



Beyond Stone Clearance: Precision Selection of Minimally Invasive Surgery for Pediatric Renal Calculi

Magdy Mohamed Abo-Doma, Osama Mostafa Kamel Kamhawy, Ehab Raafat Abdel Fattah, Hazem Mohamed El-Galaly

Urology Department, Faculty of Medicine, Zagazig University

Corresponding author: Magdy Mohamed Abo-Doma

Received: 28 October 2024, **Accepted:** 17 November 2024, **Published:** 20 November 2024

Abstract

Background: Pediatric renal stone treatment requires an individualized balance between complete clearance and the procedural burdens imposed on a growing child. For intermediate-size calculi, miniaturized percutaneous nephrolithotomy (mini-PCNL), retrograde intrarenal surgery (RIRS) and shock-wave lithotripsy may each be appropriate in selected circumstances. This narrative review examines the determinants of surgical selection, including total stone burden, calyceal geometry, age-related access limitations, stone composition, infection, operator expertise and family priorities. The discussion also evaluates weaknesses in commonly reported endpoints, particularly inconsistent definitions of stone-free status and omission of pretesting, subsequent anesthesia and retreatment from the index procedure. Comparative evidence supports the feasibility of mini-PCNL and RIRS but does not justify a universal preference across heterogeneous pediatric anatomy and stone types. A decision framework is proposed that integrates safe access, expected single-session clearance, bleeding and infection risks, radiation exposure, postoperative recovery and metabolic recurrence. Future pediatric research should standardize imaging-based endpoints, distinguish percutaneous tract sizes and measure the entire treatment pathway. Procedure selection should aim for durable stone clearance with the smallest acceptable cumulative burden rather than optimize one operative outcome in isolation.

Keywords

pediatric nephrolithiasis, miniaturized percutaneous nephrolithotomy, retrograde intrarenal surgery, surgical decision-making

Introduction

The increasing burden of pediatric kidney stone disease and expansion of endourological technology have made procedural choice a frequent clinical dilemma. Modern access devices allow children to undergo miniaturized percutaneous nephrolithotomy, retrograde intrarenal surgery or shock-wave lithotripsy with substantial prospects of successful treatment. Yet the central question is no longer whether a stone can be fragmented: it is which complete treatment pathway best protects the child while achieving durable clearance. This narrative review considers the clinical and anatomical variables that should guide individualized management, analyzes weaknesses in conventional endpoints and identifies priorities for more informative comparative research. [1, 2]

The changing clinical problem

Pediatric stone disease is increasingly encountered across healthcare settings, but a diagnosis alone does not establish that an operation is necessary. Stone-related pain, recurrent infection, obstruction, impaired drainage and evidence of growth must be considered alongside age, parental priorities and access to follow-up. Small asymptomatic stones may reasonably enter surveillance, whereas a symptomatic 15-mm calculus presents a different clinical problem from an incidentally discovered non-obstructing deposit. The distinction matters because studies comparing operations often start after the decision to intervene has already been made. Their outcomes cannot establish which children would have benefited from continued observation. [1, 2].

The relevant unit of analysis is the child rather than the stone diameter. A patient with recurrent febrile urinary infection and an obstructed collecting system may require staged drainage and infection control before definitive treatment. A child with a solitary kidney needs particular attention to preservation of drainage and renal function. Decisions also depend on whether the family can return for stent removal, surveillance imaging and possible additional procedures. These practical constraints should be documented prospectively, since they change the meaning of an apparently successful one-session procedure. [3, 4].

The clinical consequence is that burden estimates should not be treated as a substitute for a coherent history. Repeated episodes of colic and missed school may justify active management even when measured stone



dimensions change little. Conversely, an isolated ultrasound finding in an otherwise well child calls for a discussion of uncertainty, potential spontaneous course and surveillance capacity. When the indication for treatment is documented explicitly, subsequent audit can distinguish appropriate procedural selection from the earlier and equally important decision about whether intervention was warranted. This separation also avoids presenting every detected stone as an inevitable operative problem.

Moving beyond the 10–20 mm threshold

The 10–20 mm category is a convenient guideline stratum, not a biologically uniform population. A solitary round pelvic calculus, several stones whose cumulative diameter approaches 20 mm, and a branching lower-pole stone of similar maximum dimension impose different technical workloads. Volume, spatial distribution, hardness and multiplicity influence fragmentation, extraction and fragment clearance. The presence of hydronephrosis or a narrow infundibulum further modifies access. Comparisons restricted to a single linear diameter therefore risk leaving clinically important differences between treatment groups unmeasured. [5, 6].

Preoperative assessment should describe number, location, largest dimension, aggregate burden and relationship to the calyceal system. When cross-sectional imaging is available, attenuation and anatomical reconstruction may provide additional context, but routine computed tomography in every child is not justified. A reporting template using ultrasound first and computed tomography only when needed can improve the quality of clinical comparisons while respecting pediatric radiation protection. Future comparative studies should examine continuous burden measures and anatomical interactions rather than relying solely on subgroup labels. [7].

A further challenge is the distinction between the largest stone and aggregate stone burden. Two 9-mm stones in separate calyces cannot be assumed to behave like one 18-mm pelvic stone because the surgeon may need to cross infundibula, reposition equipment and manage fragments in more than one compartment. Realistic procedural planning considers expected access and extraction paths. Preoperative comparisons should describe whether the burden is unilateral or bilateral, whether a lower-pole target is reachable and whether a staged treatment is anticipated. These elements may matter more than small differences in measured diameter.

