Contemporary Minimally Invasive Surgical Management of Urinary Stones in Children

Kemal Sarica, Cahit Sahin *

Department of Urology, Dr. Lütfi Kirdar Kartal Research and Training Hospital, Istanbul, Turkey

Abstract

With increasing incidence of pediatric urolithiasis over the past two decades, surgical management poses specific challenges for urologists because of the high risk of stone recurrence in this population. Keeping this in mind, management aims should be complete stone-free status, preservation of renal function, and prevention of stone recurrence. The incidence of metabolic problems is up to 50%, and ~30% of cases involve anatomic anomalies. Therefore, in addition to stone removal procedures, treatment of pediatric urolithiasis requires a thorough metabolic and urologic evaluation on an individual basis. Obstructive pathologies and established metabolic abnormalities should be managed. Urine volume should be increased by encouraging adequate fluid intake, and medical therapeutic agents to increase urinary citrate levels may be considered. To select the most appropriate surgical treatment, the location, composition, and size of the stone(s), the anatomy of the collecting system, and the presence of obstruction or any infection in the urinary tract should all be considered. Improvements in instrument technology and increasing experience with adult cases mean that all contemporary endourologic procedures are currently being applied in the management of pediatric urolithiasis in a safe and effective manner. Shockwave lithotripsy is still the first choice for the majority of cases involving upper tract calculi; other minimally invasive methods such as ureterorenoscopy and percutaneous nephrolithotomy require more expertise, but can be successfully applied for excellent stone-free rates with minimal morbidity. In patients with complex and large stones as well as anatomic abnormalities, open surgery will continue to be the preferred treatment option for children.

1. Introduction

Among all urinary stone cases, children account for only 1–3%, with marked variations in incidence between developed and developing countries. While it has been reported that the disease is rare in some regions, such as Scandinavia and the USA, it is still an endemic problem in developing areas such as Turkey, Iran, Pakistan, and the Far East. Stones occur in children of all ages and do not disproportionately affect any age group [1,2].

With respect to chemical composition and possible etiology, calcium oxalate and calcium phosphate calculi in
the upper urinary tract account for the majority of stones in the pediatric population in developed countries. Bladder stones comprising ammonium urate and uric acid are still common in developing countries, where dietary factors, particularly a dependence on cereal and rice, play a role. Among possible underlying causative factors, metabolic abnormalities, urinary tract infections, anatomical abnormalities, and endemic factors have been identified in the etiology of the disease.

Given the high risk of recurrent stone formation, all children suffering from stone disease should be evaluated in detail to determine possible underlying causes and to plan proper management strategies. Such efforts can control future stone formation and/or growth in attempts to limit morbidity. Long-term postoperative follow-up is needed, especially after the use of more recently developed technical innovations for the management of urinary stones in children. For medical and surgical management of children prone to stone formation, clinicians have to choose the appropriate treatment on the basis of metabolic evaluation and stone analysis results and the frequency of stone events [6,7].

2. Minimally invasive surgical management

Technological advancements, miniaturization of endourologic instruments, and increasing surgeon experience have significantly altered the surgical management of pediatric stone disease. Currently, the majority of stones in children can be managed using shockwave lithotripsy (SWL), percutaneous nephrolithotomy (PNL), ureterorenoscopy (URS), or a combination of these modalities, with open surgery needed in a limited number of cases [3–5,8–10]. As in adults, accumulated experience has reveal that stone (location, composition, and size) and patient factors (body mass index, anatomy of the collecting system, and the presence of obstruction with or without infection) are crucial when planning stone removal procedures for high-stone free rates with minimal or no complications. We discuss contemporary approaches for minimally invasive management of stones in the pediatric population in further detail.

2.1. Extracorporeal SWL

Following its clinical introduction in the early 1980s, experience demonstrated the efficacy and safety of SWL in adults. As experience increased, this modality has also become the preferred treatment approach for management of stones in children because of its minimally invasive nature. Despite increasing use of other endourologic methods (URS and PNL) as a result of the development of miniaturized instruments and clinical introduction of flexible ureteroscopes, fine ancillary instruments, and holmium YAG lasers, SWL remains the least invasive, simplest, safest, and most effective treatment for upper urinary tract stones in children [9,11–13]. However, because of the higher incidence of metabolic and anatomic abnormalities in this population, this method should achieve completely stone-free status (if possible) over a short period of time with a reasonable number of high-energy shockwaves and limited auxiliary procedures. Moreover, residual fragments that may predispose patients to further recurrences after SWL should be followed closely with regular visits [14–16].

