DISCUSSION

The ultimate objective of stone therapy is to render the patient stone free. This is particularly crucial in the pediatric population that is by default considered high risk for complications and for recurrence.

The importance of post-treatment stone-free status in children was demonstrated by Afshar et al., who showed that 69% of the children with residual fragments ≤ 5 mm up to 48 months after ESWL had symptomatic episodes or increase in stone size(116). This feature of pediatric stone disease should be factored in the choice of treatment modality.

Indeed, ureteroscopy in children lagged behind its use in adults owing to the initial unavailability of small instruments, coupled by the plethora in ESWL in the 1980s. However, ESWL was not the best choice in renal stone management, despite a cumulative success rate of 60-99%. The results of ESWL are worse in stone burden of ≥2 cm, lower pole or impacted ureteropelvic junction stones and in dense stones composed of calcium oxalate monohydrate or cystine(117) The main drawback of ESWL is, depending on stone burden, that up to 75% of the patients would require multiple sessions(118,119). In children, that would translate into additional general anesthesia sessions and further radiation exposure, which opposes the concept of minimizing interventions and fluoroscopy(120). Recent concern arises on the possible long-term risks of hypertension and diabetes with ESWL(121). The susceptibility of pediatric kidneys in this regard is still unexplored. It remains to say that ESWL is still not Food and Drug Administration approved in children(122).

On the other hand, PCNL has a role in larger stone burden/staghorn calculi, acute obstruction or infection and after failed ESWL. Despite a success rate of 85-98% and "mini-perc" modification, PCNL remains relatively invasive, which is restrictive in infants and younger children as well as when further procedures for recurrent stones are required(123-125).

With the realization of the limitations of ESWL and PCNL and the progressive technology in miniaturization of semi-rigid ureteroscopes, Ritchey et al. Adopted retrograde endoscopy for pediatric distal ureteral stones in 1988, with high success approaching 100%(126). Further refinement of flexible scopes, as fine as 6.7 Fr, with improved optics and durability, has expanded the use of retrograde endoscopic surgery to target more proximal stones as first-line modality. Holmium:YAG laser offered an efficient energy source for now possible single-session treatments and 270º deflecting tips offered access to lower calyceal stones.

As RIRS was getting established in clinical practice, concerns were raised regarding its safety and efficacy as well as its potential complications. In theory, manipulation of the delicate ureteral orifices and ureters in children could lead to ischemic insult as well as dilation and decompensation of the ureterovesical junction, leading to vesicoureteral reflux, ureteral strictures, perforation or avulsion. However, Schuster et al. reviewed 221 ureteroscopies in children and found only two patients developing strictures and eight having low-grade vesicoureteral reflux(127). This low complication rate was not correlated with the size of the scope used, duration of the procedure or the length of follow-up. As in this study, with comparable results, from 21 ureteroscopies, none of them developed strictures and only one patient had low-grade vesicoureteral reflux; despite of endoscopic ureteral dilatation. Other studies demonstrated the safety of RIRS in children[128].

Furthermore, RIRS was shown to have comparable or better efficacy to established modalities. De Dominicis et al. randomly compared ureteroscopy and ESWL in 31 children. After single treatment, 16 of 17 (94%) patients were stone free after ureteroscopy versus 6 of 14 (43%) patients being stone free after ESWL[129].

Given that this was an adult study, cautious extrapolation into children is warranted. Raza et al. retrospectively compared a 15-year experience (1988-2003) with different stone management modalities. They concluded that for renal stones < 20 mm, ESWL was the most effective primary treatment modality. For renal stones ≥ 20 mm or staghorn stones, PCNL was the preferred primary treatment with lower rates of ancillary procedure and re-treatments. Holmium laser ureteroscopy and RIRS had high stone-free rates and low complication rates, but superiority was demonstrated for ureteral stones only[130] Table below.