Anatomy as the decisive modifier

The renal collecting system determines whether a flexible scope can reach the calculus and whether a percutaneous tract can access the involved calyx safely. An acute infundibulopelvic angle, long narrow infundibulum, unfavorable lower-pole location or anterior calyx can compromise retrograde deflection and retrieval. By contrast, PCNL creates a direct pathway but introduces a parenchymal tract whose position must respect adjacent vessels and organs. Pediatric kidneys are smaller and may be more mobile, leaving less margin for error during puncture and instrument movement. [8, 9].

Procedural planning should consider the geometry of both possible routes instead of treating access as a binary variable. For RIRS, the expected degree of maximal scope deflection under laser fiber load is particularly relevant. For mini-PCNL, the calyx selected for access should permit clearance without excessive torque or a second tract. Detailed understanding of papillary, infundibular and segmental vascular anatomy helps explain why an anatomically uncomplicated 18-mm stone may be easier than a technically challenging 12-mm stone. [10, 11].

Anatomical constraints also influence which additional risks are accepted. An upper-pole puncture may provide broad collecting-system access, but the trajectory and surrounding structures deserve special scrutiny. A lower-pole route can be attractive for selected burdens while making remote calyces difficult to reach. During retrograde surgery, the need to maintain maximal deflection with an instrument in the working channel may limit access or impair visualization. Three-dimensional representations can help selected complex cases, although routine use would require evidence of meaningful pediatric benefit, availability and cost effectiveness rather than proof of anatomical elegance alone.

Guideline interpretation and clinical equipoise

European pediatric recommendations allow several approaches for selected 10–20 mm renal pelvic stones, including shock-wave lithotripsy, PCNL and RIRS, while larger lower-pole stones more often favor percutaneous treatment. These statements reflect differences in stone site, expected retreatment and quality of available evidence; they do not establish universal equivalence. Adult treatment algorithms offer useful mechanical principles but cannot be transferred unchanged to children, whose ureters, kidneys and lifetime exposure horizons differ. [12, 13].

An explicit statement of equipoise is useful when counseling. A stone-free endpoint after one procedure may favor direct extraction, whereas lower bleeding risk, reduced hospitalization or avoidance of renal puncture may favor retrograde access for a particular child. Families should understand that procedural choices can trade a lower immediate physiological burden against a higher probability of pretesting or later retreatment. Institutional expertise



and availability of pediatric-sized instruments remain relevant determinants rather than sources of evidence that one technology is inherently superior. [14].

Guideline recommendations also vary with the exact calyceal site. A 12-mm lower-pole calculus should not automatically receive the same ranking of options as a similarly sized renal pelvic stone, since fragment passage and access differ. Interpretation should account for the chronology of evidence synthesis: novel technologies can reach clinical practice before pediatric comparative trials establish their relative outcomes. A useful guideline discussion separates strong recommendations supported by consistent evidence from permissible alternatives supported by smaller or indirect studies. In counseling, uncertainty should be communicated as uncertainty, not hidden behind a simplified algorithm.

Imaging and radiation-aware planning

Ultrasonography is the preferred initial examination in most children with suspected stones because it avoids ionizing radiation and identifies hydronephrosis, collecting-system enlargement and many renal calculi. Its limitations include operator dependence, imperfect visualization of some ureteral stones and less precise quantification of complex stone burden. Low-dose noncontrast computed tomography may be justified when ultrasound is inconclusive or when anatomical detail would materially change surgical planning. The justification should be recorded and acquisition protocols optimized for body size. [15, 16].

The imaging strategy also affects the interpretation of stone-free rates. A child assessed by ultrasound at one month cannot be assumed to have the same probability of detecting tiny residual fragments as a child assessed by computed tomography. Trials that mix imaging modalities or follow-up windows create differential outcome ascertainment. Comparisons should therefore report the modality, timing, residual-fragment threshold and management of equivocal images, with sensitivity analyses when definitions differ. [17].

The child's previous imaging history should be reviewed before ordering new studies. Repeat examinations conducted at different hospitals can produce substantial unnecessary exposure or contradictory estimates of size. Where ultrasound measurements differ, repeat standardized assessment may be preferable to immediately escalating to CT. If CT becomes necessary, the clinician should define the management question it is expected to answer, such as uncertain location or planning of complex access. Imaging reports are most useful when they address stone burden, obstruction and anatomical relationships in language that directly informs the operative decision.

Stone composition, infection and metabolic phenotype

Stone composition affects fragmentation strategy, susceptibility to shock-wave treatment and expectations concerning recurrence. Infection-associated stones, cystine stones and metabolic disorders introduce problems that cannot be reduced to a surgical efficiency comparison. Preoperative urine culture and treatment of active infection are essential, while stone analysis after retrieval provides information that may modify prophylaxis. The association between metabolic abnormality and recurrent stone formation argues for assessment beyond serum creatinine alone. [18, 19].

A procedure is only one component of treatment for children with hypercalciuria, hypocitraturia, cystinuria, renal tubular acidosis or anatomic urinary stasis. Complete extraction without preventive follow-up may produce a favorable early surgical metric but limited long-term benefit. Conversely, residual fragments in a child with an aggressive metabolic phenotype may carry more clinical significance than similarly sized fragments in a lower-risk patient. Future decision models should incorporate metabolic and infection-related variables as predictors of durable outcomes. [20].