Published data indicate that SWL is ideal for renal pelvic stones or calyceal stones of up to 2 cm in diameter, but success rates tend to decrease as stone size increases. Currently, with careful selection of cases, nearly 80% of all stones in children could be treated successfully with SWL. Following SWL, stone-free rates range from 57% to 97% for short-term and from 57% to 92% for long-term follow-up [8,11,12]. Unlike pelvic calculi, SWL results in lower stone free-rates in children with larger stones and stones located in the lower calyx or in abnormal kidneys. Retreatment rates range from 13.9% to 53.9% in different series [13–15], and rates for auxiliary procedures and/or additional interventions range from 7% to 33% [16,17].

Although general anesthesia is generally administered in younger children, especially for those treated with first-generation lithotriptors (because of greater energy applied to a larger focal zone), sedation is sufficient to relieve possible discomfort in relatively older children during SWL [18–21].

In addition to the success of the SWL technique, children pass stone fragments after SWL treatment in a quick and easy fashion. However, depending on the size and number of stones and the presence of certain anatomic abnormalities, the stone-free rate after SWL may be lower and auxiliary procedures may be required for larger stones [22–24]. Despite its effective and minimally invasive profile, theoretical concerns have been raised regarding the safety and bioeffects of SWL on the immature, growing kidney and surrounding organs, but no irreversible serious side effects of high-energy shockwaves could be demonstrated during short- and long-term follow-up. Although deterioration of renal function and new-onset hypertension have been discussed, long-term evaluation of children in various series did not show any significant morphologic or functional changes after SWL. Taking the potential risk of deterioration in renal function into account (although it is transient), restriction of the number of shockwaves and the energy used in each session could be helpful in protecting the kidneys [25–30].

As in adult cases, up to 98% of ureteral stones of <5 mm are likely to pass spontaneously; stone removal is required for larger and for impacted stones. In addition to size, stone location is also important. Data indicate that although SWL is highly successful for the majority of upper ureteral calculi, stone-free rates decrease with increasing distance to the more distal parts of the ureter [9,17,18]. SWL is less effective for larger stones (>1 cm), impacted stones, calcium oxalate monohydrate and cystine stones, and stones in children with unfavorable anatomy and localization difficulties.

In comparison to adults, children pass fragmented stone particles more quickly owing to their anatomy, higher ureter elasticity, and early mobilization after SWL, so ureteral stenting to ease stone passage is rarely needed. In
cases with a large stone burden requiring placement of a ureteral stent, alternative treatment procedures such as PNL should be considered. Although indwelling ureteral stents are seldom required after SWL for upper tract stones, ureteral pre-stenting appeared to decrease the stone free-rate after initial treatment by 12–14% in some studies [19–21].

To summarize, the evidence shows that when combined with judicious use of auxiliary procedures, SWL is a safe and highly effective management approach for the majority of pediatric stones, particularly for upper tract calculi.

2.2. **Ureteroscopy**

As in adult cases, optimal management of children with ureteral calculi is not without controversy. However, a result of remarkable advances in endoscopic technology and increased experience in this field, surgical management of ureteral calculi in children has considerably changed and these stones are being managed using the same principles as for treatment in adults, with open surgery rarely required [31–33]. In contrast to the rapid acceptance of these modalities for management of ureteral stones in adults, lack of experience, small body habitus, and concerns regarding intraoperative complications and long-term means that acceptance has been gradual and slower for the pediatric population.

As already mentioned, ureteroscopy can be applied for both diagnostic and therapeutic purposes. With the clinical introduction of fine, smaller-caliber, and flexible instruments, this modality has become the treatment of choice not only for middle and distal ureteric stones but also to a considerable extent for upper urinary tract stones in children. Data in the literature indicate that ureteroscopic lithotripsy is an acceptable treatment modality with successful outcomes in terms therapeutic efficacy and complication rates similar to if not better than those reported for adults [34–36].

Ureteroscopic removal of ureteral and renal calculi in prepubertal children is now common with the successful use of fine, small-sized instruments and holmium:YAG laser lithotripsy. Concerns that the use of relatively large-caliber instruments (11.5F and 8.5F) posed a risk of damage to the ureteral mucosa, ureteral meatus, and urethra, particularly in boys, arc longer more valid. The availability and successful use of 4.5F and 6.0F semirigid ureteroscopes and 6.9F flexible ureterorenoscopes with a holmium:YAG laser energy source mean that instrument-related complications are rare [37–41].

Studies on pediatric ureteroscopy have shown satisfactory results, particularly for mid and lower ureteral stones, with success rates ranging from 87.5% to 100%. However, results for upper ureteral stones are less encouraging, with a lower success rate of 78%. Removal of upper ureteral stones requires a high level of endoscopic skill, and the risk of trauma to the ureter is higher, particularly for large and impacted stones.

