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TOPIC PAPER

Stones in special situations

Mordechai Duvdevani[1] · Stavros Sfoungaristos[2] · Karim Bensalah[3] · Benoit Peyronnet[3] · Amy Krambeck[4] · Sanjay Khadji[5] · Ahmet Muslumanuglu[6] · David Leavitt[7] · Jude Divers[7] · Zeph Okeke[7] · Arthur Smith[7] · Janelle Fox[8] · Michael Ost[8] · Andreas J. Gross[9] · Hassan Razvi[10]

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Abstract There are several special situations in which urinary lithiasis presents management challenges to the urologist. An in-depth knowledge of the pathophysiology, unique anatomy, and treatment options is crucial in order to maintain good health in these patients. In this review, we summarize the current literature on the management of the following scenarios: bladder stones, stones in bowel disease, during pregnancy, in association with renal anomalies, with skeletal deformities, in urinary diversions, and in children.

Keywords Urolithiasis · PCNL · Ureteroscopy · SWL

✉ Mordechai Duvdevani
moti_duv@yahoo.com

1 Hadassah Hebrew University Medical Center, Jerusalem, Israel

2 1st Department of Urology, Aristotle University of Thessaloniki, G. Gennimatas Hospital, Thessaloniki, Greece

3 Centre Hospital, University of Rennes, Rennes, France

4 Mayo Clinic, Rochester, MN, USA

5 Nidan Hospital, Kathmandu, Nepal

6 Bagcilar Training and Research Hospital, Istanbul Bilim University, Istanbul, Turkey

7 Long Island Jewish Medical Centre, New Hyde Park, NY, USA

8 Asklepios Campus, Hamburg, Germany

9 Children's Hospital of Pittsburgh University Medical Center, Pittsburgh, PA, USA

10 Western University, London, ON, Canada

Introduction

There are several special situations in which urinary lithiasis presents management challenges to the urologist. An in-depth knowledge of the pathophysiology, unique anatomy, and treatment options is crucial in order to maintain good health in these patients. In this review, we summarize the current literature on the management of the following scenarios: bladder stones, stones in bowel disease, during pregnancy, in association with renal anomalies, with skeletal deformities, in urinary diversions, and in children.

Bladder lithiasis

Bladder lithiasis represents 5% of urinary stones [1]. Several causes have been implicated in the formation process, including bladder outlet obstruction (BOO), neurogenic bladder disorders, infections, augmentation of the bladder, and foreign bodies.

Bladder stones can be classified as migrant, primary idiopathic, and secondary. Migrant stones reach the bladder by passing from the upper urinary tract and can grow to a large size mainly in cases with underlying BOO.

Stone composition is mainly uric acid and calcium oxalate. Urease-producing microorganisms, mainly *Proteus, Klebsiella*, and *Ureaplasma urealyticum*, increase urinary pH and promote supersaturation and bladder stone formation [1, 2].

Bladder stone management has dramatically changed during the last decades. Transurethral disintegration represents the main endoscopic technique, with or without transurethral resection of the prostate. The theory that supports the fact that bladder lithiasis represents an absolute indication for prostate removal has lately been questioned with contemporary reports demonstrating medical treatment remains an alternative therapeutic option [3].

A number of lithotripters have been employed for stone fragmentation, including mechanical, electrohydraulic, pneumatic, ultrasonic, and Holmium laser [4–11].

Percutaneous techniques have been described for the management of large calculi mainly as an alternative to open techniques with stone-free rates reported between 89% and 100% [12–16]. History of bladder cancer, previous abdominal surgery, and radiation to the pelvis may represent a contraindication to this approach.

Concomitant transurethral and percutaneous suprapubic cystolithotripsy using a laparoscopic entrapment sac have been evaluated with good results [17–22].

Extracorporeal shockwave lithotripsy (ESWL) as an alternate for high-risk patients may have a role in select patients. Removal of stone fragments is not feasible, which however results in lower stone-free rates than other options. The overall reported success rates are between 72 and 99.4% [23–29].

Stones and bowel disease

Bowel diseases can be responsible for fluid–electrolyte imbalance, and can thereby increase urinary stone formation [30]. Many patients with bowel disease suffer from chronic dehydration and have decreased urine output. Other pathophysiologic mechanisms depend on the segment of the gastrointestinal tract that is affected. Bowel pathologies responsible for stone disease are divided into:

a. Small bowel diseases: responsible for malabsorption and steatorrhea associated with enteric hyperoxaluria and low urinary excretion of magnesium and citrate causing mainly calcium oxalate stones.
b. Colonic lesions: responsible for decreased urine volume and decreased urine pH due to loss of water, salt, and bicarbonates in diarrheal stool causing mainly uric acid stones.
c. Lack of an oxalate-degrading bacteria (*Oxalobacter formigenes*) in the intestinal flora leading to enhanced oxalate absorption and hyperoxaluria.

