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Review

Current minimally invasive and endourological therapy in pediatric nephrolithiasis

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Abstract

Introduction: Children with complex urinary tract stones present a treatment challenge. There is still no clear consensus regarding their management. Therefore, our goal was to review the endourological therapies in children presenting with complex nephrolithiasis, updated to 2013.

Methods: This was a review of published articles, from 1981 to 2013, related to pediatric nephrolithiasis, staghorn calculi, lower pole kidney stones, and uninephric children. The sites from which information was retrieved covered PubMed, the American Urological Association, and Medline.

Results: We reviewed 147 articles that demonstrated that small lower pole stones of <1 cm may be treated successfully with ESWL in children who are able to cooperate or under sedation; staghorn stones, are better treated by PCNL. Flexible ureterorenoscopy is considered a second option for smaller stones and an alternative for middle size stones in case of failure of ESWL or contraindications for PCNL.

Conclusion: ESWL alone, for a large stone, or in a lower pole in uninephric children is not the standard of care. PCNL offer an appropriate and therapeutic modality in specific situation i.e. larger stones, the lower pole stones with stone free rate approaching 80%. Nevertheless, flexible ureteroscopy with the newest high definition cameras has a promising potential in reaching a 100% stone-free rate in the near future.

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Introduction

"Nephrolithiasis occurs in around 1% of children and about 5–9% of adults" [1,2]. The incidence is higher in countries with low socio-economic status [3], and in countries with high temperatures and hot climate like the Middle East, and Far East [1,2]. Children have been reported to present from the first visit with large staghorn calculi in almost 20% of the cases [4]. These cases represent a real challenge to the urologic surgeon, therefore a highly skilled and fellowship-trained endourologist should to be consulted.

These complex cases become more problematic when a large stone burden is present in uninephric children, and their management more

problematic. Solitary kidneys are the result of either congenital renal anomalies or acquired renal diseases. For decades, and before the era of endourology and minimally invasive therapies, kidney stones in children have been treated by open surgery. Uninephric patients presenting with large kidney stones or staghorn calculi were initially treated with techniques including open nephrolithotomy and pyelolithotomy.

Since its introduction in the early 1980s ESWL replaced open surgery and even PCNL as the preferred modality for the treatment of upper tract stones [5–7].

Nowadays, ESWL is considered an optimal method for the treatment of mid-sized and small upper tract stones. However, ESWL has shown to have limits and shortcomings for stones with a large burden, in a solitary kidney, or in lower poles, or even when the stone composition is an obstacle (cystine, calcium oxalate monohydrate). In parallel, endourological modalities have flourished and expanded, including rigid and flexible ureterorenoscopy (fURS) [8–10], in addition to percutaneous nephrolithotomy (PCNL) that was introduced in the 1970s. On the other hand, when considering nephrolithiasis in a solitary kidney, multiple other factors should be taken into consideration, in order to choose the best therapeutic option, including the renal anatomy, obesity of the pediatric patients if present, equipment and the surgeon's expertise and skill [11].

Therefore, the objective of the present review was to detail current techniques and results, including ESWL, fURS, PCNL, discussing the efficacy and disadvantages of each procedure, with future trends, for the treatment of children presenting with complex nephrolithiasis, including lower pole stone or staghorn calculi, and solitary kidneys, as updated to 2013.

Methods

We performed a literature search of papers published between 1981 and 2013, and included 147 results, between published papers and guidelines, in our review. Around 200 papers were identified in our literature search. The criteria for inclusion of a paper in our review were the presence of the combination of the following key words: solitary kidney, pediatric nephrolithiasis, lower pole, percutaneous nephrolithotomy, extra-corporeal shock wave lithotripsy, ureteroscopy, and staghorn calculus.

The information covered was retrieved electronic Database such as PubMed, Medline, Medscape, Cochrane database, and the American Urological Association. Some articles were identified using table of contents of the Journal of Endourology, Clinical Imaging, the Journal of Urology, and Archives of Surgery.

The role of ESWL, PCNL and fURS in the management of complex pediatric nephrolithiasis was reviewed including lower pole stone or staghorn calculi, and solitary kidneys, as updated to 2013.

Results

Endourology and minimally invasive methods have progressively replaced open surgery, for the treatment of kidney stones, over the past 30 years. Pediatric endourology has been replacing open surgery too, with the first reported pediatric PCNL in 1984 and ESWL in 1986 [12,13]. The European Society of Pediatric Urology

Table 1 Criteria associated with the lowest SFR during ESWL for lower pole kidney stone in children with a solitary kidney.