Stone-free rates for stones >10 mm were 93% with ureteroscopy and 50% with SWL; for stones <10 mm the rates were 100% for ureteroscopy and 80% for SWL. Similar to adult cases, ureteroscopy may provide more efficient stone clearance and should be preferred in all children with distal ureteral stones and for large and impacted proximal stones [9,32,35,36,40]. Overall, ureteroscopy for ureteral calculi in children resulted in a 90% stone-free rate after a single procedure.

Despite the use of smaller instruments and greater experience, endourologists should keep in mind that pediatric ureteroscopy requires greater technical skill and necessitates judicious use of instrumentation because of the potential risks of major traumatic complications, such as ureteric perforation and strictures. Complications such as ureteral avulsion, perforation, hematuria, infection, and ureteral stricture may occur after ureteroscopy in 0–7% of patients. Related to this issue, there are concerns regarding ureteral dilatation before ureteroscopy in children. These include the risk of stricture, the need for an indwelling stent or a second procedure under anesthesia for removal, and the risk of development of vesicoureteral reflux. However, it has been shown that ureteral dilatation does not increase the risk of stricture or of significant reflux. Moreover, with the use of smaller-caliber ureteroscopes, ureteral dilatation may not be required. Routine screening for reflux after ureteroscopy in children is not required and should only be considered in symptomatic children [4,32,35,36,40,41].

As in adult cases, stenting after ureteroscopic stone removal will not be necessary for short and uncomplicated procedures for relatively small stones. If the procedure is complicated due to the size and the location of the stone(s), or if there is any question of ureteral injury, a ureteral stent should be left in place for a variable time depending on the surgeon’s experience and preference. If injury to the ureter is suspected, the stent should be left for 1–2 wk. Following all ureteroscopic procedures, careful ultrasound evaluation of the upper urinary tract after 2–4 wk is recommended to check for the presence of hydronephrosis. Vesicoureteral reflux may occur after ureteral dilation but does not seem to cause clinical problems; therefore, routine voiding cystography is not considered necessary [4,9,40].

2.3. **Retrograde intrarenal surgery (RIRS)**

As experience with RIRS in adult cases has increased, the number of reports on successful use of flexible ureterorenoscopy for management of renal stones in children has grown. The adoption of techniques used in adults and the use of 6.9F flexible ureteroscopes and ureteral access sheaths has facilitated access to the entire pediatric urinary tract. This approach has allowed efficient treatment of lower pole calculi that would previously have required SWL or PNL [42,43]. Cannon et al reported a 76% stone-free rate in 21 children with lower pole calculi with a mean stone diameter of 12.2 cm. After mean follow-up of 11.4 mo, no major complications were observed [44]. In a series of 52 URS procedures for intrarenal calculi, Tanaka et al [45] demonstrated that flexible URS management of renal stones is safe and effective, with an initial stone-free rate of 50% after the first session. The stone-free rate increased to 58%
during a mean follow-up period of 246 d. Predictors for further treatment in this study were younger age and preoperative stone size >6 mm. Re-treatment was not necessary for stone sizes <6 mm [45]. Although the number of cases treated is limited, other authors also reported safe and successful use of this method even in pre-school-aged children [46–50].

Current contraindications to ureteroscopic management of stones in children include large and complex stones, anatomic anomalies making retrograde access difficult, and previous endoscopic failure.

2.4. PNL

Despite the use of SWL as the first choice for the majority of stones located in the renal collecting system, similar to indications in adults, PNL can be used for larger and complex calculi in children.

Following the first report in 1985, PNL has been widely applied in adults. There was some initial hesitancy regarding PNL application and indications in children. However, as a result of increasing success rates and experience obtained in adults, the technique is now performed in children as monotherapy or in combination with other approaches for large stone burdens. Acceptance of this technique for children was gradual because of concerns regarding long-term renal damage, small kidney size, relatively large instruments, radiation exposure, and the risk of major complications such as bleeding. However, as PNL experience increased, results for relatively large series demonstrated that there may be minimal scarring and no significant loss of renal function after PNL. Radioisotope scans before and after PNL revealed no change in differential function and no evidence of significant renal scars [51–53]. Thus, the same techniques are used in this population as in adults, and age is not considered a factor or limitation.