Table 15: Raza et al.: Comparative outcomes for different treatment modalities[130]

	ESWL	PCNL	RIRS (+ Ho laser)
	122	37	35
No. of renal units	140	43	35
Mean age (years)	7.7	6.4	5.9
No. of treatments	209	46	53
Mean stone size (mm)	17	40	12
Need for ancillary procedures	45%	34%	26%
Complication rate	26%	6%	0%
Overall stone-free rate	84% (for <20 mm) 54% (for >20 mm)	79%	100%

Over the last half decade, less than a dozen case series are published reporting on their experience in utilizing RIRS for the management of renal stones in children (Table 16)[131].

Table 16: Contemporary results of RIRS for pediatric renal calculi(131).

Series	Patients (n)	Ureteral stones	Renal stones	Average size (mm)	Outcome
Tan *et al.*[8]	23	25 stones	2 stones	9	95% success
Minevich *et al.*[9]	58	58 stones	7 patients	Not available	98% success
Thomas *et al.*[10]	29	28 patients	1 patient	6	88% success
Sofer *et al.*[11]	21	12 patients	9	11	100% success
Smaldone *et al.*[12]	100	67	33	8.3	91% success
Cannon *et al.*[13]	21	0	All lower pole	12	76% success
Dave *et al.*[14]	19	0	23 stones	17	Pelvic 75% success Polar 100% success Staghorn 14% success
Kim *et al.*[15]	167	66 stones	101 stones (87 lower pole)	6	100% success (<10 mm) 97% success (>10 mm)
Tanaka *et al.*[16]	50	0	52	8	58% success

Many of those case series(132-135) had small study populations and included the outcome of ureteral calculi, being the major stone location managed, to the overall analysis. Reporting on a heterogeneous stone location skewed and increased the success rates to a misleading higher rate ranging from 88 to 100%. Smaldone et al(136) had one of the largest case series of 100 patients, one-third of who had renal stones. A success rate of 91% is reported, noting that the average size of the stones was only 8 mm. The outcome for renal stones was not reported separately and more than 20 patients underwent ureteroscopy as a staged or a secondary procedure, making it difficult to interpret the outcome of RIRS as a single modality.

Lower success rates were generally noted in studies that exclusively reported on renal stones. The location of stones seems to impact the success rate as well. Cannon et al(137) noted a 76% success rate in a series of 21 patients, all having lower pole stones averaging 1.2 cm in size. Similar success was noted by Dave et al. Who reported a 75% success for pelvic stones. Polar calculi had a 100% success, but results should be cautiously interpreted as only four patients were treated (two upper pole and two lower pole), all requiring multiple sessions (2-3 times). Of note, seven patients had staghorn calculi, with a discouraging success rate of 14%(138). In this series, three out of five patients whom had staghorn calculi rendered stone free (60%) after initial intervention.

The Children′s Hospital of Philadelphia reported the largest case series utilizing flexible pediatric ureteroscopy(139) with RIRS used to manage 101 renal stones (87 lower polar). The overall average stone size was 6 mm. For an arbitrary cut-off of 10 mm, this study shows a success rate of 100% for sub-centimetric calculi, yet an impressive 97% success for calculi larger than 1 cm. However, it is noteworthy that access was not possible in the first surgery for 59% of the patients, raising concerns for additional anesthesia for more than half of their patients. Current study implemented, on the other hand, a single session strategy (no pre-stenting and single session treatment) in patients' majority.

In another recent publication, Tanaka et al(140) reported their 5-year experience in pediatric RIRS, noting a 50% stone-free rate on initial post-operative follow-up and 58% on extended follow-up. Peculiar to this study is its assessment of the influence of pre-operative factors on initial stone-free status and the need for extra procedures. Interestingly, initial stone-free status depended on pre-operative stone size (P = 0.005) but not on stone location. The younger patient age (P = 0.04) and larger pre-operative stone size (P = 0.002) influenced the need for extra procedures that were required in more than half of the stones ≥ 6 mm but in no stone < 6 mm.

In our series, 71% stone-free rate was achieved for patients who were treated solely with RIRS on initial post-operative follow-up, increasing to be 95% on 1 month extended follow-up, after secondary procedure.

