INTRODUCTION

Urolithiasis is a rare condition in pediatric age groups in developed countries. Its incidence and characteristics in children reflect a wide geographic variation, but stones occur in children of all ages without clear gender predominance[1, 2].

Third world nations have a much greater incidence of pediatric stone disease, often attributed to malnutrition and metabolic abnormalities. The incidence of urolithiasis in general is known to be high in the "stone belt" region of Saurashtra and Kutch in Gujarat state of India. Apart from undernourishment, such as ketogenic diets that include a very small amount of carbohydrates, probably the high salinity and warm temperature are the probable contributing factors for the prevalence

Despite this discrepancy between hemispheres, urolithiasis in children is increasing in occurrence globally[3], likely reflecting westernized lifestyle and dietary changes[2].

The algorithm in these patients for diagnosis, treatment and follow-up considerably differs from the adult counterpart. With improving sensitivity of radiologic imaging and changing referral patterns, there is an increasing trend in the diagnosis of urologic stone disease in children[4]. Although pediatric stone disease is still less common than in adults, with a prevalence of 4.7 per 100,000 versus 62 per 100,000 inpatients[5], stones in children pose unique concerns in their management, owing to the distinct pediatric urologic anatomy and stone pathophysiology as well as profound healthcare concerns, owing to the high recurrence rate.

Metabolic abnormalities can also stem from genetic, environmental or dietary factors[6,7]. Children with recurrent urolithiasis are more likely to have detectable metabolic abnormalities than adults. In some cases, there is no underlying cause that can be identified[8-10].

It is established that children with anatomical abnormalities, urinary tract infections, and metabolic disturbances are considered to be at high risk for stone development. In developing nations, recent reports suggest that a metabolic risk factor can be found on urine studies in 84% to 87% of children, most commonly hypercalciuria or hypocitraturia. However, evidence is accumulating that stones in majority of westernized children are calcium based without any evidence of metabolic abnormality on 24 hour urine collection[11].

Pediatric stone disease affects both sexes almost equally, whereas in adults there is a male predominance. Most of the stones are located in the upper urinary tract. Bladder stones are more common in underdeveloped areas of the world and usually are secondary to infection. Since nations have become more industrialized, the site of stone presentation shifted from the lower to upper urinary tract.

Pathogenesis of Stone Formation and Medical Management

Multiple mechanisms play role in the formation of different types of stones in children.

❖ Calcium stones

Most calcium stones are composed of calcium oxalate. Super saturation of calcium (hypercalciuria) and/or oxalate (hyperoxaluria) or decreased concentration of inhibitors as citrate (hypocitraturia) play a major role for calcium oxalate stone formation.

Hypercalciuria

Hypercalciuria is diagnosed by a 24-hour urinary calcium excretion greater than 4 mg/kg/d in a child weighing less than 60 kg. In infants younger than age 3 months, 5 mg/kg/d is considered the upper limit of normal for calcium excretion[12].

Hypercalciuria can be classified as idiopathic or secondary. The term "idiopathic" hypercalciuria is used when clinical, laboratory, and radiographic investigations fail to delineate an underlying cause. Secondary hypercalciuria occurs when a known process produces excessive urinary calcium such as increased bone resorption (hyperparathyroidism, hyperthyroidism, immobilization, acidosis, metastatic disease) or gastrointestinal hyperabsorption (hypervitaminosis D, sarcoidosis, milk-alkali syndrome).

Testing for the calcium-creatinine ratio on spot urine does an excellent screening test for hypercalciuria in children. The normal calcium-to-creatinine ratio in children is less than 0.2. If the calculated ratio is higher than 0.2, repeat testing is indicated. One approach is to recheck the ratio at monthly intervals for 2 months. If follow-up ratios are normal, then no additional testing for hypercalciuria is needed.

On the other hand, if the ratio remains elevated, a timed 24-hour urine collection should be obtained and the calcium excretion calculated. The 24-hour calcium excretion test is the criterion standard for the diagnosis of hypercalciuria. If the calcium excretion is higher than 4 mg/kg/d, the diagnosis of hypercalciuria is confirmed, and further evaluation is warranted[13]. Unless renal stones form and are not spontaneously passed, procedures usually are not necessary in the evaluation of children with hypercalciuria.

Further evaluation includes serum bicarbonate, creatinine, alkaline phosphatase, calcium, magnesium, pH, and parathyroid hormone levels. Freshly voided urine should be measured for bicarbonate and PH. A 24-hour urine collection should also be collected for measurement of calcium, phosphorus, sodium, magnesium, citrate, and oxalate. In the meantime, dietary manipulations should be tested to normalize urine calcium. Urinary calcium may change with restriction of sodium in the diet, especially when it is higher than normal.

Dietary modification is a mandatory part of effective therapy. The goal of therapy is to increase urinary flow and restrict dietary sodium. The child should be referred to a dietitian to accurately assess daily calcium, animal protein, and sodium intake. A trial of a low-calcium diet can be done transiently to determine if exogenous calcium intake is contributing to the high urinary calcium[14]. However, restriction of calcium intake for long

periods should be avoided in children. Hydrochlorothiazide and other thiazide-type diuretics may be used to treat hypercalciuria. The dose is 1 to 2 mg/kg/d. Citrate therapy is also useful if citrate levels are low or if hypercalciuria persists despite other therapies[15].

Hyperoxaluria

Oxalic acid is a metabolite excreted by the kidneys. Only 10% to 15% of oxalate comes from diet. The remainder is derived from hepatic metabolism. Normal school children excrete less than 50 mg/1.73 m2 a day. This is four times more than in infants[16].

Hyperoxaluria may result from increased dietary intake, enteric hyperabsorption (inflammatory bowel syndrome, pancreatitis, and short bowel syndrome) or inborn error of metabolism. In primary hyperoxaluria there is increased deposition of calcium oxalate in the kidney and in urine[17]. Presentation of primary hyperoxaluria is usually quite early in childhood, and urolithiasis is the common mode of presentation. Symptoms due to deposition of calcium oxalate in other tissues like retina, myocardium, and bone marrow usually become manifest in later stages of the disease. The diagnosis is made upon laboratory findings of severe hyperoxaluria and clinical symptoms. The definitive diagnosis requires liver biopsy to assay the enzyme activity.

