Current status of minimally invasive management of pediatric upper urinary tract calculi

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ABSTRACT

The surgical management of pediatric upper urinary tract calculi has evolved from open surgery to minimally invasive techniques. With advancement in instrumentation, endourological procedures are being performed more commonly in children. However, the endourological management of renal and ureteral stones in the pediatric population is considered challenging, owing to the smaller size of the urinary tract. Various minimally invasive techniques that are being applied in the management of pediatric urolithiasis, include shock wave lithotripsy (SWL), percutaneous nephrolithotomy (PCNL), ureterorenoscopy and a combination of these procedures. The role of SWL is well established and is considered the first line of treatment in the management of urinary calculi in pediatric patients. Recent reports have confirmed the safety of PCNL and ureteroscopy in children, although they are not as widely practiced in children as in adults. This article reviews literature published till October 2005, pertaining to the minimally invasive management of pediatric upper urinary tract calculi.

KEY WORDS: Minimally invasive, pediatric urolithiasis, PCNL, SWL, ureteroscopy

Pediatric urinary tract calculi, although relatively uncommon in comparison to adult stone disease, pose a significant challenge in view of the smaller size of the urinary tract and a greater risk of stone recurrence, due to higher incidence of metabolic causes and longer risk period, especially in the presence of residual calculi.

The reported incidence of stone disease in children is estimated at 0.13 to 0.94 cases per 1000 hospital admissions in the western world,[1] occurring twice as commonly in boys than girls.[2] Pediatric nephrolithiasis can be broadly categorized into: those secondary to an underlying urological cause and those without such a cause. Nearly 3.6-40% cases are reported to have a congenital abnormality, predominantly ureteropelvic junction obstruction, in the cases secondary to urological causes.[3] Other diseases include meningomyelocele and neurogenic bladder, especially after bladder augmentation with bowel. In such cases, a high incidence of urinary tract infection (~75%) is noted. Infected urolithiasis also occurs more commonly in children younger than 4 years.[4] Although a metabolic etiology is defined in roughly half those evaluated,[2,5-6] in the absence of anatomic disorders or urologic intervention, a metabolic abnormality can be identified in about 90% cases, if searched for diligently.[7] Metabolic causes are more commonly identified in older children and adolescents, hypercalciuria being the most common. Thus, a thorough metabolic evaluation with specific medical therapy, correction of anatomic abnormalities and primary complete stone clearance should be the aim of treatment.

Prior to the miniaturization of instruments and endoscopic equipment, pediatric urolithiasis was routinely treated by open techniques, even though adult stone disease was effectively managed by endourology. However, the advent of smaller caliber rigid and deflectable endoscopes, improvement in percutaneous techniques and availability of effective shock wave lithotriptors providing a high safety profile and minimal morbidity, have almost entirely replaced the need for open surgery for stone disease in children. The universal principles of surgical treatment of stone disease entail: preservation of renal function, maximal stone clearance and minimal patient morbidity. With the current array of minimally invasive techniques [Table 1] available at the disposal of the urologist, the challenge lies in selecting the most appropriate treatment modality and using it judiciously.
keeping in mind the small size of the urinary tract in children. Generally, the location of the stone and the stone burden; whether renal or ureteral, determine the possible treatment options. The various factors influencing the management of renal calculi [Table 2], are similar to those identified for the management of adults.

**PEDIATRIC SHOCK WAVE LITHOTRIPSY (SWL)**

Since the introduction of SWL into clinical practice by Chaussy et al. in 1980, its safety and efficacy has been well established in both adults and children.[5] Newman et al. (1986) reported the first successful use of SWL in children.[9] SWL has the advantage of shorter hospital stay, rapid recovery and minimal morbidity. Acceptable success rates and high safety profile has made SWL the preferred first line of treatment for children with renal calculi.

Current controversies regarding SWL in the pediatric population address two prime issues. Are there long-term bioeffects of SWL on the developing kidney? Is larger stone burden amenable to SWL in children? SWL is well known to induce acute structural changes in the kidney and is associated with temporary immediate decrease in effective renal plasma flow.[10] The theoretical long-term safety and bioeffects of SWL on renal function and growth, however, continue to raise significant concern regarding the use of this modality for treating stone disease in children. Although long-term detrimental effects of SWL on renal function and permanent histological changes have been noted in young rats,[11] long term follow up with renal scintigraphy of children treated with SWL could not demonstrate any parenchymal damage.[12] Brinkman et al. noted no evidence of renal scarring, change in blood pressure, or renal function loss following SWL in 63 children, over a follow-up of 45 months.[13] Similarly, no adverse parenchymal effects, functional compromise, or neo-onset hypertension, was reported in infants undergoing SWL for urolithiasis.[14] Vlajkovic et al. evaluated GFR of 84 children undergoing SWL using 99 m Te-DTPA and noted a decrease in GFR immediately after SWL, which returned to pre-SWL levels at 3-months.[15] Concerns over radiation exposure secondary to SWL have been raised. Kroovand et al. estimated that radiation exposure during SWL treatment was typical of other diagnostic abdominal radiographic procedures, such as VCUG.[16]