Technical aspects associated with RIRS include the need of dilatation and stenting. Intuitively, dilatation of the ureter would be needed when larger rigid ureteroscopes are used. In fact, Bassiri et al[(141)] performed 66 rigid ureteroscopies using 11.5, 9, 8.5 or 8 Fr ureteroscopes on 26, 14, 5 and 21 patients (mean age 9 years, range 2-15 years), respectively; ureteral dilatation was necessary in 23, 0, 0 and 2 cases, respectively. Herndon et al did not require dilatation using Wolf 4.5 Fr or 6.5 Fr tapered semi-rigid ureterescope alongside a guide wire to access the upper tracts for stones[(142)]. Closely to our series, we used subsequent visual endoscopic dilatation, using 4.5 Fr semi-rigid ureteroscope by Wolf followed by 6.5 Fr tapered ureteroscope by Storz on the guide wire in a monorail fashion. Only 5 from 21 patients (24%) were pre-stented, including two patients for relieve of obstruction.

With the advent of flexible ureteroscopes, rendered as fine as 6.5 Fr, coupled with ureteral access sheaths, dilatation of the ureter becomes virtually pointless. Indeed, in the Philadelphia flexible ureteroscopy case series, no ureter was actively dilated[(139)]. The need for post-operative stenting seems inconsistent and controversial in literature. Some investigators prophylactically stented all their patients based on perceived complexity or difficulty of case, with no clear indicators; dangler strings, to obviate the need of further general anesthesia, were again used based on unclear surgeon discretion[(138,139)]. Hendron et al. stented six of 29 children (21%): two had infection associated with either autonomic dysreflexia or stone impaction, two for extravasation or perforation, one for edema and one for subsequent ESWL[(142)]. All of our cases were stented to facilitate and insure the fragmented large stone burden passage.

On the other hand, the safety and efficacy of PCNL for large stone burdens have been well established in adults. Initially, urologists were reluctant to perform PCNL in children because of concerns regarding the use of large instruments in pediatric kidneys, parenchymal damage and the associated effects on renal function, radiation exposure with fluoroscopy, and the risk of major complications including sepsis and bleeding[(143)].

Since the advent of PCNL in 1976, there have been many improvements in the technique and in the instruments used. With smaller-sized instruments, a better irrigation system, and the use of an endocamera, it is possible to perform PCNL in almost all patients with a good clearance rate and faster recovery.

The overall stone-free rate of our pediatric series was 95.5 % after a single PCNL procedure. With subsequent secondary procedure, it increased to 100%. These results are within the previously reported range of 67%-100%[(124,143,144)].

There is no general agreement that using small caliber instruments necessarily brings lower complication rates than adult-size devices. In adult standard technique, the kidney can be accessed through 24F-30F Amplatz sheaths. Some authors have reported that 24F-30F dilation does not cause significant morbidity in children, and it has been shown in animal models that there is no advantage of using a small access on the basis of renal scarring alone(145). Bilen et al(146) compared PCNL procedures using 3 different sizes of instruments in children less than 16 years of age, and showed that complication rates did not differ. However, Zeren et al(147) reported a significant correlation of intraoperative bleeding with operative time, stone burden, and sheath size. In current study all cases were treated using 17 Fr MiniPerc Nephroscope.

Renal access is the most critical factor for blood loss. Therefore, the urologist must be involved since the first puncture. The ideal access is one that enters a posterior calyx at the fornix, minimizing renal parenchyma traversed, and avoiding injury to large vessels. The second most inferior calyx seen on retrograde pyelography is typically posteriorly oriented and is ideal for initial access for most patients(148). In contrary, the most ideal puncture in this series was posterior middle calyx (59%), followed by posterior upper calyx (32%) and only 2 (9%) cases a posterior lower calyx puncture was used. In addition, to avoid extensive angulation and multiple punctures, a flexible nephroscope may be a useful tool(149).