Culture status and metabolic context should also influence procedure timing. Stone-related infection is not equivalent to asymptomatic bacteriuria, and an obstructed infected system requires prompt drainage and stabilization rather than elective definitive fragmentation. The surgeon should recognize the limits of a negative voided culture as a complete assessment of organisms that may persist within stones or the upper tract. Coordinated management with pediatric nephrology can identify children for whom stone extraction should be followed immediately by targeted preventive investigation. This minimizes the chance that a technically excellent operation is followed by early recurrence.

The procedural profile of mini-PCNL

Miniaturized percutaneous nephrolithotomy provides a direct tract into the collecting system and facilitates irrigation, fragmentation and removal of stone material. Its principal advantage is the potential to clear larger or awkwardly located burdens within a single session. Tract caliber, use of single-step versus sequential dilation, position, access guidance, fragmentation technology and nephrostomy strategy vary between centers. Describing all of these under



one label hides differences in bleeding, operative duration and postoperative recovery. [21, 22].

A smaller tract does not eliminate the possibility of vascular injury, collecting-system perforation, infection or adjacent-organ damage. Multiple tracts may extend tissue exposure, and prolonged high-pressure irrigation can complicate infection prevention. The operative team must also consider the feasibility of postoperative drainage and the circumstances in which a nephrostomy tube, ureteral stent or tubeless approach is appropriate. Mini-PCNL should therefore be compared as a defined protocol rather than as a generic instrument category. [23, 24, 25].

For mini-PCNL, outcome comparisons must report sheath diameter in French units, number and location of tracts, patient position and use of fluoroscopic or sonographic guidance. Whether fragments were removed actively or dusted also alters stone-free assessment. A lower complication rate in one series may reflect smaller stones, single-tract access or selection of less complex cases. A technically refined percutaneous protocol can be highly efficient, yet direct access does not excuse aggressive scope manipulation or pressure-laden irrigation. The skill of renal puncture and clarity of intraoperative imaging often determine the safety margin more than the nominal label of the procedure.

The procedural profile of RIRS

Retrograde intrarenal surgery avoids intentional renal parenchymal puncture and has become increasingly feasible with smaller digital and fiberoptic flexible ureteroscopes. Its performance depends on safe access through the pediatric ureter, working-channel function, scope deflection, irrigation and laser delivery. A ureteral access sheath can facilitate repeated passage and outflow in selected children but must never be forced through an immature or narrow ureter. Failure of initial access may require passive dilation with prestenting followed by a second anesthetic. [26, 27].

The practical significance of prestenting should be included in the denominator of treatment burden. Children who undergo stent placement before definitive lithotripsy have undergone two procedural episodes even when the stone is ultimately cleared in a single RIRS session. Additional stent symptoms, infections, emergency presentations and family time away from normal activities are patient-relevant outcomes. Whether a sheathless strategy can avoid these burdens without sacrificing safety depends on the scope, technique, ureteral caliber and operator experience. [28, 29, 30, 31].

For retrograde surgery, one-stage feasibility is highly sensitive to whether the operator insists on a sheath or accepts a sheathless approach. The decision should be made in response to ureteral compliance and visualization, not simply to preserve a predefined operative pathway. Smaller single-use scopes may improve access and eliminate repair-related downtime, while their economics depend on institutional case volume and procurement. A child whose ureter does not admit the planned equipment should not be exposed to forceful dilation merely to avoid another anesthetic. Successful staged access is often preferable to avoidable ureteral trauma.

Laser strategy and operative efficiency

Holmium:YAG remains an established intracorporeal lithotripsy technology, while thulium fiber lasers offer alternative pulse characteristics and fiber options. In pediatric practice, laser power should be chosen to balance fragmentation speed, visibility and thermal exposure rather than maximizing settings. The narrow collecting system and variable irrigation outflow can make heat accumulation particularly relevant. Evidence from adult and experimental studies requires cautious interpretation before asserting pediatric superiority of any laser. [32, 33].

Dusting and active fragment extraction represent different strategic choices. Dusting can reduce basket passes but leaves clearance partly dependent on urine flow and favorable calyceal geometry. Extracting larger fragments may improve immediate removal yet prolong instrumentation and potentially increase trauma. Operative time alone should not define efficiency; it must be interpreted with the final residual burden, irrigation conditions, postoperative drainage, complications and need for auxiliary procedures. [33].

Thermal risk is especially relevant when the surgeon is operating in a relatively confined space with poor irrigation outflow. Laser platforms differ in pulse and fiber characteristics, but these differences alone do not establish superior pediatric outcomes. Comparative research should record settings, cumulative energy and whether the working channel became obstructed during fragmentation. Reporting the system model without operative parameters is insufficient for reproducibility. The practical objective is adequate fragmentation at settings that maintain visualization, protect urothelium and avoid unnecessary extension of the procedure.

Comparative stone-free outcomes

Evidence syntheses comparing pediatric PCNL and RIRS support the feasibility of both interventions, but estimates vary across access caliber, stone burden, study design and definitions of stone-free status. Some analyses favor



percutaneous modalities for single-session clearance, whereas others identify comparable outcomes in selected medium-sized stones. A meta-analysis of 13 studies involving 1,019 children found important differences between micro-PCNL, mini-PCNL and RIRS rather than a consistent effect attributable to all percutaneous methods. [34, 35].

Studies should not pool micro-PCNL, ultra-mini PCNL and larger mini-PCNL tracts indiscriminately when their mechanisms and complication profiles differ. Likewise, RIRS outcomes depend on pretesting and use of access sheaths. Short-term comparative estimates may also be biased by imaging modality, differential follow-up and selection of children with simpler retrograde anatomy. A clinically useful synthesis specifies what treatment was delivered, what constituted success, and whether second procedures were counted. [36, 37, 38, 39, 40].