Long lower pole (>1 cm)
Infundibular length of <3 cm
Steep infundibulo-pelvic angle <45degrees
Infundibular width <5 mm
Resistant stones in children (cystine, calcium oxalate monohydrate,...).

Criteria related with the lowest SFR during ESWL for lower pole kidney stone in a solitary kidney.

(ESPU) recently published guidelines, recommending PCNL as the treatment of choice in children with staghorn calculi, and ESWL as a second line treatment [14]. Nevertheless, these recommendations need to always be tailored to the child's anatomical factors, including the renal collecting system, in addition to the size of the stone, exact location, and chemical composition. Children need not to be excessively radiated too during these minimally invasive procedures, therefore the shortest, fastest, and most efficient technique is the one to adopt.

1-ESWL

In adults as well as children ESWL has been adopted as a first option for intermediate and small kidney stones. The limitation in a solitary kidney would be mainly in the presence of a lower pole stone, because of a lower stone-free rate (SFR) varying between 25 and 85%. Therefore, ESWL might be adopted, in a solitary kidney in case the stone is present in the upper or middle calyces. In the presence of a lower pole kidney stone, ESWL has been considered for sizes reaching a maximum of 1.5 cm; nevertheless, certain criteria would make this intervention less successful (Table 1).

In children, ESWL was introduced for the first time in 1986 [12], and Orsola et al. [15], in 1999, were the first to report ESWL as a single therapy in children with staghorn calculi, rendering 11 out of 15 children stone-free.

SFR are recently reaching higher rates, up to 88%, for children with staghorn calculi, as reported by Lottmann et al. [16,17].

Recommendations for ESWL in children with staghorn calculi differ slightly from adults, since children have a smaller stone burden in general, with smaller body volume and less abdominal fat, allowing a better shockwave transmission, resulting in higher SFR's [15,17]. Therefore, some authors suggest that ESWL can be offered as a single therapy in children with staghorn calculi [15,17]. It is a safe and effective technique as reported in large series of children, and despite some discouraging reports, ESWL showed no evidence of renal scarring, renal function loss nor change in blood pressure, as demonstrated in multiple studies [18,19], and as outlined in the recent reports of the (ESPU) [14]. Some minor side effects are nonetheless reported, such as ecchymosis, hematuria (40%) and renal colic (10–50%). When the stone is fragmented, multiple small fragments can accumulate in the distal ureter, causing again a secondary obstruction of the collecting system, called "Steinstrasse", and it may occur in the pediatric population in 2–6% [20,21]. The major limitations of ESWL in pediatric patients are mainly the need for multiple sessions, most of them requiring general anesthesia, an increased clearance time, obstruction resulting in renal colic, and a higher rate of admission to the hospital.

Concerning lower pole stones, by reviewing the literature, The SFR after ESWL is lower in patients with a large stone burden or lower pole stones [22], because gravity impedes the clearance of stone fragments from lower pole calyces. [23]. Over the last two decades, numerous anatomical factors have been identified resulting in lowest clearance rates after ESWL, for lower pole stones (Table 1) [24–28]. Even the skin-to-stone distance that has been thought to be an important factor in the past is nowadays not accepted by all authors [29–32].

New approaches have been implemented recently to minimize the temporary damage to the kidney during ESWL [33,34]. These techniques may be applied to children with solitary kidneys, and include the use of a low-energy shockwave pretreatment, followed by high energy treatment. It will induce a diffuse renal parenchymal vasoconstriction during ESWL, instead of afterwards, as is the case with no pretreatment [35]. Lowering the rate to 60/min also improves stone fragmentation and minimizes parenchymal damage [36]. Higher clearance rates are achieved in treating nephrolithiasis in uninephric children.