However, in the majority of children with high levels of urinary oxalate excretion in urine, no metabolic dietary problem is usually identified; these cases are designated idiopathic hyperoxaluria. In these patients, urinary oxalate levels are only mildly elevated. Treatment of hyperoxaluria consists of promotion of high urine flow and restriction of oxalate in diet. Use of pyridoxine may be useful in reducing urine levels, especially in type I primary hyperoxaluria[15].

Hypocitraturia

Citrate is a urinary stone inhibitor. By binding to calcium the formation of calcium oxalate or calcium phosphate crystals is prevented. Therefore, low urine citrate may be a significant cause for calcium stone disease. Normal citrate values for children are not known. Hypocitraturia is excretion of citrate in urine less than 320 mg/d for adults. This value may be adjusted for children depending on body size. Hypocitraturia usually occurs in the absence of any concurrent symptoms or any known metabolic derangements.

It can also occur in association with any metabolic acidosis, distal tubular acidosis, or diarrheal syndromes. Environmental factors that lower urinary citrate include a high-protein intake and excessive salt intake. Many reports emphasize the significance of hypocitraturia in pediatric calcium stone disease. Presence of hypocitraturia changes from 30% to 60% in children with calcium stone disease[18].

Because of the increased stone risk in hypocitraturia, restoration of normal citrate levels is advocated to reduce stone formation. Hypocitraturia is treated by potassium citrate at a starting dose of 1 mEq/kg in two divided doses. Response to treatment is monitored with urinary citrate determinations and dose is adjusted. Although there are studies that show citrate replacement therapy reduces stone formation risk in an adult population, studies in children are few[19].

❖ Uric acid stones

Uric acid stones are responsible for urinary calculi in 4% to 8% of children[20]. Uric acid is the end product of purine metabolism. Daily output of uric acid more than 10 mg/kg/d is considered to be hyperuricosuria. The formation of uric acid stones is dependent mainly on the presence of acidic urinary composition. Uric acid remains in an undissociated and insoluble form at a pH of less than 5.8[15].

Hyperuricosuria is the main cause of uric acid stone formation in children. In the familial or idiopathic form of hyperuricosuria, children usually have normal serum uric acid levels. In other children, it can be caused by uric acid overproduction secondary to inborn errors of metabolism, myeloproliferative disorders, or other causes of cell breakdown[15]. Uric acid stones are non-opaque stones, and plain radiographs are insufficient for uric acid stones.

Alkalinization of urine is the mainstay of prevention for uric acid stones. Potassium citrate preparations are useful as alkalinizing drugs. Maintaining a urine pH of 6 to 6.5 is sufficient for prevention of uric acid stones.

❖ Cystine stones

Cystinuria is the cause of cystine stone formation and accounts for 2% to 6% of all urinary stones in children. It is an incompletely recessive autosomal disorder characterized by failure of renal tubules to reabsorb four basic amino acids: cystine, ornithine, lysine, and arginine. All except cystine have good urine solubility, and only cystine stones may form in case of excessive excretion in urine. Cystine stones are faintly radio-opaque and may be difficult to identity by as a plain film. They are also non-brittle in texture and more difficult to disintegrate by extracorporeal shock-wave lithotripsy (ESWL).

The alkalinization and dilution of urine is extremely important in the treatment of cystinuria. Maintaining high urine flow and use of alkalinizing drugs, such as potassium citrate, to maintain urine pH at above 7.0 is the initial treatment. When this treatment fails, use of D-penicillamine or alpha-mercaptopropionylglycine may reduce cystine saturation in urine and prevent stone formation[15]. Use of these drugs can be associated with severe side effects such as bone marrow depression and nephrotic syndrome.

❖ Infection stones (struvite stones)

Infection-related stones constitute nearly 5% of the urinary stones in children. Those bacteria that are capable of producing urease enzyme (Proteus, Klebsiella, Pseudomonas) are responsible for the formation of such stones. Urease converts urea into ammonia and bicarbonate[21]. This alkalinizes the urine, and bicarbonate is further converted into carbonate[22].

In the alkaline environment triple phosphates form, and eventual outcome is the super saturation of magnesium ammonium phosphate and carbonate apatite that lead to stone formation. In addition to bacterial elimination, stone elimination is essential for treatment because stones will harbor infection inside, and antibiotic treatment will not be

effective. Consideration should be given to investigate any congenital problem that causes stasis and infection. Genitourinary tract anomalies predispose to formation of such stones.

Metabolic evaluation

Because of the high incidence of predisposing factors for urolithiasis in children and high recurrence rates, a complete metabolic evaluation of every child with urinary stones should be done[23]. Metabolic evaluation includes:

- Family and patient history of metabolic problem.
- Analysis of stone composition Complete blood count, electrolytes, blood urea nitrogen, creatinine, calcium, phosphorus, alkaline phosphatase, uric acid, total protein, albumin, parathyroid hormone (if there is hypercalcemia).
- Spot urinalysis and culture, including ratio of calcium, uric acid, oxalate, cystine, citrate, and magnesium to creatinine.
- Urine tests, including a 24-hour urine collection for calcium, phosphorus, magnesium, oxalate, uric acid citrate, cystine, protein, and creatinine clearance.

In (Figure 1) an algorithm is given regarding how to perform a metabolic investigation and plan medical treatment accordingly[24].