Meta-analytic estimates must be interpreted alongside heterogeneity. Different centers include children of differing ages, use different instruments and apply variable exclusion criteria for congenital anomalies or infections. A pooled stone-free percentage can obscure clinically important effect modification by location and accessibility. The appropriate interpretation is not that all studies agree, but that the available procedures are effective in selected circumstances while comparisons remain sensitive to definitions and case mix. Individual trials should therefore be read for both the estimate and the actual operative technique that generated it.

Bleeding and infectious complications

Bleeding is a distinctive concern for percutaneous surgery because tract creation crosses renal parenchyma and may encounter segmental or intrarenal vessels. Smaller instruments are intended to reduce trauma but cannot prevent all hemorrhagic events. Hemoglobin fall is an informative continuous outcome, yet its magnitude depends on perioperative fluids, timing of laboratory testing and baseline values. Transfusion, angioembolization and clinically important hematoma should be reported separately rather than inferred from mean changes in hemoglobin. [41, 42].

Febrile infection can occur after either route. A positive culture, obstructed infected system, elevated intrarenal pressure or long operative duration may increase risk, and a postoperative temperature rise alone does not necessarily establish sepsis. Comparative safety reporting should apply consistent Clavien–Dindo grading, specify the denominator, and distinguish perioperative fever from culture-proven urinary infection and organ dysfunction. Without standardized reporting, apparent differences between techniques can reflect surveillance intensity rather than biological safety. [43].

Safety discussions should include the severity and consequence of an event, not only its frequency. A transient postoperative fever and a major bleeding episode have different clinical weights, and combining all Clavien grades into a single endpoint can distort decision-making. Adequate sample sizes for rare severe events are difficult to achieve in pediatric practice, reinforcing the value of collaborative registries. When events are absent in a small study, this does not prove that a complication is impossible. Confidence intervals and transparent follow-up are more informative than categorical descriptions of a procedure as complication-free.

Treatment burden beyond the index admission

Length of hospital stay measures one aspect of recovery but does not capture the full burden experienced by children and caregivers. Pretesting, repeat stone surgery, postoperative stent removal under anesthesia and unplanned emergency visits can accumulate even when each episode is brief. A longer initial PCNL admission may sometimes be offset by fewer subsequent procedures, whereas short RIRS hospitalization may be attractive when ureteral access is straightforward and clearance is achievable. [44, 45].

A comprehensive outcome should include the number of anesthetic events, time to confirmed clearance, postoperative pain, analgesic use, school absence, caregiver work loss and total healthcare contacts. Such measures are rarely reported consistently and should be prioritized in prospective studies. The clinically relevant unit is the completed treatment pathway from diagnosis to sustained stone-free follow-up, not simply the duration of the principal operation. [45].

The total burden of a treatment pathway can be represented as the number of treatment episodes, the time to confirmed stone-free status and the burden of each episode. This approach discourages selective counting of the main lithotripsy while excluding pretesting, stent removal or emergency revisits. Cost analyses should similarly recognize equipment, hospitalization, repeat intervention and caregiver expenses. The most economical procedure for a hospital may not minimize disruption for a family, and a short index admission may not imply low total treatment cost.

Interpreting operative and fluoroscopy times

Procedure duration varies with the exact point at which measurement begins and ends, whether positioning and anesthetic induction are included, and whether access is obtained before instrumentation. The learning curve,



imaging guidance, stone complexity and equipment availability can therefore dominate comparisons. Radiation time is an imperfect proxy for delivered dose because pulse rate, collimation, detector geometry and body size affect exposure. [46].

Pediatric studies should report fluoroscopy dose metrics where available, describe low-dose protocols and separate radiation from diagnostic imaging and treatment. Ultrasound-guided puncture and fluoroscopy-sparing retrograde techniques may reduce exposure without removing the need for safe visual confirmation. An operation with modestly longer fluoroscopy time cannot be assigned a precise lifetime cancer risk from that figure alone, and claims of radiation-free surgery require scrutiny of the entire treatment pathway. [46].

Operative metrics are useful for improving local practice when definitions are stable. Tracking fluoroscopy dose by child size and procedural phase may identify avoidable exposures; tracking access time separately from lithotripsy time may reveal equipment or training bottlenecks. Comparisons between institutions should adjust for case complexity and learning curves before implying technical superiority. The aim of measurement is to improve safety and throughput while maintaining clearance, rather than to reduce a single numerical metric at any clinical cost.

Special groups and anatomical exceptions

Infants, preschool-aged children, patients with a solitary kidney and those with congenital anomalies may not respond to the same treatment algorithm as adolescents with normal anatomy. Instrument diameter becomes proportionally more consequential as ureteral caliber decreases. In complex kidneys, the safest puncture tract may be constrained by bowel position, rotation or vascular variation, while retrograde access may be limited by tortuosity and collecting-system configuration. [47, 48].

Evidence from mixed pediatric cohorts may conceal age-specific technical failure rates. Decisions for the youngest children should rely on demonstrated local expertise and access to suitably scaled equipment rather than extrapolated adult success. Multidisciplinary input is warranted when a congenital obstruction needs correction or when underlying nephrological disease threatens renal function. A successful stone operation that leaves a major drainage problem unaddressed is not definitive management. [48].