Most centers and authors assess the SFR, after ESWL, at 3 months. The reported SFRs at 3 months after ESWL for stones <10 mm, 10–20 mm, and >20 mm in diameter are 64–84%, 38–66%, and 25–49%, respectively [25,37–39]. Several authors have tried to compare different modalities for the treatment of staghorn or lower pole calculi in children with a solitary kidney. In 1994, Lingeman et al. [40] did a meta-analysis and compared ESWL to PCNL, in the management of lower pole stones. In that study, PCNL was associated with a significantly higher SFR of 90%, compared to 59% with ESWL. Stone burden and size were negative factors for the results of ESWL as expected. Furthermore, the "Lower Pole Study Group" published a randomized controlled trial comparing ESWL with PCNL [41]. At 3 months follow-up PCNL was associated with a high SFR of 97%, compared to only 37% after ESWL. But when incorporating stone size, the SFR after ESWL for stones of <10 mm was 63%, decreased to 21% for stones between 10 and 20 mm, and 14% for those of >20 mm. Hospital stay was shorter for ESWL as well. The authors demonstrated that ESWL was an acceptable method for lower poles stones of <10 mm, but patients presenting with larger stones may benefit from other endourological techniques especially in children with solitary kidneys.

2-fURS

Over the past ten years, some new case series have been published, on the role of ureteroscopy and mostly flexible ureteroscopy (fURS) in the management of renal stones in children (Table 2) [42–50]. The main limitations of these case series are the small number of cases reported, and the location of those stones, that is mainly in the ureter, therefore providing less data on the complex stones in children, represented by the lower pole stones, as published by Cannon et al. [47] and Kim et al. [49]. Success rates as high as 98% and 100% were reported [43,45], however this SFR becomes smaller (76%) when it involves lower pole stones, as reported by Cannon et al. [47]. Dave et al. [48] reported a similar SFR reaching 75% when it involved renal pelvis stones.

In order to access lower pole kidney stones in children, the newest generation of flexible ureteroscope represent an ideal tool. It may be utilized safely in case of solitary kidney in children, however

concerns may exist in case of a large stone burden as in staghorn calculi. Actually, fURS is recommended as a second-line treatment for calculi of <10 mm, or as the third option for stones of 1–2 cm, by the Guidelines of the European Association of Urology (EAU). fURS is not recommended for stones of >2 cm [51]. The newest 2012 EAU guidelines changed that [52]. While fURS was considered till now a second option for small stones, it has now been upgraded as an alternative to PCNL for stones of intermediate size (1–2 cm). ESWL has been downgraded to the second option for the management of such stones. Multiple improvements have been made, for the successful management of stones in the lower pole, while using fURS, in particular the deflection mechanisms allowing better intrarenal navigation [53]. Nowadays, the newest ureteroscopes have an outer diameter of <9 F allowing direct access to the upper tract without dilatation of the ureteral orifice [9,10,54–56]. Using access sheaths also facilitates this intervention and improves the results [57,58]. The newest generation of flexible endoscopes allowed the urologic surgeon to make better use of fURS [59–62]. Consequently, Flexible ureteroscopes have been used with great success in lower pole stones in a solitary kidney. Digital ureteroscopes have been recently introduced. They have a better resolution than the first generation fiber-optic endoscopes, since they include a camera chip at their tip, resulting in the best visual quality, in addition to an incorporated light source [63]. In 2005, the Lower Pole Study Group published a second randomized controlled trial, and compared fURS to ESWL for small lower-pole stones [64]. After 3 months, fURS did not have a better outcome statistically, when compared to ESWL (SFR 50% vs. 35%, fURS vs. ESWL, respectively). However, the length of hospital stay, complication rates and the need for other secondary procedures were the same. But this study had some limitations. It included a limited number of patients, and 19 centers that recruited patients with a different caseload and tools. In some recent studies, authors have reported that fURS could be considered for even larger stones [38–41]. In some series, fURS achieved a high SFR after 1month, similar to that reached by PCNL [65–67].

Ureteroscopy in children has some technical aspects that need to be taken into consideration. Ureteral dilatation was needed when large rigid ureteroscopes were used, as reported in the series of Bassiri et al. [68], where most of the children had a ureteral dilatation when 11.5 French rigid ureteroscope was used. With the newest generation of flexible ureteroscope (4.5 French), ureteral dilatation is not needed, as published in the Philadelphia series [49]. The other technical issue is the need for ureteral stenting after stone removal. The need for ureteral stenting after stone removal remains controversial, but is determined by the stone burden, the degree of ureteral edema, and patient characteristics. Herndon et al. [69] stented 21% of the children, and the main reasons were the need for subsequent ESWL, ureteral edema, perforation and stone impaction.