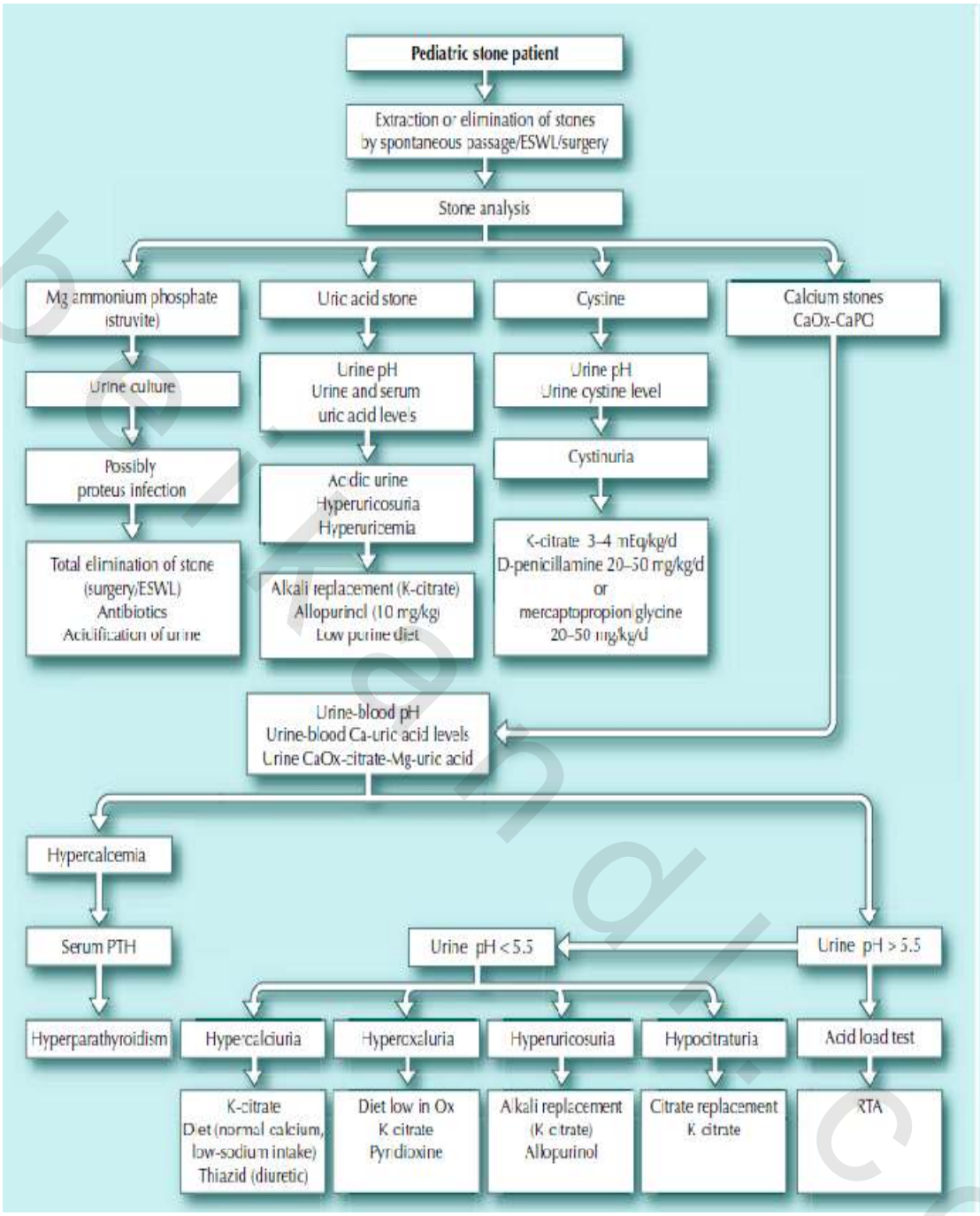

Figure (1): Metabolic investigation and medical treatment plans for children with urinary stones [24].

These patients have historically been treated with open procedures that can result in considerable morbidity and lengthy convalescence. In the modern era, treatment of urolithiasis has been revolutionized with the advent of endoscopic techniques and improved technology[25]. Until the last several years, most of the technology has benefitted the adult population. Initial concerns for extending the procedures to children arose from potential morbidity related to the size of the instruments. Furthermore, because of the rarity of urolithiasis in this population, little data has been available.

Open stone surgery for this age group still reserved from some circumstances. The few who still require open surgery are the patients with anatomical abnormalities, such as PUJO required open correction and complex large stone burden[26]. In fact open surgery is now a last resort when all else fails with minimal invasive surgeries (MIS)[27,28]. However there is a contrast when it comes to developing countries where open surgery still retains its importance in the armamentarium for the management of stone disease[29-31]. Indications for open surgery can be divided into two groups – first technical which are more or less prevalent in every part of the world. These include anatomical abnormalities, complex and large stones, neglected stones with renal failure, and failed MIS[29,32], the second is socioeconomic which are generally specific to developing countries[31].

With the development of smaller instrumentation, pediatric patients have begun to profit from skilled endoscopists. Surgical management of urolithiasis in children has evolved dramatically over the past 3 decades. In the 1980s, the advent of shock wave lithotripsy (SWL) revolutionized pediatric stone management and is currently the procedure of choice in treating most of upper tract calculi in industrialized nations, especially if less than or equal to 15 mm[33].

Although SWL is well tolerated in children with few complications, stone-free rates following single-session monotherapy can remain as low as 44%[34,35]. As a result, children are subjected to multiple treatments requiring general anesthesia. The need for multiple treatment sessions is also concerning, as the effects of shock waves on renal tissue are unclear

In children, there is currently no consensus regarding the maximum size of residual stone fragments that are considered clinically significant, and as a result, there is no clear definition to what constitutes “stone-free” status[33,36].

Stone-free rates are significantly affected by various factors. In the retrospective study of Muslumanoglu et al.[37], which has one of the largest pediatric patient populations, it was reported that regardless of the location, as the stone size increases the stone-free rates decrease and the retreatment rates increase. The stone-free rates for less than 1 cm, 1 to 2 cm, greater than 2 cm, and overall were reported as 87.8%, 75.5%, 56.7%, and 79.9%, respectively[37]. Similar results were reproduced by Raza et al.[38]. Furthermore, Anther and Noor[39] reported that up to 30 mm, stone clearance was not found to be affected by size, and it was overall 95%, which was supporting the findings of Rodriguez Netto et al.[40] who had a 97.6% stone free rate.