Treatment of an anatomically unusual kidney may require adaptation that is not represented in standard comparative studies. A child with a solitary functioning kidney, for example, may place greater weight on preserving drainage and avoiding postoperative obstruction. In a rotated kidney, direct puncture trajectories that seem familiar on standard images may be misleading. Complex congenital conditions may make a combined surgical approach more appropriate than repeated isolated stone procedures. Clear referral pathways to experienced pediatric endourology teams help ensure that technical capacity is matched to the child.

Shared decision-making and a practical framework

A useful framework begins by confirming the indication for intervention, excluding untreated infection and defining stone anatomy. The surgeon then estimates whether a single safe retrograde procedure can achieve clearance without traumatic access or whether a percutaneous route offers a more reliable pathway. Alternatives such as shock-wave lithotripsy should remain part of the conversation when appropriate. A preference-sensitive comparison follows, covering bleeding, infection, pain, stent burden, radiation, admission and the possibility of repeat intervention. [49].

The recommendation should be revisited if intraoperative findings invalidate the original assumptions. Abandoning unsafe ureteral advancement, placing a temporary stent or deferring percutaneous puncture can be better than forcing completion of the selected modality. Recording why a technique was chosen and documenting deviations creates an audit trail that improves the usefulness of future comparative datasets. Families deserve estimates based on local outcomes, not only pooled reports from highly experienced centers. [49].

An effective conversation can present a small number of credible choices with the major trade-offs stated plainly. The family should hear whether a second procedure is a realistic possibility, whether a stent may be needed and how the child will be followed afterward. Discussion of uncertainty is particularly important when evidence comes predominantly from retrospective cohorts. Shared decisions do not transfer technical responsibility to parents; they incorporate family values into a recommendation based on clinical assessment, equipment availability and procedural expertise.

Evidence gaps and research priorities

Comparative pediatric evidence remains constrained by small cohorts, heterogeneous tract definitions, varying stone-free criteria and inconsistent measurement of cumulative procedural burden. Many studies are retrospective and susceptible to selection bias: a technically favorable case may be preferentially assigned to one modality. Even



randomized trials may lack power to detect uncommon but serious adverse events or clinically important subgroups. [50].

The next generation of research should prespecify standardized imaging endpoints, include complete anesthesia and reintervention counts, measure kidney function over time and collect patient-reported recovery outcomes. Treatment interactions with stone volume, age, calyceal anatomy, pretesting and metabolic phenotype warrant investigation. Prospective multicenter registries with linked long-term follow-up may provide more practical external validity than a series of underpowered single-center comparisons. [50].

The literature would benefit from a common core outcome set developed with patients, families, pediatric nephrologists and surgeons. Such a set could include freedom from clinically significant stones, time to clearance, retreatment, severe complications, pain, caregiver burden, and longer-term renal outcomes. Reporting protocols and prospective registration would reduce selective emphasis on the endpoint most favorable to a technique. Until those standards become widespread, clinicians should compare detailed patient populations and operative definitions rather than rank approaches based on isolated headline percentages.

The stone-free rate paradox

Stone-free status is attractive as an outcome because it appears objective and directly linked to treatment. In practice, its meaning depends on when and how it is measured. A child with no visible calculus on an early ultrasound may harbor fragments below the detection threshold; a child assessed by low-dose CT may be categorized as having residual disease despite being asymptomatic. A one-month assessment is not equivalent to durable stone freedom, particularly in patients with active metabolic risk. Consequently, comparing percentages without harmonized definitions may imply a precision that the underlying evidence does not possess. For clinical counseling, reported stone-free rates should be paired with the threshold for residual fragments, imaging method, duration of follow-up and frequency of later intervention. [33, 34]

An additional problem arises when studies use a per-procedure rather than a per-patient denominator. If pretesting followed by RIRS is counted as one definitive procedure, while a percutaneous treatment is counted from its first intervention, the comparison becomes asymmetrical. Equally, a technically complete lithotripsy with planned later fragment clearance should not be described as an uncomplicated one-session cure. Intention-to-treat reporting from the initial planned modality can help capture access failure and conversion, although crossover should be documented for both safety and effectiveness. These choices are not statistical formalities; they influence how the expected journey is explained to parents. [35, 36]

For a decision-oriented interpretation, outcomes can be presented in layers: technical completion, stone-free status after the index intervention, stone-free status after auxiliary procedures, and durable absence of clinically important recurrence. The first describes operative feasibility, the second compares initial efficacy, the third reflects the practical ability to achieve clearance, and the fourth approaches the actual objective of care. Including each stage reduces the risk that a technology appears superior simply because a study chooses the most favorable reporting window. Future evidence syntheses should avoid combining studies that define these layers differently without sensitivity analysis. [37, 38]

Center expertise and generalizability

Experience with pediatric percutaneous access and flexible ureteroscopy is unevenly distributed. The smallest devices are not always available, and purchasing a technically sophisticated instrument does not immediately confer expertise. Access-related complications are influenced by puncture planning, ultrasound interpretation and dilatation technique, while retrograde results depend on atraumatic navigation, recognition of unsafe resistance, effective deflection and irrigation management. Comparisons performed at a center proficient in one technique may therefore reflect a center effect as much as a true difference between interventions. This issue is seldom resolved by statistical adjustment in small observational series. [21, 25]

When developing a local protocol, teams can identify the complexity at which their established outcomes become less predictable. Repeated difficulty with upper-pole access, unfavorable lower-pole deflection, long operative duration or high rates of pretesting may indicate a need for equipment refinement, training or referral. A transparent audit can examine severe complications, postoperative fever, radiation dose, auxiliary procedure rates and patient-reported recovery. Benchmarking should distinguish children with a solitary simple calculus from those with multiple or anatomically difficult stones. A high reported clearance rate without its corresponding case mix provides limited guidance to another institution. [26, 29]

