizes that the same stone size can be managed by more than one modality (10). For an asymptomatic, non-obstructing stone below 4–5 mm, observation with prevention and ultrasound surveillance is usually appropriate, particularly in infants. Intervention is favored for symptoms, obstruction, infection, growth, recurrent hematuria, solitary kidney risk, or stones unlikely to clear spontaneously.

For renal pelvic or upper/middle calyceal stones below 10 mm, SWL remains an excellent option when the stone is easily targeted and expected to fragment. fURS becomes more attractive when stone density is high, prior SWL has failed, anatomy is unfavorable for fragment clearance, or single-session treatment is strongly preferred. For 10–20 mm stones, all three modalities can be appropriate; the practical choice depends on density, location, number of stones, ureteral caliber, surgeon expertise, and willingness to accept staged treatment. For lower-pole stones above 10 mm, mini-PCNL or fURS/RIRS is generally favored over SWL because fragment clearance is less predictable. For burdens above 20 mm, staghorn stones, or complex multiple stones, mini-PCNL/PCNL is usually the most efficient route to a stone-free kidney (10–13).

Table 3. Suggested management matrix for renal stones in infants and preschool children

Clinical scenario	Preferred strategy	Reasonable alternative	Factors that shift choice	Evidence base
Asymptomatic non-obstructing <4–5 mm	Observation + metabolic prevention	-	Growth, symptoms, infection, solitary kidney → intervene	EAU (10)
Pelvis/upper calyx <10 mm	SWL if targetable	fURS	High HU, cystine, prior SWL failure, need for one-session clearance → fURS	(10,11,14,18)
Lower pole <10 mm	Observation or SWL in selected cases	fURS	Unfavorable lower-pole anatomy or hard stone → fURS	(10,11,18)
Renal 10–20 mm	SWL or fURS/RIRS	Mini-PCNL	High density, multiple stones, lower pole, prior failure, anatomy, access feasibility	(10–18,33–39)
Lower pole >10 mm	Mini-PCNL or fURS	SWL selected cases	Large burden and need for single-session clearance → mini-PCNL	(10–13,31–37)
>20 mm / staghorn / complex	Mini-PCNL/PCNL	Staged RIRS or combined approach	Bleeding risk, anatomy, center expertise	(10–13,27–37)
Active infection + obstruction	Urgent drainage + antibiotics	—	Definitive stone treatment after infection control	(10)

The treatment matrix should be used as a framework rather than a rigid size-based rule. A practical age-sensitive pathway integrating observation, stone characteristics, infection, anatomy, and access feasibility is summarized in Figure 1.

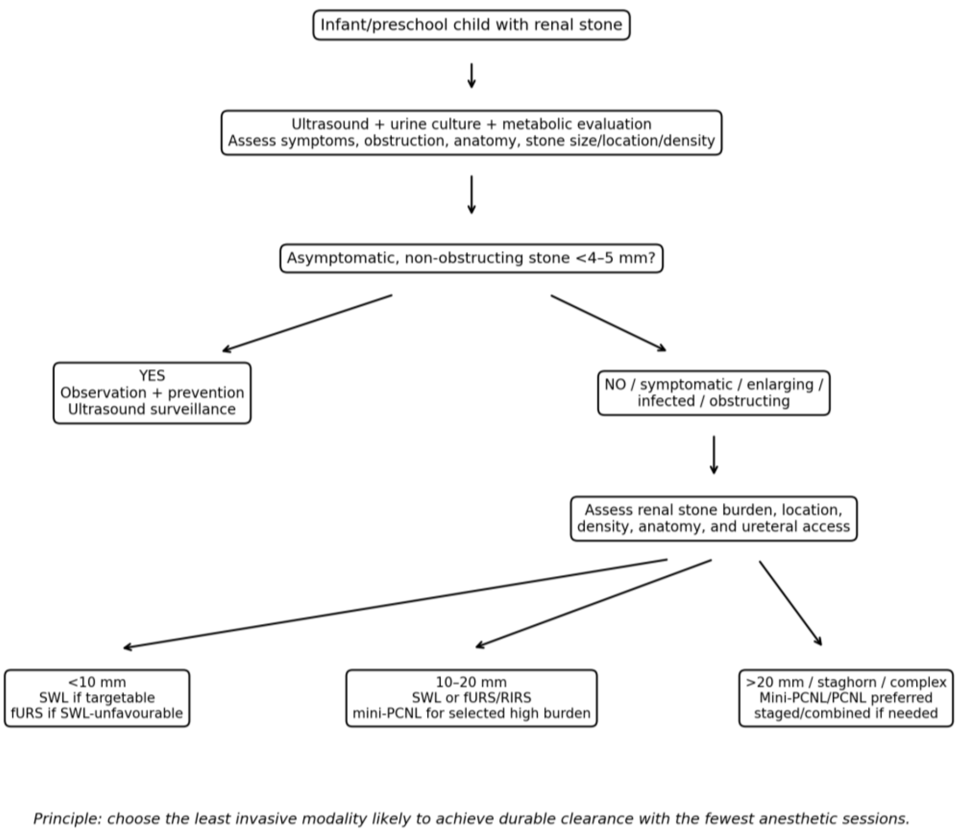

Figure 1. Proposed age-sensitive treatment algorithm for renal stones in infants and preschool children, synthesized from current EAU guidance and comparative pediatric evidence (10–13,17,18,31–39).