In treatment of urinary stone disease, complete removal of stone is essential. Thus, the residual fragments (RF) labeled as “clinically insignificant” may be important in practice. An interesting study by Afshar et al.[41] revealed that children with RFs (≤5 mm) following SWL had a significant increase in adverse clinical outcome (symptoms or RF growth) compared with stone free subjects, and RF growth was found to be significantly associated with the presence of metabolic disorders. One of the important factors affecting the results of ESWL is the presence of metabolic or anatomic abnormalities. Tan et al.[42] reported a decreased stone-free rate in patients who had metabolic or anatomic risk factors (31.7% vs. 69.4%). Therefore, treatment of underlying causative factors and follow-up after SWL is of great importance.

ESWL is not without complications; however, these complications are frequently

self-limiting and transient. The most frequently observed complications are renal colic, transient hydronephrosis, dermal ecchymosis, urinary tract infection, formation of Steinstrasse, and very rarely hemoptysis and sepsis. In children with sterile preoperative urine cultures, antibiotic prophylaxis to decrease the infectious complications is not recommended. However, every effort should be made to sterilize the urine before ESWL, ureteroscopy, or percutaneous nephrolithotomy, as stated by Wu and Docimo[43].

Recently, with miniaturization of equipment and refinement of techniques, access to the entire urinary tract in children is now possible[44].

Endoscopic evaluation of the upper urinary tract was first performed with a pediatric endoscope in 1929 in a male with posterior urethral valves[45]. Since that time, advances in optics, energy sources, and endoscopic equipment have resulted in new and advanced endoscopic operations and applications in the urinary tract.

In addition to miniaturization of the standard rod lens, fiberoptic technology has permitted the development of small flexible endoscopes to better visualize and treat stones in the proximal collecting system. Following the advances in endoscope technology has been a complement of baskets, graspers, small hydrophilic wires, and energy sources to facilitate treatment of urinary stones[46].

Ureteroscopy:

The urologic community has been slow to accept ureteroscopy for the pediatric population. Concerns of trauma of the urethra and ureter have been the root of the hesitation. However, multiple reports of pediatric ureteroscopy have put these concerns to rest.

Although a case report in 1988 pioneered the use of ureteroscopy for pediatric stone disease[47], the first well-documented series of pediatric ureteroscopic procedures was reported in 1990[48,49].

With the development of smaller endoscopic instruments, ureteroscopic management has become increasingly common in pediatric stone patients. At some institutions, ureteroscopy has become the first-line therapy for pediatric patients with upper urinary tract stones, especially those with stones in the distal ureter[50].

Furthermore, with the introduction of flexible scopes from different companies and holmium laser, the reach of entire collecting system is now possible, adding treatment options for kidney and calyceal stones (Figure 2) (Table 1).

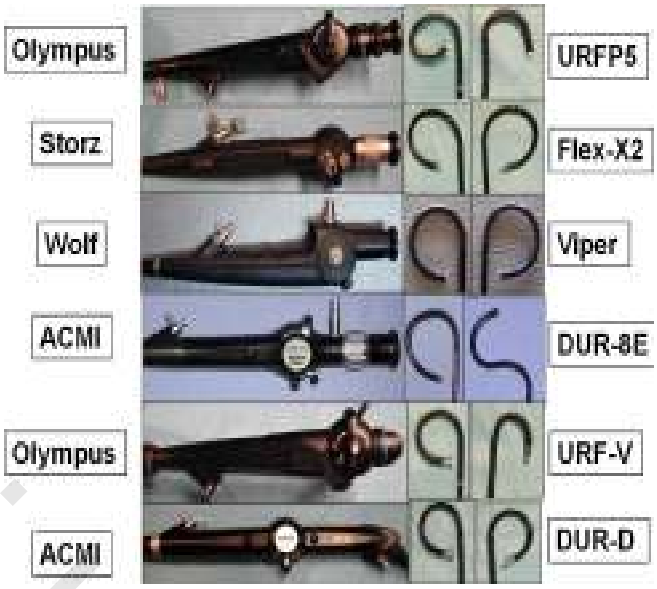

Figure (2): Different models for new generations of flexible ureteroscopes in the market with possible ventral and dorsal deflection[51]

Table 1: Characteristics of new generation flexible ureteroscopes[51]

	Length (cm)	Distal diameter	Proximal diameter	Field of view	Angel of view	Working channel	Deflection Ventral/dorsal
Olympus URFP5	67	5.9	8.9	85	0	3.6	275/180
Olympus URFP6	67	4.9	7.95	90	0	3.6	275/275
Karl Storz FLEX-X2	67	6.5	8.4	88	0	3.6	270/270
Wolf Viper	68	6	8.8	85	0	3.6	270/270
Gyrus-ACMI DUR-8Elite	64	6.75	10.1	80	0	3.6	270/180
Karl Storz FLEX-XC	67	8.5	8.4	88	0	3.6	270/270
Gyrus-ACMI DUR-D	65	8.7	10.9	80	0	3.6	250/250
Olympus URF-V	67	9	10.9	85	0	3.6	275/180

Digital flexible Ureteroscopes are now the leading innovation in flexible armamentarium. With the far better HD vision, integrated design, assumed durability, it becomes number one tool for diagnostic and tumor ablation purposes in the upper collecting system (Figure 3). Especially when adding narrow band imaging (NBI) URF-V by Olympus, for diagnosis and treatment of urothelial tumors and carcinoma in situ.