The types of urinary stones most commonly seen in patients with bowel diseases include calcium oxalate, uric acid and ammonium acid urate [31, 32].

Patients who have undergone bariatric surgery, such as gastric/intestinal bypass surgery represent a special subgroup. Valezi et al. examined 151 obese patients after Roux-en-Y gastric bypass surgery to detect possible predictors for stone formation. These patients were assessed before surgery and followed for 1 year. While median BMI decreased, urinary oxalate and uric acid increased significantly postoperatively. Similarly, urine volume and pH decreased postoperatively [33].

Whether the reversal of bariatric bypass surgery will normalize the metabolic consequences of such procedures is uncertain. Dhar et al. evaluated patients with refractory stone disease after jejunoileal bypass surgery and reported on their renal function, serum and urinary metabolic stone profiles, and clinical stone formation. The 24-h urine results in all patients showed an increase in oxalate values and lower citrate excretion, parameters that normalized after reversal of their bypass procedure [34].

Patients with bowel disease and urinary stones have a high risk of recurrence.

The prevention strategies include avoiding dehydration and attaining a 24-h urine volume of >2 l, urinary alkalinization, and correction of hyperoxaluria, hypocitraturia and hypomagnesuria.

Stones in pregnancy

Although rare, urolithiasis during pregnancy can adversely affect the pregnancy, with afflicted women being at increased risk of premature labor [35–39]. Furthermore, stones in pregnancy may become symptomatic more frequently due to physiologic dilation of the collecting system, allowing for migration of renal stones into the ureter [40, 41].

Although calcium oxalate is the most common stone composition observed in healthy young females [42–44], the majority of stones in a pregnant women are calcium phosphate. Moreover, stone formers with a history of stone disease convert from other stone types to calcium phosphate while pregnant [45].

Ultrasound examination of the kidney is considered to be the best initial screening tool for the evaluation of the pregnant female with flank pain. Although the sensitivity of ultrasound is highly operator dependent, ranging from 28.5 to 95.2% [46–51], it is still considered first-line testing without the risk of ionizing radiation as an adjunct endovaginal ultrasound can help to demonstrate stones in complicated cases [52].

Ultrasound-determined resistive indices (RI) have also been found to be a potential diagnostic tool during pregnancy. An elevated RI of greater than 0.70 may be a marker for urinary obstruction; however, its use of an absolute value as a cutoff for obstruction is controversial [52].

In certain instances, despite physical and ultrasound examination, the diagnosis of acute renal colic in pregnant women remains uncertain. Current studies have indicated that a single childhood exposure to a CT scan may increase the risk of developing childhood cancer [53, 54]. Thus, if radiation imaging is needed to provide the best care for the patient, then it should be performed with the goal of limiting the total exposure. The American Urological Association (AUA) introduced imaging recommendations in 2013, which suggested the use of low-dose CT as a second-line imaging modality in the second and third trimester of pregnancy when ultrasound studies failed to secure a diagnosis [55]. MRI imaging using a half-Fourier single-shot turbo spin-echo (HASTE) protocol has also improved the time it takes to obtain MR imaging. MRI without gadolinium as a second-line imaging modality in the first trimester of pregnancy when ultrasound imaging has failed, has also been proposed [55].

Once the diagnosis of urolithiasis is made, appropriate treatment should be rendered. Treatment can range from conservative management to temporizing measures until definitive management can be rendered postpartum, to definitive management during pregnancy. The first line of therapy in uncomplicated cases is conservative or expectant management. The classic choice of nonsteroidal anti-inflammatories should be avoided in pregnancy, as these medications have been linked with fetal pulmonary hypertension, and there is a risk of premature closure of the ductus arteriosus when given in the third trimester [35]. Codeine has also been shown to have a teratogenic effect in the first trimester, and thus opioid analgesia is the mainstay of therapy. Although a single case report of the use of medical expulsive therapy with alpha-blockers has been published, further study is necessary before this treatment can be recommended [56].