Bleeding was the most prominent complication in our series. Five out of the 22 patients in PCNL (group B) had intraoperative bleeding, but only 2 of them (9%) required blood transfusions. Second most encountered complication was pyrexia (< 39 C/< 2 days) in 3 patients (13.6%), none of them was a serious pyrexia. Similar data from the literature was reported by Desai et al(150), in which they achieve stone free rate of 41 out of 45 renal units, giving an overall clearance rate of 91%. Minor pyrexia (< 100° F/< 2 days) was seen in 10 patients, whereas serious pyrexia was seen in 5. One patient had a prolonged leak from the nephrostomy site, which responded to double-J stenting, and one patient had a pelvic perforation with hyponatremia, which responded to conservative treatment. The average fall in hemoglobin was 1.6 g/dL, but none of the patients required blood transfusion. In current series, the average hemoglobin drop was 1.4 g/dL, with 9% transfusion rate. None of the patients had urinary leak or perforation.

Chest complications are known after supracostal percutaneous access(151-154). The majority of hydrothoraxes are asymptomatic, and intervention is required in only a small percentage of patients(153). In current series seven patients (32%) needed a supracostal puncture for access either a staghorn stone or stone located in upper calyx. Only one patient developed hydrothorax, which was resolved spontaneously with no need for subsequent drainage. In another series Anand A et al reported 13 out of 26 patients required a supracostal puncture. Hydrothorax developed in one patient with supracostal puncture necessitating tube drainage while abdominal collection developed in one patient who underwent a subcostal lower calyx approach. Both patients recovered with no sequels(154).

Certain measures should be taken while performing supracostal punctures. First, the supra 11th rib approach may be better avoided because of the higher incidence of pleural and pulmonary violation. The use of an Amplatz sheath, which should be well positioned, reduces the risk of symptomatic hydrothorax by allowing free exit of irrigant. Additionally, intra-operative chest fluoroscopy at the end of the procedure is beneficial to identify a fluid collection. Injury to the pelvicaliceal system and sepsis are the other major concerns. Desai et al recommended staged operation to reduce these complications(123). Another potential complication of percutaneous nephrolithotomy is hypothermia, especially in this age group(155). The decrease in body temperature is correlated with the duration of the procedure and preoperative preparation.

Adjacent visceral injuries are another potential complication of percutaneous nephrolithotomy(156-159), although it is rare complication, it includes liver, spleen and colon. Most of these cases can be managed conservatively(156,158,159). Early diagnosis is crucial for conservative management and to decrease morbidity for the patient. In current series, we reported one patient with a posterior lower calyx puncture who encountered Ileum injury. To the best of our knowledge, this is the first case report of ileum injury during PCNL in a pediatric patient(160). The rarity of this complication maybe due to the lying of ileum within the peritoneal cavity.

There are two mechanisms that explain this injury. The first is the retrorenal position of the intestinal segment that leads to injury of the bowel before percutaneous access reaches the kidney. Therefore, an inlet and outlet injuries of the bowel are identified. This mechanism was more noticed with colonic injury because retrorenal position of the colon was identified in 15% on multiplaner reformatted CT(161). The second mechanism explains duodenal injury when the renal pelvis is inadvertently perforated during the right PCNL because the duodenum is present antero-medially to the renal pelvis(162). Therefore, an inlet injury of the duodenum will be seen. In our case, the first mechanism was the most probable explanation because there were an inlet and outlet injuries of the ileum, and no perforation of the renal pelvis during PCNL. It is very rare to find the ileum posterior to the kidney. However, the incidence of retrorenal colon occurs more in thin patients, where the perinephric fat is minimal and the space behind the kidney is empty(163). In our case, the ileal segment was in a peritoneal recess behind the lower pole of kidney at time of surgery. Exploration was needed as in cases of intraperitoneal injuries, contamination of the peritoneal cavity with intestinal contents resulting in fever, sepsis or peritonitis.