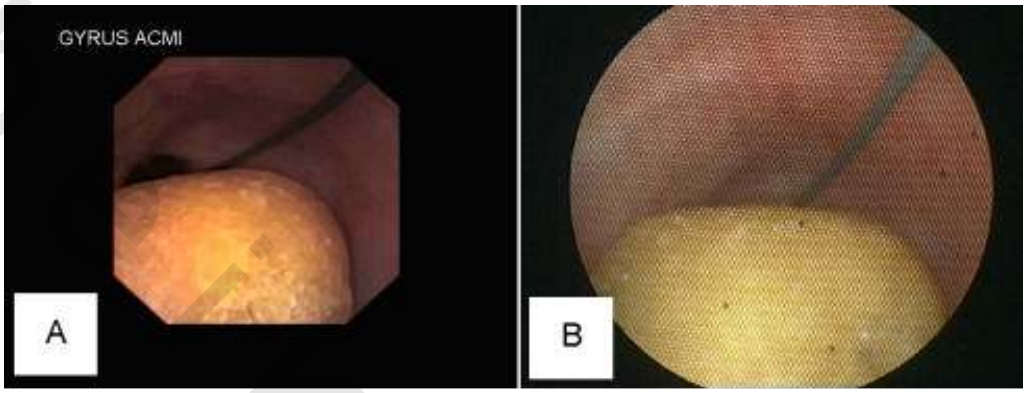

Figure (3): Comparing the image of (A) C-MOS digital system and (B) conventional 7500 fiberoptic[51]

However, regarding the video Ureteroscopes, with great vision come a bigger tip diameter, and much higher cost. Questioning its use in stone treatment in general and in children in particular (Figure 4).

Figure (4): Different tip shapes and diameters of fiber optics and digital ureteroscopy by several companies[51]

Today, there is a plethora of instruments in the market offering different calibers and properties and can be used for a number of purposes in children. Guide wire array: 0.035 in Sensor GW, 0.018 to 0.025 in Glide wire, Ureteral access sheaths (9.5- and 11-Fr internal diameter), Double-J ureteral stent array (3-, 4.8-, and 6-Fr internal diameter), Basket devices: Zero-tip ranging from (1.5, 1.7, 2.2, 2.4, 3.0, 3.2-Fr) (Figure 5).

Figure (5): Different shapes and sizes of Nitinol stone extractor (Photos provided by CooK Urology; ® Cook Urology, all rights reserved.)

The technique used in children is similar to the technique used in adults. Use of guide wires and the availability of direct vision scopes make this the preferred option.

Access sheath is routinely used or whenever the ureter can acquire the 11.5 Fr outer diameter of the sheath. It is used to facilitate flexible ureteroscopy, reducing pressure in the relatively small delicate collecting system, especially in cases of large proximal ureteral stones and heavy renal pelvis stone burdens. Access sheaths may also serve to facilitate flexible ureteroscopy when altered anatomy or torturous ureters are encountered.

Routine balloon dilation of ureterovesical junction and ureteral stenting are still controversial[52]. Instead, a smaller diameter ureteroscopies (4.5Fr tip semirigid ureteroscope (Wolf company) (Figure 6) can be used for passive dilatation of the ureteric orifice and proximal ureter

Figure (6): Pediatric semirigid self-dilating ureteroscopes may be used for rigid ureteroscopy in toddlers. A 4.5-Fr distal beak allows easier passage to facilitate dilation with the 6.5-Fr proximal component. (Photo provided by Richard Wolf; © Richard Wolf, all rights reserved.)

Ureteroscopic lithotripsy can be managed safely in the pediatric population with a laser, electrohydraulic lithotripsy, or pneumatic lithotripsy. Ultrasonic lithotripsy has also been employed[53–57]. However, this technique requires a larger-caliber scope. With the advent of the holmium laser, the use of pulsed-dye lasers and electrohydraulic lithotripsy has become relatively extinct. In fact, according to Scarpa and colleagues, electrohydraulic lithotripsy should be avoided[58]. Both 200-micron and 365-micron holmium laser fibers are easily accommodated by the semirigid and flexible scopes and are safe to use in the pediatric ureter[59]. The laser should be used to vaporize the calculus. However, if small

fragments are created, 2.4F or 3.0F nitinol tipless baskets can safely extract the stones.

Early postoperative complications include hematuria, pyelonephritis, stent migration, and fever, whereas ureteral stricture and vesicoureteral reflux constitutes the delayed postoperative complications. Appropriate sized pediatric instruments allow easy access to the stone and lessen the possibility of ureteral trauma

Vesicoureteral reflux and strictures, which could develop secondary to instrumentation, dilation, or stenting has been reported 0% to 17%[60–62]. In most of these cases, only reflux has resolved with no additional treatments.

Patients should be followed closely following ureteroscopy to evaluate for the redevelopment of stones or complications. Intravenous urograms are very useful to evaluate for stones and strictures. Alternatively, a plain abdominal film and renal ultrasound may be used to limit radiation exposure. Helical computed tomography is an excellent way to evaluate for recurrent or residual stones, but its expense and radiation exposure may limit its use[63]. Routine voiding cystourethrogram is not necessary and should be reserved for those cases where reflux is suspected[63].

Percutaneous nephrolithotomy:

The knowledge of the intrarenal collecting system and the intrarenal vasculature is of paramount importance in making the percutaneous procedure safe and effective. The main renal artery divides into anterior and posterior segmental artery. The anterior branch supplies the anterior surface and the poles. The posterior segmental artery supplies the posterior surface. This artery is commonly injured during any endourologic procedure. The Brodel's line is the avascular plane between these two vascular territories. The needle tract in PCNL should traverse along Brodel's line posterolaterally. Unlike the arteries, the intrarenal veins do not have a segmental structure; there is free circulation throughout the renal venous system. A medial upper polar puncture may result in injury to the posterior segmental artery. Sampaio's pioneering work in delineation of the variations in the calyceal anatomy using the endocasts is useful in determining the exact calyx of puncture depending on the relation of the stone to the calyx[63,64]. Theoretically, if the needle traverses through the cup of the calyx through a shortest distance the chance of vascular injury dramatically decreases.