3-PCNL

In the 1970s PCNL was adopted as a minimally invasive therapy for large kidney stones, and subsequently it has been optimized [70]. It has an excellent efficacy in the treatment of large staghorn calculi, renal pelvic stones, in specifically lower-pole ones with a very high clearance rate [40]. It demonstrated an SFR of 100%, 93% and 86% for stones measuring <1 cm, 1–2 cm and larger stones, respectively, in the Lower Pole I Study [41], in addition to other studies too [71,72]. To make PCNL even less invasive, mini-PCNL (using 18F sheaths, compared to 24-30F in regular PNCL) was introduced for stones <2 cm in diameter [73–75]. Mini-PCNL has the advantage

Table 2   Current published case series on the ureteroscopic management of pediatric nephrolithiasis.

Authors	Number of children treated	Ureteral stones	Renal stones	Stone size (mm)	Success and stone-free rate (SFR)
Tan et al. [42]	23	25	2	9	95%
Minevich et al. [43]	58	58	7 patients	N/A	98%
Thomas et al. [44]	29	28	1 patient	6	88%
Sofer et al. [45]	21	12	9	11	100%
Smaldone et al. [46]	100	67	33	8	91%
Cannon et al. [47]	21	0	Lower pole	12	76%
Dave et al. [48]	19	0	23 stones	17	Pelvic 75% Polar 100% Staghorn 14%
Kim et al. [49]	167	66	101 stones (87 lower pole)	6	100% if < 10 mm 97% if >10 mm
Tanaka et al. [50]	50	0	52	8	58%

of causing less morbidity, less painful, with reduced bleeding [76]. Several studies have compared conventional PCNL to mini-PCNL [74,77,78]. The studies of Lahme et al. [74,79] emphasized the question of whether mini-PCNL will result in an extension of the indications for percutaneous therapies. Nagele et al. [80] demonstrated the safety of mini-PCNL even for smaller stones of 8–15 mm with an excellent SFR. It seems to be the method of choice for staghorn and lower pole calculi, particularly in uninephric children. However, further prospective studies will need to assess this technique.

The first pediatric PCNL was reported in 1985 by Woodside et al. [13]. Some initial concerns, including parenchymal damage, exposure to radiation, bleeding and sepsis [81–83], lead to a delay in adopting this technique in children. Initial reports on PCNL in the pediatric population emphasized that the main reason behind these complications was the use of large adult-sized catheters, sheaths, and devices, as demonstrated by Desai et al. [84], and Zeren et al. [85].

However, with time leading to a higher learning curve, several recent studies showed that PCNL was not correlated with renal parenchymal damage, and that it was a safe technique in children with staghorn calculi, as reported by Mor et al. [82], and by Dawaba et al. [83].

Discussion

Pediatric nephrolithiasis is a well known entity. It becomes more problematic in children who present with complex kidney stones, including staghorn calculi, stones in lower pole calyces, or the combination of complex stones in uninephric patients.

Staghorn stones are branched stones that typically fill the renal pelvis with branching into the calyces. They may be complete or partial [86], and in pediatric population, like in adults, their chemical composition is magnesium ammonium phosphate (struvite), in the context of infectious stones [87] and/or calcium carbonate apatite, less frequently uric acid or cystine. As in adult patients, treatment of pediatric nephrolithiasis starts with treatment of the underlying medical cause if it exists, like treatment of infections, to avoid recurrence of any infectious stone [88,89]. Any cystine stone should be treated with alkalinization and Tiopronin (Thiola®). The challenge becomes more problematic in the presence of staghorn calculi in children with repetitive infections since the endourologic surgeon

needs to have the best treatment in the armamentarium with the least damage to the renal parenchyma [86,90–94].

Raza et al. [95] reviewed papers published between 1988 and 2003 in the management of pediatric nephrolithiasis, by comparing the three modalities, but not necessarily including complex stones. In general, the authors concluded that renal stones <20 mm are effectively treated by ESWL. For renal stones ≥20 mm or staghorn stones, PCNL was the preferred primary modality, with high SFR (stone-free rate). Ureteroscopy with holmium laser stone fragmentation has high SFR, low complication rates, however this superiority was demonstrated for ureteral stones only [95], and not for complex cases (Table 3).