The choice of treatment can legitimately differ between hospitals while remaining evidence-informed. If reliable ultrasound-guided percutaneous expertise is unavailable, selecting a safe retrograde technique or arranging transfer may be better than pursuing an unfamiliar puncture. Conversely, a team with strong pediatric percutaneous



experience may achieve efficient clearance for challenging configurations that would otherwise require staged ureteroscopy. The relevant ethical standard is not allegiance to a procedure, but a realistic account of local capability and its limitations. Multicenter trials should record surgeon experience and device characteristics so their findings can be translated beyond elite programs. [30, 31]

A pathway-based model for future trials

Randomized comparisons in intermediate-size pediatric stones should begin at the decision to intervene, not only after successful access. Enrollment criteria should describe age bands, single versus multiple stones, anatomical anomalies, infection status and baseline metabolic risk. Stratification by lower-pole location or clinically significant stone volume may limit imbalance in the small samples typical of pediatric trials. Investigators should state whether the treatment strategy permits elective pretesting and how failed access will be analyzed. The intervention is properly defined as a pathway, including any planned preparatory or completion steps, rather than the lithotripsy component alone. [40, 42]

Core endpoints should include stone-free status assessed using a standardized imaging strategy, grade-specific complications and the number of treatment and anesthesia episodes through complete clearance. Hospital stay should be accompanied by time to normal activity, analgesic use, caregiver burden and unplanned care. Radiation should be expressed using dose indicators rather than fluoroscopy time alone. The same postoperative culture, fever and infection definitions should apply to both groups. These changes would make the resulting evidence more meaningful to families without requiring all centers to use identical equipment or techniques. [44, 46]

Longer-term outcomes should include recurrent interventions, growth in residual fragments and development of new stones. Baseline and follow-up renal assessment are also appropriate, particularly after complications or in high-risk patients. Research teams should avoid interpreting any small nonsignificant between-group difference as proof of equivalence; a meaningful equivalence or noninferiority claim requires an appropriately specified margin and sufficient precision. Pragmatic multicenter studies can provide broad generalizability, while mechanistic substudies might examine pressure, thermal conditions or access injury. The final goal is to support an individualized recommendation that remains credible outside a single specialist hospital. [47, 50]

One further implication for clinical research is that surgeons should describe what they would have done had the assigned technique proved impossible. Planned escalation thresholds, conversion options and rescue drainage procedures are part of a safe protocol. Without this information, results from selected successful procedures can substantially overestimate feasibility in everyday practice. Reporting consent discussions, aborted procedures and deviations from the original plan would also improve interpretation of adverse event rates. A transparent treatment algorithm should permit a patient to receive a safe alternative when anatomy or infection creates an unanticipated concern. This flexibility is a strength of thoughtful individualized care, not a failure of the initial strategy. [40, 41]

There is also value in recording outcomes that matter directly to children. Recovery of appetite, ability to sleep, return to school, fear of a stent and parental anxiety are rarely captured by standard surgical datasets. Validated age-appropriate measures may show important differences even when two techniques yield statistically similar stone-free rates. These outcomes should supplement rather than displace objective clearance and serious-complication measurements. The best procedure is the one that combines adequate disease control with an acceptable personal and family burden over the full treatment course. [45, 46]

Conclusion

For children with renal stones in the intermediate-size range, mini-PCNL and RIRS should be viewed as complementary rather than interchangeable techniques. A defensible recommendation considers anatomy, stone distribution, safe access, expected clearance, cumulative procedural burden and locally demonstrated expertise. Research that standardizes imaging and counts the entire treatment pathway is needed to convert technical comparisons into dependable patient-centered decisions.

References

1. Clayton D, Pope JC. The increasing pediatric stone disease problem. *Ther Adv Urol*. 2011;3(1):3-12.
2. Dwyer ME, Krambeck AE, Bergstralh EJ, Milliner DS, Lieske JC, Rule AD. Temporal trends in incidence of kidney stones among children: a 25-year population based study. *J Urol*. 2012;188(1):247-52. doi:10.1016/j.juro.2012.03.021.
3. Edvardsson VO, Ingvarsdottir SE, Palsson R, Indridason OS. Incidence of kidney stone disease in Icelandic children and adolescents from 1985 to 2013: results of a nationwide study. *Pediatr Nephrol*. 2018;33(8):1375-1384.
4. Sultan S, Aba Umer S, Ahmed B, Naqvi SAA, Rizvi SAH. Update on surgical management of pediatric urolithiasis. *Front Pediatr*. 2019;7:252.
5. Pięta J, Szyszka M, Lipiński P, Skrzypczyk P. Urolithiasis in children: clinical picture, pathogenesis, and diagnostic approach. *Biomolecules*. 2024;16(1):119. doi:10.3390/biom16010119.
6. Marra G, Taroni F, Berrettini A, Montanari E, Manzoni G, Montini G. Pediatric nephrolithiasis: a systematic approach from diagnosis to