An important variable in viewing the anatomy prior to PCNL is determining the relation of the rib to the calyx. If the stone-bearing calyx is above the 12th rib it requires probably a supracostal puncture. These stones have increased incidence of thoracic complications. Secondly, the degree of hydronephrosis has a bearing on the difficulty of access. Dilated calyces are technically less challenging to puncture. It is important to decide if the stone-bearing calyx is the anterior or posterior calyx. The preferred one is the posterior calyx because major vascular structures surrounding the renal pelvis are avoided and the transparenchymal route stabilizes the nephrostomy tube. Puncture of anterior calyces may be required for a stone in the calyceal diverticulum but is used only if access from posterior calyces is not possible. Further, access from an anterior calyx to the renal pelvis is technically demanding because it requires directing the wire backward[64].

Percutaneous renal surgery for children has also its concerns as far as renal trauma. The most common concern is that the size of sheath traditionally used in adult surgery can

pose a risk of injury to the smaller pediatric kidney. For instance, Jackman and colleagues noted that a 24F sheath in a small child would be the equivalent to a 72F sheath in an adult[65]. Later on, studies have shown that even with adult-sized instruments, renal function is not significantly altered[66,67].

Initially, adult-size instruments were used in children. These instruments have achieved good results. However, the use of adult-sized instruments in association with the increased number of tracts and sheath size seems to increase the blood loss[68]. With the invention of small-caliber instruments, some advantages (particularly in smaller children), such as smaller skin incision, single step dilation, and sheath placement; good working access for pediatric instruments; variable length; and lower cost have been available[69].

Because the appropriate sized instruments are available, age no longer plays a limiting role for PCNL. Even infants' age 3 months have been reported in the literature[70].

The advancement in technology will additionally decrease renal and body-wall trauma, which will result in less pain, reduced severity or risk of complications, and shorter hospital stays, including the possibility of performing "tubeless" outpatient PCNLs as mentioned by Jackman et al[71].

❖ Supine vs. Prone:

The ideal patient position for optimal renal access is still controversial. PCNL can be done in prone, prone-flexed, supine, supine oblique, and split-leg modified lateral positions[72-76]. The advantages of the prone position are significantly shorter nephrostomy tract length and potentially greater access sites. Simultaneous antegrade and retrograde upper urinary tract access is the advantage of supine and lateral positions.

Percutaneous nephrolithotomy is usually performed with the patient in prone position through a posterior calyx. This technique is well established, with high rate of success and accepted morbidity[77]. Since 1998 when Valdivia-Uria[78] described the lateral access with the patient in supine position, few groups have used this approach for PCNL. The potential advantages of the supine position over the prone position include ease of patient positioning, ability to perform simultaneous PCNL and ureteroscopic procedures, better control of the airways, dependent Amplatz sheath drainage facilitating the evacuation of stone fragments[78].

Despite the potential advantages of the supine position, it is not widespread trough the urologic community, perhaps due to the lack of experience and afraid of colonic injuries.

All of the PCNL cases in this series were treated in prone position fashion. One case in the Ureteroscopy group; endo-vision puncture was used to convert it into PCNL in supine position.

❖ The Modalities of imaging for puncture guidance:

1. Ultrasonography:

Real-time diagnostic ultrasonography (US) has been widely accepted as the imaging guidance for a dilated renal collecting system. The overall success rate is 88-99%. The complication rate is 4-8% and depends on the indications[79-81]. Ultrasound is radiation free, effective, and rapid, and is possible with a portable machine causing minimal complications in experienced hands.

The primary advantages of ultrasonographic guidance are as follows:

- Minimizes radiation exposure for patients and operating personnel
- Imaging of structures between skin and kidney; the depth of access needle and the anatomy around kidney can be evaluated by ultrasound. This technique can prevent adjacent and visceral organ injury
- No need of contrast media, especially for patients with azotemia
- Avoids intrarenal vascular injury (color Doppler ultrasound)
- Overcomes the problem of unsuccessful retrograde ureteral catheterization that is required for contrast media injection in fluoroscopic guidance
- Safe for patients, especially pregnant and pediatric patients
- The procedure can be performed in supine position.

The disadvantages of ultrasonographic guidance are:

- Sonographic identification of the needle needs operator skill but successful puncture of the collecting system can be confirmed by the appearance of urine following removal of the needle obturator.
- Technical difficulty in percutaneous access of non-or mild hydronephrosis; this can be overcome by administration of diuretic which transiently dilates the calyces.
- Inability to clearly visualize and manipulate a guide wire following renal access.

The important anatomical landmarks during sonographic examination are renal capsule, renal cortex (low-level homogenous echoes), renal medulla (sonolucent structure), and hydronephrosis (hypoechoic cavity surrounded by a central echo complex).

Access under ultrasonographic guidance without a needle guide is an alternative technique useful in bedside, grossly hydronephrotic kidney but requires special training[82].

During PCNL, renal access is usually achieved by fluoroscopy under combined fluoroscopic/ultrasound guidance. Hosseini and colleagues[83] performed ultrasound-guided PCNL in 47 patients of renal pelvic stone of size 24-46 mm with mild to moderate hydronephrosis. The success rate was 93.61%. All steps of PCNL including dilatation were performed under ultrasonographic guidance. The advantage of this technique is that it is an alternative method to fluoroscopy-guided PCNL without radiation exposure to the operator and patient. Ultrasound can be used for localization of renal stone, especially non-opaque stone. Basiri et al. presented the technique of totally US-guided PCNL in 30 patients under flank position. This technique provided satisfactory outcomes without any major complications[84].

2. **Fluoroscopy:**

The high-quality of current C-arm fluoroscopic equipment and the familiarity among urologists of fluoroscopic imaging has led to its preferred use in percutaneous renal access, particularly in the operating room. Surgeons prefer fluoroscopy for guidance due to the clear visibility of the needle and guide wire. For percutaneous renal surgeries such as PCNL or endopyelotomy, fluoroscopic monitoring is very important for the entire procedure during renal access, guide wire manipulation, tract dilatation, residual stone evaluation, and post-procedural nephrostogram.

The advantages of fluoroscopic guidance are:

- Its familiarity to most urologists
- Its ability to visualize radiopaque calculi
- Iodinated contrast media can be used to aid in stone localization
- Demonstrates anatomical details.