While earlier reports on PNL in children described the use of adult-sized instruments, advances in instrumentation, miniaturization of instruments, and the availability of more efficient energy sources for intracorporeal lithotripsy have revolutionized endourologic procedures in children. With the clinical introduction of smaller nephrosopes, mini, ultra-mini, and miniperc procedures are feasible for percutaneous stone removal in this population. Holmium:YAG lasers or smaller pneumatic lithotriptors and ultrasound probes can be used with smaller nephrosopes during PNL in children. The use of holmium:YAG lasers is appealing in children, and various studies have demonstrated safe use of this system in this population. Ultrasound-guided puncture is a good alternative to fluoroscopy and has the advantages of avoiding radiation, providing a straight peripheral calyceal puncture, and preventing visceral injury [54–57].

Indications for PNL in children are similar to those in adults and include a large stone burden, significant renal obstruction, urinary infection, failure of SWL, and a significant volume of residual stones after open surgery. Intraoperative bleeding requiring blood transfusion, injury to the pelvicalyceal system, and sepsis are major concerns for PNL in children. To reduce complications in the initial part of the learning curve, the procedure may be staged in selected cases such as patients with a non-dilated collecting system, an associated urinary infection, and a large stone burden. Staging the procedure, whereby percutaneous access is obtained in the initial stage and stone manipulation is performed subsequently through a mature tract, may decrease PNL complications in children [58–61]. PNL has been advocated as a suitable treatment for children with a significant stone burden to avoid numerous SWL sessions under anesthesia and the prospect of repeated open surgery.

According to published data, PNL for larger calculi in children is a safe and feasible method for maximal clearance of stone burden and should be the treatment of choice in skilled hands. PNL as monotherapy in combination with SWL is still not widely practiced in children because of the higher risk of complications in a relatively small kidney with large instruments. With the availability of smaller instruments and ultrasound guidance, the procedure can now be safely performed in experienced hands. The main indications for PNL in children are large stones, an obstructed system, infection, radiolucent or cystine stones, and residual stones after failed SWL or open surgery [4,8,11,60,62,63].

In terms of PNL efficacy, stone-free rates of ~90% (ranging from 67% to 100%) with no significant complications have been reported in many series [2,55–58,62,63].

2.5. Cystolithotomy

Historically, it has been reported that bladder calculi are an endemic pathology in many developing countries. In addition to the bladder stones commonly seen in underdeveloped and developing countries, the incidence of calculi after bladder augmentation and continent urinary diversion may approach 50%. The majority of stones located in the bladder are usually large and hard, and can be treated using either transurethral or percutaneous suprapubic lithotripsy or litholapaxy. The major concern with the transurethral approach is possible damage to the male urethra, so judicious use of this technique is required.

Suprapubic cystolithotomy has evolved as an effective and safe alternative for such cases. After removing an intact stone, one option is primary closure of the bladder; alternatively, for small openings, the bladder can be allowed to drain for several days to let the opening close on its own over time. This procedure can be performed on an outpatient basis. Finally, by making a small incision and placing a sheath into the bladder (mini lap approach) the stone can be removed safely and the bladder cavity can be examined [11,64,65].

The management principles for bladder calculi are similar to those for upper urinary tract calculi. Approaches for bladder stones include the endoscopic route, suprapubic percutaneous access, and open surgery. Suprapubic cystolithotomy is appropriate for large, hard, vesical calculi [64,65].
2.6. **Laparoscopic surgery**

The role of laparoscopy in the management of pediatric stone disease still needs to be explored. There are limited data in the literature, and further studies including larger series of children are warranted [66,67].

3. **Conclusions**

Management of urinary stones in children poses a specific technical challenge. Evolution of techniques and miniaturization of instruments have changed the management concepts for pediatric stone disease to some extent. Improvements in technology (ie, smaller-caliber rigid and actively deflectable endoscopes), increasing experience, and refinement of SWL and PNL techniques have resulted in greater acceptance of minimally invasive techniques for the management of such stones, and urologists can apply the whole spectrum of stone management alternatives in children. With judicious application of these treatment modalities, excellent stone-free rates with minimal morbidity can be obtained in this patient population.

The aims for management should be complete clearance of stones, preservation of renal function, and prevention of stone recurrence. Similar to applications in adult cases, while SWL is still considered first-line therapy for upper tract calculi of <2.0 cm, there is increasing evidence that SWL and URS may result in equally safe and successful results for upper tract stones in children. While PNL remains the most effective technique for large and complex calculi in the upper tract, there are now reports of laparoscopic and robotic-assisted laparoscopic pyelolithotomy from major pediatric academic centers where extensive experience has been accumulated. We believe that in addition to stone and patient factors, individual surgeon experience is a crucial factor in planning the most effective primary treatment option. Finally, it is clear that despite encouraging results, concern remains regarding the safety of endourologic treatment in younger patients and its subsequent effects on the growing kidney.

**Conflicts of interest**

The authors have nothing to disclose.

**Funding support**

None.

**References**