- treatment. *J Nephrol.* 2019;32(2):199–210.
7. Tasian GE, Copelovitch L. Evaluation and medical management of kidney stones in children. *J Urol.* 2014;192(5):1329–36.
8. Talyshinskii A, Juliebø-Jones P, Hameed BMZ, Tzelves L, Pietropaolo A, Somani BK. Classifying Renal Pyelocaliceal System: A Complete Literature Overview of All Existing Classification Approaches. *J Endourol.* 2024 Apr;39(4):405–417.
9. Lojanapiwat B. The ideal puncture approach for PCNL: fluoroscopy, ultrasound or endoscopy? *Indian J Urol.* 2013;29(3):208–13.
10. Chu C, Masic S, Usawachintachit M, Hu W, Yang W, Stoller M, Li J, Chi T. Ultrasound-guided renal access for percutaneous nephrolithotomy: a description of three novel ultrasound-guided needle techniques. *J Endourol.* 2016;30(2):153–158.
11. Gao K, Li S, Raj A, Li S, Liu S, Zhang Y, Zhu H, Wang J. A 3D printing personalized percutaneous puncture guide access plate for percutaneous nephrolithotomy: a pilot study. *BMC Urol.* 2021;21(1):184.
12. Türk C, Petřík A, Sarica K, Seitz C, Skolarikos A, Straub M, Knoll T. EAU guidelines on interventional treatment for urolithiasis. *Eur Urol.* 2016;69(3):475–82. doi:10.1016/j.eururo.2015.07.041.
13. Tekgül S, Stein R, Bogaert G, Nijman RJM, Quaedackers J, 't Hoen L, Silay MS, Radmayr C, Doğan HS. European Association of Urology and European Society for Paediatric Urology guidelines on paediatric urinary stone disease. *Eur Urol Focus.* 2022;8(3):833–839.
14. Assimos D, Krambeck A, Miller NL, Monga M, Murad MH, Nelson CP, Pace KT, Pais VM Jr, Pearle MS, Preminger GM, Razvi H, Shah O, Matlaga BR. Surgical management of stones: American Urological Association/Endourological Society guideline, part I. *J Urol.* 2016;196(4):1153–1160.
15. Gupta A, Castellán M. Use of computed tomography (CT) for urolithiasis in pediatric patients. *Transl Pediatr.* 2015;4(1):33.
16. Palmer JS, Donaher ER, O'Riordan MA, Dell KM. Diagnosis of pediatric urolithiasis: role of ultrasound and computerized tomography. *J Urol.* 2005;174(4 Pt 1):1413–1416.
17. Cao B, Daniel R, McGregor R, Tasian GE. Pediatric nephrolithiasis. *Healthcare (Basel).* 2023;11(4):552.
18. Penido MGMG, de Sousa Tavares M. Pediatric primary urolithiasis: symptoms, medical management and prevention strategies. *World J Nephrol.* 2015;4(4):444.
19. Barreto L, Jung JH, Abdelrahman A, Ahmed M, Dawkins GPC, Kazmierski M. Medical and surgical interventions for the treatment of urinary stones in children. *Cochrane Database Syst Rev.* 2019;10(10):CD010784.
20. Lu P, Wang Z, Song R, Wang X, Qi K, Dai Q, Zhang W, Gu M. The clinical efficacy of extracorporeal shock wave lithotripsy in pediatric urolithiasis: a systematic review and meta-analysis. *Urolithiasis.* 2015;43(3):199–206. doi:10.1007/s00240-015-0757-5.
21. Woodside JR, Stevens GF, Stark GL, Borden TA, Ball WS. Percutaneous stone removal in children. *J Urol.* 1985;134(6):1166–7. doi:10.1016/s0022-5347(17)47669-5.
22. DeMarco RT. Percutaneous nephrolithotomy in children. *Adv Urol.* 2011;2011:123606. doi:10.1155/2011/123606.
23. Jackman SV, Docimo SG, Cadeddu JA, Bishoff JT, Kavoussi LR, Jarrett TW. The "mini-perc" technique: a less invasive alternative to percutaneous nephrolithotomy. *World J Urol.* 1998;16(6):371–4. doi:10.1007/s003450050083.
24. Patel SR, Nakada SY. The modern history and evolution of percutaneous nephrolithotomy. *J Endourol.* 2015;29(2):153–7.
25. Helal M, Black T, Lockhart J, Figueroa TE. The Hickman peel-away sheath: alternative for pediatric percutaneous nephrolithotomy. *J Endourol.* 1997;11(3):171–172.
26. Alenezi H, Denstedt JD. Flexible ureteroscopy: technological advancements, current indications and outcomes in the treatment of urolithiasis. *Asian J Urol.* 2015;2(3):133–41. doi:10.1016/j.ajur. 2015.06.002.
27. Keller EX, De Coninck V, Traxer O. Next-generation fiberoptic and digital ureteroscopes. *Urol Clin North Am.* 2019;46(2):147–63.
28. Somani BK, Aboumarzouk O, Srivastava A, Traxer O. Flexible ureterorenoscopy: tips and tricks. *Urol Ann.* 2013;5(1):1–6.
29. Campbell P, Mudd B, Craig K, Daugherty M, Vanderbrink B, DeFoor W, Minevich E, Reddy P, Strine A. One and done: feasibility and safety of primary ureteroscopy in a pediatric population. *J Pediatr Urol.* 2024;20(2):224.e1–224.e7.
30. Doizi S, Traxer O. Flexible ureteroscopy: technique, tips and tricks. *Urolithiasis.* 2018;46(1):47–58.
31. Buttice S, Sener TE, Netsch C, Emiliani E, Pappalardo R, Magno C. LithoVue: a new single-use digital flexible ureteroscope. *Cent European J Urol.* 2016;69(3):302–5.
32. Ulvik Ø, Sørstrand Æsøy M, Juliebø-Jones P, Gjengstø P, Beisland C. Thulium fibre laser versus holmium:YAG for ureteroscopic lithotripsy: outcomes from a prospective randomised clinical trial. *Eur Urol.* 2022;82(1):73–79.
33. Sierra A, Corrales M, Kolvatzis M, Panthier F, Piñero A, Traxer O. Thermal injury and laser efficiency with holmium:YAG and thulium fiber laser: an in vitro study. *J Endourol.* 2022;36(12):1599–606.
34. Geraghty RM, Davis NF, Tzelves L, Lombardo R, Yuan C, Thomas K, Petřík A, Neisius A, Türk C, Gambaro G, Skolarikos A, Somani BK. Best practice in interventional management of urolithiasis: an update from the European Association of Urology Guidelines Panel for Urolithiasis 2022. *Eur Urol Focus.* 2023;9(1):199–208.
35. Yuan Y, Liang YN, Li KF, Ho YR, Wu QL, Zhao Z. A meta-analysis: retrograde intrarenal surgery vs. percutaneous nephrolithotomy in children. *Front Pediatr.* 2023;11:1086345.
36. Chen Y, Deng T, Duan X, Zhu W, Zeng G. Percutaneous nephrolithotomy versus retrograde intrarenal surgery for pediatric patients with upper urinary stones: a systematic review and meta-analysis. *Urolithiasis.* 2019 Apr;47(2):189–199. doi: 10.1007/s00240-018-1039-9. Epub 2018 Jan 24. PMID: 29368009.
37. Lu P, Song R, Yu Y, Yang J, Qi K, Tao R, Chen K, Zhang W, Gu M. Clinical efficacy of percutaneous nephrolithotomy versus retrograde intrarenal surgery for pediatric kidney urolithiasis: a PRISMA-compliant article. *Medicine (Baltimore).* 2017;96(43):e8346.
38. Pelit ES, Atis G, Kati B, Akin Y, Çiftçi H, Culpun M, Yeni E, Caskurlu T. Comparison of mini-percutaneous nephrolithotomy and retrograde intrarenal surgery in preschool-aged children. *Urology.* 2017;101:21–5.
39. Mahmoud MA, Shawki AS, Abdallah HM, Mostafa D, Elawady H, Samir M. Use of retrograde intrarenal surgery (RIRS) compared with mini-percutaneous nephrolithotomy (mini-PCNL) in pediatric kidney stones. *World J Urol.* 2022 Dec;40(12):3083–3089. doi: 10.1007/s00345-022-04186-x.
40. Darwish AE, Abdel Moneim AE, Ahmed AI, Hamdy SM, Abolella HA, Reda A. A randomized comparative study of flexible ureterorenoscopy versus mini-percutaneous nephrolithotomy for treatment of renal stones 2 cm or less. *Curr Urol.* 2024;18(4):273–7.
41. Michel MS, Trojan L, Rassweiler JJ. Complications in percutaneous nephrolithotomy. *Eur Urol.* 2007;51(4):899–906. doi:10.1016/j.eururo.2006.10.020.
42. ElSheemy MS, Elmarakbi AA, Hytham M, Ibrahim H, Khadgi S, Al-Kandari AM. Mini vs standard percutaneous nephrolithotomy for renal stones: a comparative study. *Urolithiasis.* 2019;47(2):207–14.
43. Zeng G, Zhao Z, Wan S, Zhong W, Wu W. Comparison of children versus adults undergoing mini-percutaneous nephrolithotomy: large-scale analysis of a single institution. *PLoS One.* 2013;8(6):e66850.
44. Desoky EAE, Sakr AM, ElSayed ER, Ali MM. Ultra-mini-percutaneous nephrolithotomy in flank-free modified supine position vs prone position