Radiation safety is one of the major concerns during PCNL under fluoroscopic guidance. The maximum yearly whole-body exposure to radiation recommended by the National Council on Radiation Protection is 5 rem[85]. The radiation dose exposure depends on time, distance, and shielding. The fluoroscopic time should be as minimal as possible. Fluoroscopic screening time (FST) during PCNL is the main factor in radiation exposure. During fluoroscopic guidance in PCNL, the maximum radiation exposure is to the surgeon, especially to the legs and least to the eye, followed by the assistant and nurse[86]. Tepeler et al.[87] reported that large stone and multiple accesses are factors that can affect the FST during PCNL. FST is not affected by body mass index (BMI), stone configuration, degree of hydronephrosis, site of access, and history of open nephrolithotomy. In patients with large stones requiring multiple accesses, experienced surgeons to diminish radiation exposure should perform the procedure.

Radiation dose reduction can be achieved by directing the fluoroscopy beam from under the table. The surgeon should wear a lead apron, thyroid shields, lead-impregnated glasses, and lead gloves.

Young children are more radiosensitive and radiation exposure has been linked to malignancies, including thyroid cancer and leukemia. Radiation exposure should be minimized in this specific group of patients.

The renal collecting system can be opacified with contrast following cystoscopic retrograde ureteral catheter placement or by injection of intravenous contrast material. During this procedure, injecting the collecting system with contrast can cause pyelotubular and pyelovenous backflow. The two methods of percutaneous renal access under fluoroscopic guidance are “triangulation” and “eye of the needle” (Bull's eye) techniques. The choice of the technique depends on the experience of the operator. There was no difference in fluoroscopic time, operative time, hospital stay, complication rate, and success rate between both groups (patients in the “eye of the needle” group had higher complication and more blood loss than patients in the “triangulation” group)[80].

A novel digital technology fluoroscopy system with three-dimensional (3D) reconstruction for renal access has been attempted in a pig model. The advantages of the

system are determination of the volume of kidney and renal calyx anatomy for delineation of the target calyx[88].

The ideal imaging guidance for renal access may be a combination of initial ultrasonography followed by fluoroscopy for control of catheter and guide wire manipulation[89].

The international Clinical Research Office of the Endourological Society (CROES) analyzed the perioperative outcomes of PCNL using different imaging modalities such as ultrasound or fluoroscopic guidance. For renal access, 453 matched samples of both groups were compared with respect to frequency and pattern of Clavien complications and success rate. The stone-free rate was not different between both groups, but longer hospital stay was found in the ultrasound group (5.3 days compared to 3.5 days in the fluoroscopy group, $P > 0.001$). Postoperative blood transfusion was significantly higher in the fluoroscopy group (11.1% compared to 3.8% in the ultrasound group, $P = 0.001$). Larger size of access sheath was used in the fluoroscopy group (average 29.5 F compared to 22.6 F in the ultrasound group), which might be related with the higher incidence of hemorrhage[90].

3. Endoscopic guidance:

Ureteroscopic equipment, including flexible scopes are now widely available permitting retrograde intra-renal surgery (RIRS). Retrograde nephrostomy by Lawson's procedure was reported in 1980. Using the same principle, flexible ureteroscopy-assisted retrograde nephrostomy is a new option for renal access in a non-dilated collecting system[91]. The advantages of this technique are continuous visualization of all steps of PCNL by renal access through Amplatz sheath placement, less radiation exposure, less bleeding, and being a shorter procedure especially in patients with non-dilated collecting systems.

Grasso et al.[92] performed flexible ureteroscopy for assisting renal access in seven patients in minimally dilated collecting systems, obese patients, those in whom prior attempts of percutaneous access had failed and in patients who had calyceal diverticular calculi. The desired calyx can be selected under direct vision. The renal access is achieved under fluoroscopic guidance, but the tip of the needle is visualized and monitored by fluoroscopy and endoscopy. The guide wire can be placed through-and-through, allowing safe PCNL.

Bader et al.[93] described the experience of "all-seeing needle" as an optical puncture system in PCNL procedure for optimal renal access. The micro-optics of 0.9 mm and 0.6 mm diameter with integrated light lead was inserted through the working channel of an access needle of size 4.85 Fr outside diameter, which was connected to an irrigation system for better intraoperative view. The punctured calyces and calculi in all 15 patients could be visualized prior to placement of guide wire and tract dilatation. This technique can improve the safety of renal access.

❖ Standard vs. Tubeless:

After stone fragmentation and extraction, the standard procedure is the placement of a nephrostomy tube. Many groups propose the elimination of the nephrostomy with the advantages of shorter hospitalizations, lack of external drainages tubes, and less postoperative pain. A lack of standardization with regard to kidney drainage and precise indication for the tubeless PCNL are an obstacle to widespread utilization of this technique, and its real benefits are not clear.

Tefekli et al.[94] prospectively compared the outcomes of standard and tubeless PCNL in 38 patients with renal stones. They excluded cases that intraoperative complications occurred, operation times exceeding 2 h, cases with more than one puncture, and cases with significant residual stone burden necessitating a second-look PCNL. The tubeless group was associated with shorter hospital stay (1.6 vs. 2.6 days) and less postoperative analgesia than the nephrostomy group. Mean decrease in serum hemoglobin level, duration of hematuria, and successful stone clearance was similar in both groups. None of the patients showed evidence of perinephric collection and there was no readmission to the hospital due to postoperative problems. They concluded that tubeless PNL is safe for selected patients with simple renal stones of mild-moderate burden and that mean hospitalization time and analgesia requirement is diminished with this modification.

Different substances have been used to seal nephrostomy tracts to reduce bleeding and extravasation after tubeless PNL, such as fibrin glue, gelatin matrix and oxidized cellulose (Surgicel®), but the real role of these agents in tubeless PNL are still to be defined.

In general, as a monotherapy modality, PCNL is considerably effective and safe. The reported stone-free rates in the recent literature are from 86.9% to 98.5% after a single session, and these rates increase with adjunctive measures such as second-look PCNL, ESWL, and ureterorenoscopy[68-71,95]. Even in complete staghorn cases, an 89% clearance following a single session has been achieved by Aron et al[70].