It is known, as in adult patients, drainage tube is a standard after the procedure. Besides causing immediate tamponade of the tract bleeding, a re-look nephroscopy option is available. This is of importance particularly in children because any residual fragments in children are likely to be a nidus of infection and future stone formation(116). Many authors propose tubeless PCNL with the advantages of shorter hospitalizations, lack of external drainages tubes, and less postoperative pain(164,165). In only 6 patients (27%), it necessitated nephrostomy tube placement at the end of the procedure and 73% were tubeless. We found that there was no statistically significant difference comparing tubeless and tubed PCNL regarding bleeding, urine leakage or urinoma, or significant chest complication. The types of nephrostomy catheters vary. We prefer to keep a 12 Fr or 14 Fr Nelatons catheter as a nephrostomy. In tubeless cases, a double J stent is inserted in solitary kidneys, renal insufficiency, bilateral procedures, suspected ureteropelvic junction obstruction or when deemed necessary by the operating surgeon. The procedure is staged if the patient is having renal insufficiency, urinary tract infection and or bilateral stone disease. An intra-operative decision to stage the procedure is done if there is significant bleeding.

Shah et al.[164] used widespread criteria for indication of tubeless PNL. They excluded only patients that needed more than three percutaneous accesses and presence of significant bleeding that persisted throughout surgery and was not adequately tamponaded by Amplatz sheath. They also left a nephrostomy tube when intraoperatively they verified the presence of a significant residual stone burden necessitating a staged second-look nephroscopy. Otherwise, at the end of the procedure, all patients were left with a double J ureteral catheter. As results, all 45 tubeless PCNL in 40 patients were successful, with no significant complications. Two patients required a blood transfusion after surgery. There was no urine leakage or urinoma, or significant chest complication, despite a high index of supracostal punctures. The stone-free status was 87%. They concluded that the tubeless PNL is safe and effective even in patients with solitary kidney, in those with three renal accesses tracts or supracostal accesses, in those with deranged renal values and in those requiring bilateral simultaneous PCNL.

Desai et al.[165] prospectively compared postoperative outcomes among tubeless, conventional large bore nephrostomy drainage (20 Fr), and small bore nephrostomy drainage (9 Fr) in selected patients following PNL. The tubeless group was associated with the least postoperative pain, urinary leakage, and hospital stay. Small bore nephrostomy drainage was associated with better outcomes than large bore nephrostomy and they concluded that it may be a reasonable option in patients in whom the incidence of stent dysuria is likely to be higher.

Percutaneous nephrolithotomy technique is in constant evolution. Supine position has been proved as an acceptable option. Urologists must be trained to gain their own renal tract access. The miniperc PNL still needs equipments improvements for better results. Tubeless PNL is increasing in popularity and different tract sealants have been studied. Medical prevention is proved to be effective against stone recurrence and should be always used after PCNL. Although the evolution of the technique in the last 20 years, urologists must continue to improve their skills and develop new technologies to offer to the patients more and more a safe and effective option to treat large renal stones.

No doubt, there is an increasing trend in the adoption of RIRS as both a first line and a single modality in the management of renal stones in children. This has been facilitated by both the rapidly evolving technology and the particular drawbacks that are associated with ESWL and PCNL. However, particular clinical scenarios, for example, anatomic anomalies, concomitant renal and ureteral stones, and decreased fragment clearance after ESWL, stone burden in size and multiplicity or dense stones such as ca oxalate monohydrate, or non-brittle as cysteine stones not favorable for ESWL, need to be factored into the decision-making process to which treatment modality/combination is preferable. The initial concerns of increased risks and complications associated with ureteroscopic manipulation of the delicate ureteral orifices and ureters of children do not seem to be substantiated in the literature. There remains, however, a limited and a non-uniform reporting in the literature of the outcome of RIRS in children, making the surgeon's experience of principal importance in counseling and offering treatment to children with renal stones. In addition, access to technology and resources in different parts of the world is inconsistent. Until prospective randomized trials comparing different treatment options are available, the ideal management of pediatric renal stones remains individualized rather than standardized.