Temporary drainage with either a stent or nephrostomy is associated with several drawbacks, such as accelerated encrustation requiring exchange every 4–6 weeks [57, 58] during pregnancy, significant pain and discomfort [48], and frequent dislodgement [59].

When considering definitive surgical intervention, ureteroscopy is the mainstay of therapy with proven efficacy and safety. The introduction of the holmium laser, which has minimal tissue penetration and is capable of fracturing stones of any composition, has led to improved operative times and decreasing complications [60]. Laing et al. recently performed a review of the current literature and identified 15 studies with a total of 116 procedures [61]. Complete stone clearance was seen in 86% of cases and only two major complications were identified: one ureteral perforation and one case of premature uterine contraction. Another recent study from five high volume endourology institutions focused on obstetric complications in 46 patients undergoing ureteroscopic stone removal during pregnancy [62]. The study found two (4.3%) obstetric complications, both premature contractions in the 3rd trimester with one resulting in uncomplicated premature delivery at 33 weeks gestational age.

Renal stone disease in renal abnormalities

Treating stones in patients with congenital renal abnormalities is challenging. The choice of procedure must take into account the difficult access associated with the anatomical positioning of the kidney, the location of the stone, the individual surgeon's skill, and available equipment. The most common congenital abnormalities and treatment options are summarized in Table 1.

Stones in association with skeletal deformities

Patients with skeletal deformities are at an increased risk of urolithiasis and recurrence due to high rates of urinary tract infection, immobilization-induced hypercalciuria, and urinary stasis [113, 114]. The main challenge when managing these patients is distortion of bony and skin landmarks used for percutaneous access or shock wave lithotripsy.

In patients with skeletal deformities, almost all stones that form will be soft and radio-opaque. Keeping this in mind, one can recommend SWL as a first-line treatment for small kidney stones if there are no medical contraindications. However, clearance of stone fragments from the collecting system may be poor and often delayed in these patients [115]. Moreover, in the instances of severe spinal curvature or muscular contractures, difficulties in accurately localizing renal calculi should be anticipated [116].

Percutaneous nephrolithotomy and flexible ureteroscopy are effective and safe procedures with limited morbidity when compared to open surgery. Loss of skin and bony landmarks, distorted position of neighboring organs to the targeted kidney, and difficulties with imaging secondary to X-ray penetration and superposition of bony structures make all aspects of PCNL more difficult. Achieving percutaneous renal access may require ultrasound or CT guidance to avoid surrounding organ injury. Optimal positioning for PCNL can be problematic. The limited published data suggest that once renal access has been successfully obtained, PCNL has been shown to be as effective and as safe as PCNL in patients without skeletal deformities [117–119]. Stone-free rates in several current publications were 60–88.8%, but with up to 40% complication rate [113, 120–122].

Ureteroscopy in these patients can be a challenge as well. Stone-free rates of 35.7–75% and a 40% complication rate were described in several publications [123, 124].

Stones in urinary diversions

In patients with urinary diversions, stone-promoting factors include urinary stasis, mucus formation and inadequate