Moreover, in a recent study by Salah et al.[96], they reported that simultaneous bilateral PCNL could be performed with the same efficacy and safety as in adults. However, they emphasized that they collected a huge amount of experience before attempting such an operation in children.

The European association of Urology (EAU) Guidelines 2013-2014 stated that in adult population, stones over 2 cm should be treated with PCNL (Figure 7). In general, PCNL is currently the first-line recommended treatment for patients with renal stones larger than 2 cm[97-98].

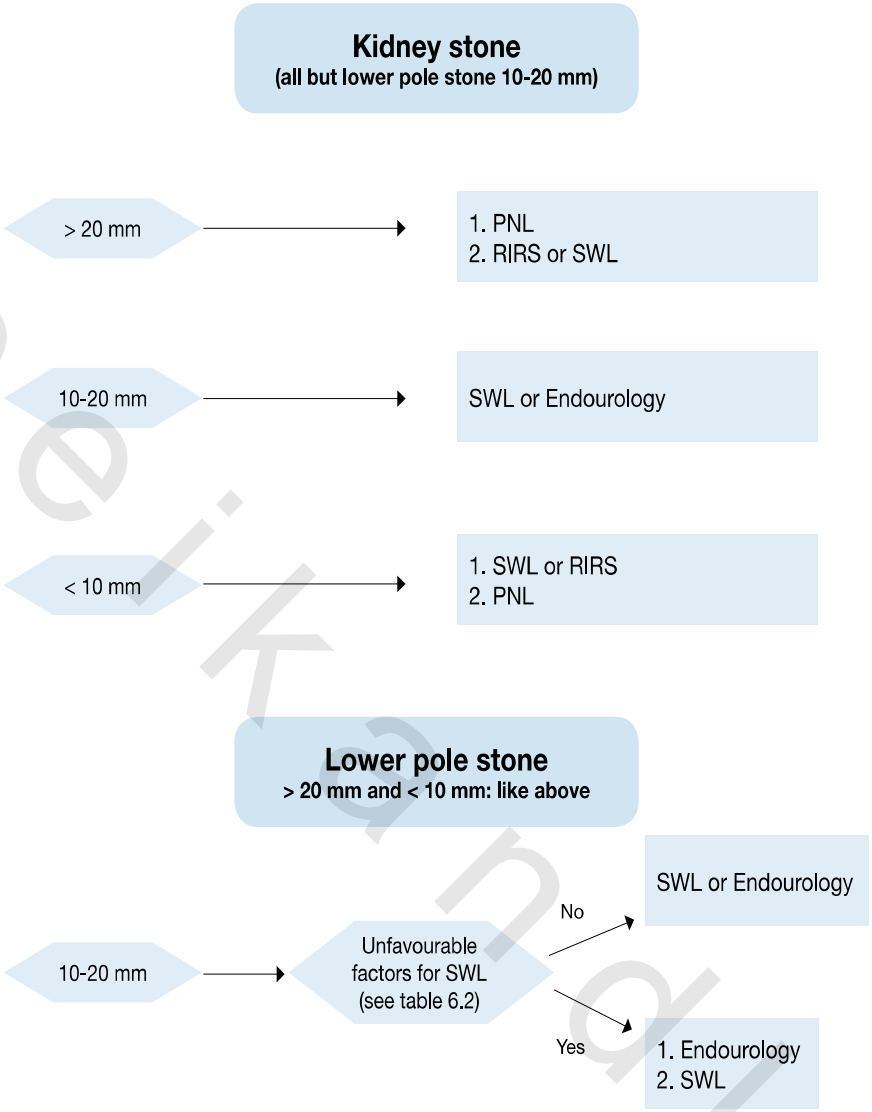

Figure (7): EAU 2013-2014 Guidelines for Kidney stones [98]

RIRS, which can be considered as a new approach for renal stones, has greatly improved as a result of advances in the technology of flexible ureteroscopes[99-101]. However, because it is a new approach in children, it is not recommended under the EAU guidelines as a first-line treatment procedure for any of the pediatric kidney stones yet. It is mentioned as a secondary treatment option to ESWL in children with stones <1cm[102].

For the treatment of kidney stones >2 cm, it is recommended that PCNL be used as first-line treatment as it returns high success rates. According to EAU guidelines, PCNL is the primary treatment option in children with kidney stones >2 cm or with staghorn calculus, and EAU guidelines also recommend PCNL for lower pole calyx stones >1 cm in children[102]. Furthermore, obstructed kidneys, hard stones such as cystine and calcium oxalate monohydrate, and ESWL-failed kidney stones are other indications for PCNL[102-105]. For proximal ureteral stones, there is no evidence about the impact of PCNL in children. So for proximal ureteral stones in children, while ESWL is the primary treatment option, PCNL is recommended as a secondary treatment option such as ureteroscopy and open surgery[102].

Compared with other procedures, including extracorporeal SWL and URS, the higher efficacy of PCNL has overshadowed its more invasive nature. After recent advances in endoscopic technology, flexible URS has become a more efficient and safer treatment of stones throughout all renal calyces. Several recent reports have shown excellent success rates with URS for large renal stones[106-108].

In 1998, Grasso et al. reported that 45 adults patients with renal stones larger than 2 cm underwent URS with 76% stone-free rates in a single procedure. Second stage procedures were carried out in 15 patients and the success rate increased 91% without intraoperative complications [106]. This remarkable result was followed by some reports[107-110]. Other studies showed that Flexible ureteroscopy is a safe and favorable option for renal stones sized 2 to 4 cm[106,111,112].

In pediatric and preschool age groups several studies showed that flexible ureteroscopy is a safe and effective option for treating kidney stones[112,113]. None of them was conducted of kidney stones over 2 cm. The risk of recurrence in this particular age group forces urologists to look for a less invasive technique to treat stones in this group of patients. URS seems to be attractive to play larger role in the management of pediatric kidney stone disease.