SUMMARY

Since the early 1980s when percutaneous nephrolithotomy (PCNL), ureteral lithotripsy, and extracorporeal shock wave lithotripsy (SWL) were introduced, open surgical procedures have virtually been replaced by such procedures in the adult population. These technological advances have been only slowly applied to the pediatric population, primarily because of the technical limitations associated with the smaller patient size and secondly because of the rarity of pediatric urolithiasis.

Urolithiasis in childhood is rare in the developed world, representing 1% to 5% of all urinary tract stones. However, in developing countries, the occurrence of pediatric urolithiasis is 30% of all urinary tract stones. Although exact statistics are not available from developing countries, pediatric urolithiasis is definitely more common than in industrialized countries. The refinement of miniaturized endoscopes and ancillary instruments has led to the application of endoscopy in children in cases in which shock wave lithotripsy would have traditionally been considered the first-line therapy.

In the present study, we prospectively evaluated our experience with the minimally invasive management of pediatric urolithiasis in urology department, Alexandria University. Our patients were divided into two groups who underwent RIRS and PCNL for large (> 2 cm) urinary tract stones.

A total of 17 children (21 renal unit) were treated with Flexible ureteroscopy. The stones were successfully approached and completely disintegrated in a single session in 15 cases (71.4%). Ureteroscopy was performed without ureteral dilation in all cases. Two patients developed mild to moderate pyrexia postoperatively.

Twenty-one children (22 renal units) underwent PCNL for renal stones were included in this study. Stones free rate was 95.5% of cases with complication rate of 41%, including bleeding in 13%, moderate pyrexia in 18%. One patient had postoperative pleural effusion didn't need intervention, and one with ileum injury necessitate open repair.

The mean hospital stay, fluoroscopy, and operation times were significantly longer in the PCNL group.

This study demonstrates that RIRS is an effective alternative to PCNL in pediatric patients with large-size renal stones. Operative time, radiation exposure, hospital stay, and morbidities of PCNL can be significantly reduced with RIRS technique

CONCLUSIONS

Technological advances in ESWL, ureteroscopy and PCNL have had a significant effect on the manage ment of urolithiasis in children, allowing a safe and successful outcome. The comprehensive care of children with urolithiasis should include a full metabolic evaluation. Anatomical anomalies contribute to the complexity of many cases, necessitating a close link between adult and pediatric urologists, nephrologists and radiologists to optimize stone management in children.

PCNL has an excellent success rate in clearing large renal stones. However, its invasiveness cannot be overlooked considering the relatively low, but not negligible major complication rates. Renal parenchymal damage is inevitable in PCNL and its major complications are usually related to the puncture or dilation of a nephrostomy tract. On the other hand, URS is an endoscopic surgery through the natural orifice, thus renal parenchymal damage can be avoided, leading to significantly less complication rate, especially hemoglobin drop and blood transfusion rate.

PCNL is more efficacious procedure than RIRS in the treatment of renal pelvic stones > 2cm in diameter (95.5% vs 71.5% stone free rate) in single procedure strategy. Becoming comparable after secondary procedures (100% vs 95.2%).

Small caliber access sheath can be used safely in most ureters of pediatric population, with minimal long-term complication.

Tubeless PCNL can be used with a favorable outcome in selected pediatric patients even in patients with large stone burden with the potential advantages of decreased postoperative pain, analgesia requirement, and hospital stay.

Both PCNL and RIRS are effective for treatment of large kidney stones. Although accompanied by higher rate of second-stage procedures compared with PCNL, RIRS has the advantages of reduced hospital stay, reduce intraoperative radiation exposure time, reduced blood transfusion requirements and decreased postoperative complications.

The efficacy of RIRS is acceptable even as multiple sessions' procedure and its safety is superior. It can be considered valuable option for treatment of renal pelvic stones over 2 cm in diameter.

Until multiple large-scale randomized trials comparing different treatment options are available, the ideal management of pediatric renal stones remains individualized rather than standardized.