Regarding children with staghorn stones, ESWL seems to have an increased rate of re-admissions, and multiple sessions. Al-Busaidy et al. [96] reported an SFR reaching almost 80%, where 42 children were treated, however adjunct procedures were added to the final management, and this indicates that PCNL is a valid alternative in the surgical treatment of children with staghorn stones, as demonstrated in multiple published series (Table 4) [15,17,84,96–99]. The issue of ureteral stenting after ESWL for staghorn calculi in children is controversial. Al-Busaidy et al. [96] reported that there were no differences in the stone-free rates between stented and unstented children, however the unstented children had more complications after the procedure. He recommended routine ureteral stenting prior to ESWL in children with staghorn

Table 3   Comparison of outcomes including SFR (stone-free rate), need for ancillary procedures and complication rate, for the three different endourological modalities in pediatric nephrolithiasis, by Raza et al. [95].

	ESWL	PCNL	URS
Number of patients	122	37	35
Number of renal units	140	43	35
Mean age (years)	7.7	6.4	5.9
Number of treatments	209	46	53
Stone size (mm)	17	40	12
Associated ancillary procedures	45%	34%	26%
Complication rate	26%	6%	0%
SFR (Stone-free rate)	84% if <20 mm 54% if >20 mm	79%	100%

Table 4 Overview and Comparison of PCNL and ESWL results in published series for the treatment of staghorn calculi in children.

Number of children treated in published series	Age and/or stone characteristics	SFR (%) (stone free rate)
PCNL		
Desai et al. [84,142]	Complete and partial staghorn	90%
Kumar et al. [97]	Staghorn defined as occupying more than 1 calyx	92%
Gonen et al. [98]	Complete and partial staghorn	68%
Aron et al. [99]	Pre-school children	90%
ESWL		
Orsola et al. [15]	1 year to 13 years	73%
Lottmann et al. [16]	5 months to 11 years	78%
Al-Busaidy et al. [96]	9 months to 12 years	79%

Overview and comparison of PCNL and ESWL results in published series for the treatment of staghorn calculi in children.

calculi [96]. ESWL in children has been shown to expose the patient to less radiation as compared to adults [18,21]. In general, children aged less than 10 years will need general anesthesia during the sessions of ESWL, whereas patients older than 10 years may benefit from a light intravenous sedation [100]. Since staghorn calculi are basically infectious stones, they represent a risk for recurrence in children, especially after an initial session of ESWL. These recurrences seem to be higher when compared to adults, as reported by Afshar el al. [90], reaching almost 35% at 4 years, and as demonstrated by Nijman et al. [101].

PCNL is now considered the safest, fastest and first-line approach for the treatment of staghorn calculi in adults [14,86], and with this gain in experience and optimization of the instruments, PCNL is becoming more adopted as a first-line treatment for staghorn calculi in children [97], as reported in the guidelines of the AUA in 2005, and the ESPU in 2012 [14,86]. PCNL as monotherapy for staghorn calculi can achieve SFRs of 60–100% in patients with a wide age range [98,102,103], and Aron et al. demonstrated that PCNL in children below age 10 has an SFR of 90% [99], and almost 100% as reported by Romanowsky et al. [104]. Nevertheless, PCNL has a reported incidence of complications in pediatric population, with a 25% risk of bleeding requiring transfusion as published by Zeren et al. [85]. Stone burden and instrument size are related to those complications, mostly bleeding, as reported by Kapoor et al. [103]. While other complications are less dangerous (urinary leak, fever...) [103,105–114], sepsis from large struvite staghorn stone is the most serious complication, and can be lethal [115].

Regarding children with small lower-pole kidney stones, ESWL seems to be the first option as a treatment modality [116], and this may be extrapolated to solitary kidneys as well. Benefits include a good SFR, minimal complications, and no need for general anesthesia if the child is above 10 years of age [25,38]. The updated EAU Guidelines in 2012 (Fig. 1) [52] underlined that the treatment outcome for stones of 1–2 cm depends on the predictive factors (Table 1). If ESWL fails to clear the stone burden, endourological approaches must be considered. Preliminary reports did not demonstrate that fURS was superior to ESWL, but more recent reports suggest that it has greater advantages [11,117,118]. A skilled urologic surgeon will be able to have an almost 100% SFR when using fURS in lower pole stone, and should be encouraged to use it more in children with a solitary kidney. In addition to that, sometimes ESWL is not an appropriate option in the presence of bleeding dysfunction, children with elevated BMI, and unusual renal anatomy [119]. In a lower pole stone of >1.5 cm in a solitary kidney, PCNL seems to be the treatment of choice [37]. It has a very high SFR,

but requires general anesthesia, and when compared to ESWL and fURS, it has a higher rate of complications [117]. Srisubat et al. [117] reported in 2009 an analysis of ESWL vs. URS vs. PCNL for treating renal calculi. ESWL had the lowest efficacy while PCNL and URS showed no statistical difference. It is obvious that the hospital stay was shorter with ESWL, but all three treatments seemed to offer a good chance of stone-free rate [38]. The available studies had low quality data, because the authors included only three studies in the meta-analysis.