- in treatment of pediatric renal pelvic and lower caliceal stones. *J Endourol.* 2022;36(5):610-4.
45. Jia H, Li J, Liu B, Zhang P, Yusufu A, Nan Y, Li X, Wen B, Pu C, Du W, Wang S. Comparison of super-mini-PCNL and flexible ureteroscopy for the management of upper urinary tract calculus (1–2 cm) in children. *World J Urol.* 2021;39(1):195-200.
46. Peng T, Zhong H, Hu B, Zhao S. Minimally invasive surgery for pediatric renal and ureteric stones: a therapeutic update. *Front Pediatr.* 2022;10:902573.
47. Gurlen G, Aydamirov M, Alma E, Altunkol A, Vuruskan E, Karkin S, Akbulut G, Kartal SB, Karkin K. Which surgical method should be used in pediatric patients with a solitary kidney and 1–2 cm kidney stones? *World J Urol.* 2024;43(1):642.
48. Suçeken FY, Akgül M, Ertaş E, Durmaz AS, Şahinler EB, Aşık A, Yaşar H, Küçük EV, Sarıca K. Management of anteriorly located renal caliceal stones with two different techniques (mini-percutaneous nephrolithotomy vs flexible ureteroscopic laser lithotripsy): a critical comparative evaluation of the outcomes. *J Endourol.* 2024;39(5):451-6.
49. Xu C, Song R, Lu P, Jiang M, Zeng G, Zhang W. A retrospective study comparing super-mini percutaneous nephrolithotomy and flexible ureteroscopy for the treatment of 20-30 mm renal stones in obese patients. *PeerJ.* 2020;8:e8532.
50. Kim CH, Chung DY, Rha KH, Lee JY, Lee SH. Effectiveness of percutaneous nephrolithotomy, retrograde intrarenal surgery, and extracorporeal shock wave lithotripsy for treatment of renal stones: a systematic review and meta-analysis. *Medicina (Kaunas).* 2020;57(1):26.