13. Complications and Their Prevention

The complication spectrum differs by modality. SWL complications are typically transient and include hematuria, renal colic, steinstrasse, urinary infection, and temporary obstruction; major renal injury is uncommon (10,14–16). ffURS/RIRS complications include fever/UTI, ureteral mucosal injury or perforation, postoperative pain, stent symptoms, and rarely urinoma or stricture. Systematic reviews report overall complication rates around 12–13%, predominantly Clavien I/II (20,21). Mini-PCNL complications include fever, urinary infection, bleeding, collecting-system perforation/extravasation, adjacent-organ injury, and rarely transfusion or secondary intervention; risk rises with larger tracts, multiple punctures, and prolonged procedures (29–31).

Prevention is therefore modality-specific. For SWL, appropriate selection, sterile urine, accurate targeting, and attention to stone burden reduce obstruction and retreatment. For ffURS/RIRS, gentle access, low intrarenal pressure, appropriate laser settings, and readiness to prestent rather than force access are central. For mini-PCNL, ultrasound-guided puncture, the smallest tract compatible with efficient extraction, a single well-positioned tract, strict temperature control, and a staged strategy when operative time becomes excessive are important. Across all modalities, the goal should be complete clearance without turning a technically ambitious operation into avoidable morbidity.

14. Follow-up and Recurrence Prevention

Surgery treats the stone episode but not the stone-forming disease. Pediatric patients have a reported recurrence risk of approximately 35–50% in guideline summaries, and very early presentation heightens concern for a persistent metabolic or genetic driver (10). Follow-up should therefore combine ultrasound-based surveillance with metabolic management. Fluid intake should be sufficient to maintain dilute urine; sodium excess should be avoided; normal age-appropriate calcium intake should be maintained rather than indiscriminately restricted; and specific abnormalities such as hypocitraturia, hypercalciuria, cystinuria, or hyperoxaluria should receive targeted therapy (8–10).

Residual fragments deserve special attention in children. Even "clinically insignificant" fragments may become a nidus over decades of future risk. This consideration favors modalities that can provide complete clearance when the incremental procedural risk is acceptable. At the same time, aggressive attempts to eliminate tiny fragments should not create greater ureteral or renal injury. Follow-up intervals should reflect stone composition, metabolic diagnosis, residual burden, and prior recurrence rather than a single fixed schedule.

15. Limitations of the Evidence

Several limitations constrain firm conclusions. First, most studies are retrospective, single-center, and heterogeneous in stone size, location, imaging, and definitions of success. Second, many cohorts include the full pediatric age range and are not powered for infants or preschool children. Third, technical evolution is rapid; outcomes from older flexible scopes or larger PCNL tracts may not represent contemporary practice. Fourth, selection bias is unavoidable because larger or more complex stones are preferentially directed to PCNL, while favorable stones are directed to SWL. Finally, long-term comparative data on renal function, ureteral integrity, recurrent anesthesia, and quality of life remain limited.

A further limitation is the inconsistency of outcome reporting. "Stone free" may mean no visible fragment on CT, no fragment on ultrasound, or residual fragments below 2–4 mm; follow-up intervals also differ. These variations can create apparent differences between techniques that reflect measurement rather than true comparative superiority. In addition, the youngest children are often a small subgroup within broad pediatric cohorts, so transfer of adolescent data to toddlers should be explicit and cautious.

The review itself also has methodological limitations: it is narrative, was not prospectively registered, did not use duplicate screening or formal risk-of-bias scoring, and did not prospectively retain a record-level screening log. Accordingly, the synthesis is intended to support clinically reasoned treatment selection rather than provide a systematic estimate of comparative effect sizes.

16. Future Directions

The next phase of pediatric stone surgery is likely to emphasize radiation-free workflows, smaller disposable or digital ureteroscopes, suction-enabled access systems, smarter intrarenal pressure control, ultrasound-guided percutaneous access, and more refined mini-PCNL platforms. However, technology should be evaluated against child-centered outcomes rather than procedural novelty. Important future endpoints include total anesthetic episodes per stone-free child, cumulative radiation dose, days away from normal activity, unplanned healthcare use, need for stent removal under anesthesia, and long-term renal growth.

Multicenter prospective registries and randomized trials should stratify children by age (<2 years, 2–5 years, >5 years), stone burden, location, density, and metabolic diagnosis. Such stratification would allow clinicians to identify when the higher initial invasiveness of mini-PCNL is justified by fewer future procedures, and when the noninvasiveness of SWL or tract-free nature of RIRS offers greater overall value.

Future comparative research should also standardize SFR definitions, postoperative imaging, complication grading, cumulative anesthetic episodes, radiation dose, retreatment, stent-related burden, unplanned healthcare use, and patient/family-reported outcomes. For recurrent pediatric stone disease, one-month SFR alone is an incomplete measure of treatment success.

17. Conclusion

Renal stones in infants and preschool children require a treatment strategy that is both technically effective and developmentally appropriate. SWL remains an important first-line option for small, targetable stones because it avoids urinary tract instrumentation and renal puncture. fURS/RIRS offers high clearance for intermediate stones and SWL-unfavorable anatomy without a percutaneous tract, but small ureteral caliber and the possibility of staged access must be anticipated. Mini-PCNL provides the most reliable route to high-volume stone clearance for large, complex, lower-pole, or staghorn stones, while miniaturization has reduced—but not eliminated—bleeding and access-related morbidity.

The preferred procedure is therefore the one most likely to achieve durable stone clearance with the fewest total anesthetic sessions and the lowest cumulative morbidity for the individual child. Stone size should guide, not dictate, treatment. Location, density, anatomy, infection, metabolic diagnosis, prior treatment, ureteral caliber, and center expertise should all be integrated into shared decision-making. Regardless of the surgical modality, complete metabolic evaluation and recurrence prevention are essential components of pediatric stone care.

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Authorship

All authors meet the ICMJE authorship criteria.

Conflicts of interest

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