First-line treatment for stones >1.5 cm in diameter, especially lower pole stones, however some clinicians have reported that this technique is effective and safe. A combined approach in children (fURS+ PCNL) might be an alternative plan in certain institutions. However, even in the presence of these combined techniques, PCNL seems to have superiority in term of results and clearance rates, when compared to fURS. In children who are not good candidates for PCNL, fURS can be used [120]. Furthermore, in obese patients, the efficacy of ESWL is limited, and PCNL can be technically impossible if the needle is unable to reach the kidney, whereas fURS can be used without these limitations [121].

Regarding children with stones in a solitary kidney, no major randomized control trial assessed head to head the outcomes of PCNL
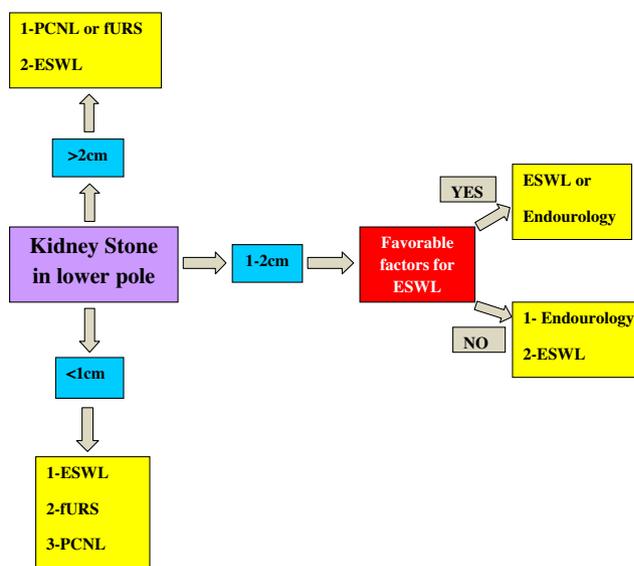
Figure 1 Management of lower pole kidney stone according to the updated 2012 EAU guidelines.

in comparison to fURS. An idea can be projected from the conclusions of many studies performed on adult subject. One such study was conducted by Kupajski et al. at the Medical University of Poland [122]. It was done to assess the risk factors that can affect the final result, PCNL and fURS in patients with a solitary kidney, taking into consideration the positioning, diameter and number of stones in the urinary tract, and to assess the impact of the location of the stones on the effectiveness of the minimally invasive treatment. In their study, 51 patients operated between 1999 and 2008 in their urology department using PCNL and fURS due to stones located in the pyelo-calyceal system or the ureter were subjected to retrospective assessment. All patients had lost the contralateral kidney from previous surgery. 34 PCNLs were performed on patients with a solitary kidney (66.7%). 17 patients required fURS (33.3%). PCNLs and fURS led to full recovery of 70.6% of patients. No complications were observed in 74.5% of patients with a single kidney. Significantly higher percentage of complications was observed in patients with two stones. The percentage of complications was also significantly higher in patients with 2 cm or bigger stones. Analysis of the impact of the positioning of stone showed that the location of the stones did not affect the treatment result.

However, there were significant differences in the occurrence of complications depending on the location of stones. Kupajski et al. concluded that the effectiveness of minimally invasive PCNL and fURS treatment of a solitary kidney is adversely affected by the size of the stones and occurrence of more than one stone, which also increases the percentage of complications, as does the positioning of stones in calyces or in calyces and renal pelvis. Therefore, care must be taken when deciding which technique to consider in the presence of stones in uninephric children.

In general, PCNL is considered the best treatment option for large and complex calculi [123]. High success rates of more than 90% have been reported [124], but bleeding is still one of the most common complications; bleeding requiring a transfusion has been reported between 0.8% and 45% in PCNL [125–127]. Most bleeding related to PCNL has been managed conservatively, with 1% of patients requiring angioembolization to control intractable bleeding [128].