Table 1 Moderate-size kidney stones

Anomaly	Treatment option	Considerations
Renal ectopia	Special considerations	Congenital displacement or malposition of the kidney with associated shortened ureter and aberrant blood supply Most ectopic kidneys are malrotated [63]
	SWL	Prone position Success rates of up to 100% for a mean stone size of 15 mm [64]
	URS	Success rates are comparable with SWL The use of access sheaths is encouraged Tortuous anterior ureters are at higher risk of trauma [65]
	PCNL	Supine and prone positions [66] Complete stone clearance [67] Miniaturization of PCNL is being popularized [68]
	Open or laparoscopic surgery	In complex situations Robot-assisted stone surgery has been described [69]
Horseshoe kidney and cross-fused ectopia	Special considerations	Incomplete ascension and malrotation of the kidneys with high insertion of the ureters A fused kidney in the shape of a horseshoe that is limited by the inferior mesenteric artery [70]
	SWL	Localization problems in relation to bony anatomy and overlying bowel Best reserved for small stones in nondependent locations Success rates of 79% for stones <15 mm which dropped to 25–53% for stones >15 mm [71, 72]
	URS	Stone-free rate of 75–88% [73] Access sheaths and dilators are often required Multiple-staged procedures May be required
	PCNL	The treatment of choice for larger stones (>15 mm) or for cases that have failed ESWL [74] Aberrant vasculature as the vessels enter the isthmus dorsally, and a retrorenal colon [75] Access is often favored via the upper pole posterior calyx The access tract is longer
	Open or laparoscopic surgery	The anterior and medial nature of the renal pelvis makes port positioning challenging, and it is a rarely used modality for treating stones alone [76, 77]
Polycystic kidney disease	Special considerations	Divided into acquired cystic degenerative, congenital autosomal recessive (infantile), and Autosomal dominant (adult) polycystic kidney disease (ADPKD) Stone formation in this group is five to ten times more common than the general population [78] urinary stasis, low urinary pH, and low levels of stone inhibitors [70] Uric acid stones are common (55–71%) [79]
	SWL	A stone-free rate of 20–33% in ADPKD patients and 75% in patients with multiple cysts [80, 81]
	URS	Initial stone-free rates of 84.5% rising to 92.3% with a second procedure [81, 82]
	PCNL	Access is the biggest challenge in ADPKD [70] A stone-free rate of up to 89.4% for a mean stone size of 24 mm [83, 84] Mini-PCNL has been described with an initial stone-free rate of 69.6% rising to 95.7% after repeat mini-PCNL [85]
	Open or laparoscopic surgery	Open surgery was historically the standard approach as there was concern that minimally invasive techniques would have an increased risk of causing hemorrhagic cyst formation [86] More recent experience, however, has not borne this out
Calyceal diverticulum	Special considerations	Calyceal nonsecretory, transitional cell epithelium-lined cystic cavities within the renal parenchyma Patients can be predisposed to recurrent infections and pain Stone formation within a calyceal diverticulum is reported in 10–50% of patients, with most stones being calcium oxalate or mixed stones [87]
	SWL	Stone-free rates are low due to the narrow neck of some infundibuli Stone clearance (20–58%) [88, 89] Pain-free rates after SWL are much higher (65–75%)

Table 1 (continued)

Anomaly	Treatment option	Considerations
	URS	Infundibulotomy is often required Complications include bleeding, perforation, and infection Stone-free rates of 19–82% and symptom-free rates of 38–90% [90–92] A recent series of 108 patients suggests for stones less than 2 cm, a stone-free rate of 90% is achievable with ureterorenoscopy [91]
	PCNL	The favored approach for calyceal diverticular stones Stone-free rates of over 78% [90, 93, 94] Percutaneous access can be achieved directly into the diverticulum, or indirectly via a neighboring calyx Allows for the fulguration/ablation of the diverticulum and either an infundibuloplasty or ablation of the infundibulum [95] Creation of neoinfundibulum has also been described [96]
	Open or laparoscopic surgery	Commonly favored for anterior and posterior thin-walled superficial diverticula in which retrograde access has failed, percutaneous access might be hazardous, or in which there is a large stone burden [97] Laparoscopy has high stone clearance rates (100%) but is more morbid than other options described [98]
Transplant kidney	Special considerations	The presentation of stone disease in transplanted kidneys is often late as they are denervated and so pain is not a typical feature of obstruction Fever, hematuria, and worsening renal function are not uncommon presentations [70]
	SWL	Spontaneous passage of stones has been reported, but close surveillance is advised to identify evolving obstruction or increasing stone size [99] SWL is often challenging and needs to be done prone, as the graft kidney overlies the pelvic bones and bowel interposition can be problematic, limiting efficacy of this treatment modality Stone clearance of up to 66% is reported using ESWL, but often multiple sessions are required in conjunction with adjunct stenting/nephrostomy placement and alternative treatment modalities [99–101]
	URS	Often technically difficult due to the angle and position of the ureteroneocystostomy at the dome/anterior wall of the bladder [70] Stone- free rates of 60–70% are reported in small case series [99, 102] Ex vivo ureteroscopy is described with good results to treat donor-gifted allograft lithiasis on the bench prior to transplantation [103]
	PCNL	PCNL is facilitated by the anterior position of the allograft kidney using ultrasound-guided or CT-guided puncture [104] Dilatation of the tract can be challenging due to the tough fibrous capsule that forms around transplant kidneys Antegrade access with a flexible ureteroscope is described for managing ureteric stones to limit the dilatation required [105] High stone-free rates (66–100%) are achievable with PCNL when combined with the use of flexible instrumentation and baskets [100, 101, 106]
	Open or laparoscopic surgery	Open surgery has an important role to play for transplant urolithiasis in those cases where other treatment modalities have failed, and may involve ureteric reimplantation for associated stricture disease [100, 107]
Pelviureteric junction obstruction	Special considerations	Is complicated by the presence of stones in approximately 20% of cases [108]
	PCNL	PCNL combined with endopyelotomy was reported in 90 patients, with all patients stone-free after surgery and an 8% stone recurrence rate at 7 years' follow-up [109]
	Open or laparoscopic surgery	Laparoscopic pyeloplasty and pyelolithotomy is well established with the use of flexible scope achieving stone-free rates of 80–90% over a 12-month period [110, 111] Concomitant PCNL and laparoscopic pyeloplasty have been described at the same sitting in a series of eight patients, with complete stone clearance and no residual obstruction or stone recurrence at 1 year [108] Robotic-assisted laparoscopic pyeloplasty and stone extraction is increasingly performed with equivalent outcomes at 1 year [112]