El-Nahas et al. reported on a large experience with PCNL (3878 cases), in order to study risk factors for extensive post-PCNL bleeding, and reported that the significant risk factors for severe bleeding included upper calyceal puncture, a staghorn stone, multiple punctures, an inexperienced urologic surgeon and the presence of a solitary kidney [129]. Therefore solitary kidneys containing a lower pole stone could be a real technical challenge in children, based on these reports. Operative time, tract size of the PCNL, and type of lithotripter are other factors that influence bleeding [130]. The impact of PCNL on renal function is one of the most important considerations. However, the confounding effects of the normal contralateral kidney might preclude an accurate assessment of PCNL effects on renal function. Therefore, evaluating the impact of PCNL on kidney function in children with solitary kidneys would be more accurate. Despite multiple reports in animal models about the impact of PCNL on renal function using nuclear scintigraphy or serum/urine biochemical analyses, few clinical studies have been performed [131,132].

Akman et al. conducted a study in Turkey [133], in order to assess the outcomes of PCNL in patients with solitary kidneys in regard to transfusion requirements, complications, and renal function at early and late postoperative periods. And it will be important to consider those outcomes on a lower pole kidney stone in a uninephric child. Between 2002 and 2009, 47 patients with a solitary kidney underwent PCNL in their medical center. Serum creatinine was measured preoperatively, on postoperative day 1, and at each follow-up visit at regular intervals. The 4-variable modification of diet in renal disease equation was used to calculate the estimated glomerular filtration rate (eGFR). The 5-stage classification of chronic kidney disease (CKD) was used according to the National Kidney Foundation published guidelines. Success was achieved in 84.5% of patients after 1 session of PCNL. Complex stones were present in 68.1% of patients. Among all patients, multiple access tracts were required in 23.4% of patients. Complications developed in 10.6% of patients. At a mean follow-up time of 18.7 months, the overall success rate improved to 97.7% after auxiliary treatments. According to CKD classification, kidney function was stable, improved and worse in 63.6%, 29.5%, and 6.8% of patients, respectively, compared with preoperative levels. Akman et al. concluded that PCNL is safe and has a low complication rate in patients with solitary kidneys. At long-term follow-up, renal function had stabilized or improved in more than 90% of patients with a solitary kidney after PCNL, and it should be considered the treatment of choice in children with lower pole stone in solitary kidneys.

Nonetheless, in order to minimize the undesired effect of multiple accesses on bleeding, the combined flexible nephroscope or ureteroscopic techniques with a single percutaneous access may be adopted instead of multiple accesses. Marguet et al. reported that though combined PCNL and ureteroscopic management can effectively decrease the number of the access tracts, this combined procedure does not significantly affect stone-free rate and operative time [134].

Furthermore, although a 30-F tract was routinely used in the Turkish study of Akman et al., using smaller tract size may be less traumatic in kidneys with non-dilated calices and narrow infundibula, and it may reduce bleeding during PCNL in children. For PCNL therapy performed on a solitary kidney, the mini-perc and/or combination of single access and flexible instruments may be preferred. In contrast, a conservative approach using a single instead of multiple access tracts may be preferable.

On the other hand, only a few studies have studied the factors affecting renal function in patients with solitary kidneys in the late post-PCNL period. Mayo et al. assessed renal function with radionuclide studies and evaluated creatinine clearances in 15 patients with a normal contralateral kidney 2–3 months after PCNL and demonstrated improvements of renal function, especially in patients with infected stones [135]. Another study also revealed that female gender is one of the most important predictive factors for the preservation of renal function after PCNL [131]. The authors concluded that young girls are 3 times more likely to manifest improved renal functional outcomes 1 year postoperatively [131]. In contrast, Akman et al. [133] found no significant correlation between postoperative kidney function and patient-related factors, like gender, presence of obesity, previous open kidney surgery, or grade of hydronephrosis.

Another very important factor that needs to be considered in PCNL is treating children with lower pole stones in a single kidney which has a potential effect on renal function from multiple access procedures. In the retrospective study of Akman et al. [133], the authors

demonstrated that renal function in the early and late postoperative periods was not clinically affected by the creation of multiple tracts. Kidney function during the late postoperative period deteriorated in 1 of the 12 patients who had undergone PCNL with multiple accesses. Traxer et al. compared the extent of renal injury incurred by different sized nephrostomy tracts in female farm pigs undergoing 11- or 30-F percutaneous nephrostomies [136]. They reported a mean estimated scar volume of the 30- and 11-F tracts of 0.29 and 0.40 mL. Recently, the negative effects of shock wave lithotripsy, percutaneous nephrolithotomy and non-interventional observation were compared among adult patients with asymptomatic lower calyceal stones [137]. Results can give us an idea and might be extrapolated to solitary kidneys in children as well, pending a comparison of complication of each technique in the pediatrics population. All patients in the adult study were evaluated by renal scintigraphy at 6 weeks and 1 year after the intervention. At follow-up, scintigraphy revealed lower pole scarring in 16.1% of cases in the ESWL group, and lower pole access site scarring was reported in 1 patient in the PCNL group [137]. Finally, in another study, Liou and Streem found no significant difference between estimated creatinine clearances in patients with solitary kidneys who had undergone PCNL, shock wave lithotripsy or combined therapies [138].

In 2011, Resorlu et al. [139] evaluated the safety and efficacy of PCNL in the treatment of complex calyceal or staghorn stones in a solitary kidney and determined long-term renal functional results. The authors presented their experience with PCNL in treating 16 patients with staghorn stones in a solitary kidney to determine long-term renal functional results. They retrospectively reviewed the records of 16 patients, including young patients, with complex calyceal or staghorn stones in a solitary kidney treated with PCNL. Of these, 62.5% patients required a single tract, while 37.5% required multiple tracts. The calculi were extracted or fragmented successfully in 81.3% patients and complete stone clearance was achieved after the first stage. In two patients with residual calculi, a ureteral catheter was inserted and ESWL was performed. There were no significant intra-operative problems except in one patient, who had bleeding from an infundibular tear attributable to torquing. During the 1-year study period, none of the patients progressed to end-stage renal disease requiring dialysis. The authors demonstrated a significant improvement in creatinine and GFR levels from preoperatively to 1-year follow-up. In this study the demonstrated efficacy, low short-term complication rate and absence of long-term adverse effects on renal function confirm that PCNL is effective and safe in staghorn and lower pole calculi in the solitary kidney, and this may also be the case in children.

In summary, several studies have been published in order to assess minimally invasive therapies for the management of staghorn calculi, lower pole stones and stones in uninephric children. However, we lack randomized controlled studies comparing PCNL, ESWL, and fURS.

Patients presenting with lower pole stones in solitary kidneys remain problematic. A combined technique termed 'sandwich therapy', which consisted of primary percutaneous stone debulking followed by ESWL of any inaccessible, residual infundibulocalyceal stone fragments. However, improved PCNL techniques, achieved complete clearance of stone material at the time of the primary procedure, have decreased or eliminated the need for additional ESWL treatment, especially in children [140–142].

For renal stones less than 20 mm in size, fURS is an excellent minimally invasive technique with high SFR. Recently, new publications report that fURS is a viable treatment for large renal calculi [143–145]. A disadvantage of fURS is that several interventions may be required to clear a large stone burden. Overall, fURS has fewer complications when compared to PCNL [146,147].

Conclusion

Children with staghorn calculi, stones in lower poles, and stones in a solitary kidney are among the most challenging cases in endourology.

Uninephric children with renal stones of <10 mm are usually successfully treated with ESWL; larger stones, especially within the lower pole, are more efficiently treated by PCNL. fURS is recommended as a second-line alternative treatment for smaller lower-pole stones and as an alternative for stones of moderate size if there are negative predictors for the success of ESWL. Nevertheless, fURS is being used for such stones by urologic surgeons. For renal stones less than 20 mm in size, fURS is an excellent minimally invasive technique with high SFR, especially in lower pole stones in uninephric children. PCNL is a safe procedure with a high SFR, and an acceptably low complication rate in children presenting with large staghorn calculi or lower pole stones in a solitary kidney. Multiple access tracts slightly increase the risk of complications, such as the risk of blood transfusion, but they do not represent a major obstacle in a young healthy child; furthermore, in the case of lower pole stones in a solitary kidney, multiple tract access does not seem to lead to a reduction in renal function, when compared to a single-tract access.

Finally, in the presence of this wide armamentarium, surgeon's preferences are to be added to the choice of the best therapy. More prospective, randomized studies with large patient numbers are required, in addition to the development of new surgical devices and minimally invasive endourological techniques to optimize endourological therapy.

Conflict of interest

The authors declare that they have no conflict of interest.

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