clearance, bacterial colonization, outlet obstruction, and foreign bodies such as staples and nonabsorbable sutures used to reconstruct the lower urinary tract [125–131].

Bacterial colonization of urinary diversions has been reported in 14–96% of patients, and affects all types of urinary diversions [132–136]. The presence of urease-producing organisms can predispose to reservoir struvite stone formation [137–139]. Moreover, intestine utilized for urinary diversions produces mucus within the urinary tract, which may serve as a nidus for crystal aggregation, play host to bacterial biofilms, and exacerbate poor urinary emptying [140].

Many of the factors underlying stone formation in the lower tract of urinary reservoirs and conduit urinary diversions also apply to the upper urinary tract. Factors unique to upper tract stone formation consist of mucus reflux into the upper tract, ureteral and ureteroenteric strictures, and rarely reflux of foreign bodies [141–143].

Furthermore, contemporary urinary diversions often utilize colonic or ileal segments, which results in hyperchloremic metabolic acidosis. The continuous presence of urine within the intestinal segment permits increased absorption of citrate from the urine and the exchange of bicarbonate, ammonium, and chloride ions across the bowel mucosa, leading to a systemic acidosis. Acidosis creates a number of changes favoring stone formation, including increased bony demineralization which promotes calcium loss in the urine, inhibits the reabsorption of calcium from the proximal tubules, contributing to hypercalciuria and decreasing citrate production from the kidney [144]. Taken together, these effects produce hypocitraturia, hypercalciuria, alkaline urine, and excess urinary phosphate and ammonium ions.

The longer urine is in contact with intestinal mucosa, the more severe the metabolic irregularities that can be expected. Urinary dwell time is longer with continent reservoirs (neobladders, Kock, and Indiana pouches) than with continuously draining diversions (ileal and colonic conduits). Patients with continent urinary reservoirs have more profound hypercalciuria, hypermagnesuria, and hyperphosphaturia than patients with ileal conduits [125, 145, 146].

The use of long segments of ileum or colon for urinary diversion predisposes patients to chronic diarrhea and dehydration promoting a stone-forming milieu. This low urine volume coupled with acidic urine ($pH < 6.0$) creates a high supersaturation of uric acid and encourages uric acid stone formation [147, 148].

Shock wave lithotripsy is rarely employed to treat stones within reconstructed urinary reservoirs. The need to rely on spontaneous passage of fragments is the main limitation [149, 150].

In orthotopic neobladders and reservoirs, transurethral lithotripsy is a viable strategy when the stone burden is relatively small and the urethra and neobladder neck will accommodate the cystoscope and lithotripsy instruments. For large stone burdens, percutaneous lithotripsy is more efficient and effective in clearing stones than transurethral or trans-stomal approaches. It is also the preferred method for smaller stone burdens when concomitant stomal or urethral strictures preclude stone removal. Performing intra-reservoir lithotripsy while the stones are secured within an endocatch bag has been described and may reduce reservoir trauma, and facilitate removal of residual stone fragments [151]. Alternatively, with lengthening of the skin incision, multiple stones, even large ones have been removed intact after being placed within the entrapment sac [152].

Although the majority of reservoir stones can be effectively managed endoscopically, there remains a small role for laparoscopic or open approaches when no safe minimally invasive option exists [153–155].

Upper tract calculi in patients with urinary diversions can be managed with contemporary stone treatment options; however, all are more challenging. Shock wave lithotripsy is a therapeutic option for stones 2 cm or less in diameter, with a success reported between 25 and 81.5% [156, 157]. The concern, however, is underlying ureteral obstruction which will impede fragment passage, and lack of easy access to the ureter via a retrograde approach.

Retrograde ureteroscopy can be technically difficult as the ureteral orifice may be hard to identify and navigation of tortuous and dilated ureters may be necessary. Given the inherent difficulties of ureteroscopy in urinary diversions, stone-free rates reported in the literature are inferior compared to series of patients with normal anatomy [158, 159]. Results of percutaneous nephrolithotomy alone or in combination with SWL describe respectable stone-free rates of 75–88% with complication rates of 8–30% [157, 160–162].

Pediatric stone disease

Over the past three decades, pediatric urologists have noticed a change in the epidemiology of pediatric urolithiasis with a migration from lower to more upper tract stones, and a rise in the incidence of calcium stones [163–168]. Younger patients tend to present with renal stones as opposed to ureteral stones in older children, often with larger stone burden [169–172].

Metabolic data suggest that the rise in pediatric urolithiasis is due to factors other than obesity. Citrate levels and urine pH appear to be fairly constant when stratifying pediatric weight by adult BMI cutoffs, and many researchers agree that calcium excretion appears more closely linked to dietary sodium and protein than obesity [173, 174].

A conscious effort is made to reduce the radiation burden during diagnostic workup in children. Initial screening with renal ultrasound, abdominal plain film, or stone protocol CT that minimizes the radiation dosage while not compromising diagnostic information is all currently practiced [170, 175–177]. The sensitivity of pediatric ultrasound for stone detection is 59–78% with up to 100% specificity [171, 178, 179].

Conservative management of pediatric nephrolithiasis is considered first-line treatment in the absence of obstruction, infection, or a child is failing to thrive as the result of stone disease. Small retrospective series suggest that stones 4–6 mm or larger are likely to require endourologic treatment [180, 181]. Alpha receptor antagonists such as tamsulosin may be safely offered on an individualized basis as adjunctive therapy to facilitate ureteral expulsion in children [182, 183].

Shock wave lithotripsy has been the preferred treatment modality for uncomplicated renal and proximal calculi ≤15 mm in the pediatric population. Current stone-free rates with SWL are difficult to interpret from the existing body of data due to discrepancies between studies with regard to type of lithotripter, number of shocks administered, and re-treatment rates [184–190]. Onal et al. have recently constructed a nomogram for predicting stone clearance following SWL [191]. Multivariate analysis revealed younger age, female gender, lower stone burden, and lack of prior ipsilateral stone treatment to be positively associated with stone clearance.

Although SWL is well tolerated in children with few complications, stone-free rates following single session monotherapy can remain as low as 44%. Existing data have failed to demonstrate significant renal scarring or functional impairment in pediatric kidneys post-SWL [192, 193].

With significant improvements in both the miniaturization and durability of endoscopic equipment and the acceptance of the holmium laser, ureteroscopy has become a more attractive option in young children. Early series using rigid ureteroscopy for distal stones reported stone-free rates ranging from 86 to 100% with minimal complications [180, 194–201]. Comparable stone-free rates with complication rates similar to that of the adult population have recently been reported for upper ureteral and renal stones employing flexible ureteroscopy [199, 201–203]. Relative contraindications to ureteroscopic management include staghorn stones in recurrent stone formers, anatomic anomalies making retrograde access difficult, and previous endoscopic failure.

The necessity of placing a stent post ureteroscopy in all children continues to be debated. While the tendency in large series has been to leave a stent in place after ureteroscopic manipulation in a majority of children, several authors have reported no acute or long-term sequelae despite leaving a postoperative stent in less than 20% of cases [204].

With accumulated experience, PCNL is currently being utilized as monotherapy and in combination with SWL (sandwich therapy) in children achieving stone-free rates ranging from 68 to 100% [194, 205]. Although there is no current international consensus, relative indications for PCNL as the primary treatment modality in children include large upper tract stone burden (>1.5 cm), lower pole calculi >1 cm, concurrent anatomic abnormality impairing urinary drainage and stone clearance, or known cystine or struvite composition [206]. Recent large retrospective series of PCNL monotherapy have demonstrated high efficacy rates approaching 90% [207–210]. Despite successes employing adult equipment, technology advancements have allowed to the development of mini-perc approaches without affecting PCNL efficacy [211]. The benefits of minimal tract dilation included increased maneuverability, decreased blood loss, and shorter hospital stay. Disadvantages, however, include longer operative times and impaired visualization when tackling very large stone burdens.

Conclusions

Although the clinical scenarios described herein may be particularly challenging, endourological management can be safely and effectively applied with a sound knowledge of anatomy and pathophysiology, the use of judicious imaging, and the full array of endourological instruments.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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