Several authors believe that the pediatric ureter is more efficient than the adult ureter in its ability to pass stone fragments, owing to its greater compliance and distensibility.[17-19] Ofrit et al. determined that young children achieved a higher stone-free rate in comparison to adults for matching stone sizes; however, they agreed that stones greater than 20 mm often required more than 1 session.[19] Notably, their stone free rate at 3 months dropped from 90% for <15 mm stones, to 77.8% for > 20 mm. In contrast, Ather and Noor reported an overall stone-free rate of 95%, with a 90% clearance for stone size >20 mm.[20] In their opinion, the indication for pediatric SWL could be extended to stone burden up to 30 mm, irrespective of stone location. The better stone-free rates reported in younger children have been linked to the better fragility characteristics of the more recently formed stones in younger children, decreased loss of shock wave impact due to lower body resistance and a more rapid evacuation of the fragments by the ureter.[3,9] Because of this observation, there is also a growing opinion that routine stenting prior to SWL in pediatric patients, may not be required. Stenting is indicated in patients with solitary kidney and in patients with significant stone bulk (>30 mm).

In contrast, other investigators have reported poorer stone free rates with increasing stone burden. In a large series of 344 children treated over 12 years, a significant drop in stone free rate (SFR) was noted, with stone size greater than 2 cm. In addition, a higher retreatment rate was required, which reduced the overall efficiency quotient (EQ) of the procedure. [21] In our experience with SWL

<table>
<thead>
<tr>
<th>Renal stones</th>
<th>Ureteral stones</th>
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<tr>
<td>Shock wave lithotripsy (SWL)</td>
<td>SWL</td>
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<tr>
<td>Percutaneous nephrolithotripsy (PCNL)</td>
<td>Ureteroscopic procedures (URS)</td>
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<td>Retrograde intrarenal surgery (RIRS)</td>
<td>- Retrograde</td>
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<td>Laparoscopic Surgery</td>
<td>- Antegrade</td>
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<td>Open Surgery</td>
<td>Laparoscopic</td>
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<td>ureterolithotomy</td>
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**Table 1: Surgical modalities available for treating urolithiasis**

**Table 2: Factors affecting management of renal calculi**

<table>
<thead>
<tr>
<th>Stone factors</th>
<th>Renal anatomic factors</th>
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<tbody>
<tr>
<td>Size</td>
<td>Calyceal configuration and spatial configuration</td>
</tr>
<tr>
<td>Number</td>
<td>Presence of obstruction</td>
</tr>
<tr>
<td>Composition</td>
<td>Anatomic abnormality</td>
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<tr>
<td>Site</td>
<td>Patient characteristics</td>
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<tr>
<td>Associated infection</td>
<td>Associated co morbidity</td>
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<tr>
<td>Body habitus</td>
<td></td>
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<tr>
<td>Coagulation defects</td>
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</tr>
<tr>
<td>Renal function</td>
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treatment of 106 children in the last 15 years, we noted an overall SFR of 87%, however, there was a significant drop in the clearance rate from 94% for stones <1 cm to 70% for stones >2 cm.\cite{22} Authors treating large stone burdens have a reported steinstrasse rate of 1.9-5.4%,\cite{20,21} while those treating smaller stones do not encounter such complications.\cite{24} Similarly, the need for ancillary procedures is directly proportional to the size of stone treated. In our experience, 28% of children required auxiliary procedures (stenting-25, Ureteroscopy-3, percutaneous nephrostomy-2). Although the impact of the lower pole calyceal anatomy on stone clearance rates after SWL is as yet not clearly defined in the pediatric population,\cite{25} stone burden of the lower pole stone appears to be the dominant factor determining its clearance rate. Stones greater than 200 mm², though amenable to therapy with SWL, are associated with greater retreatment rates, need for ancillary procedures and complications; and therefore these may be better treated with other minimally invasive modalities such as PCNL, to achieve a single session stone-free state.

Thus, from a review of the current literature on SWL in children, the procedure appears to be a safe, noninvasive and effective modality for management of smaller upper urinary tract calculi, rendering children stone free with negligible long term consequences.

**PEDIATRIC PERCUTANEOUS NEPHROLITHOTOMY (PCNL)**

Pediatric stones tend to recur more frequently than in adults and repeated open surgery to deal with this problem is not a feasible option. Although SWL is considered the treatment of choice for symptomatic upper urinary tract calculi in children; this may not be a preferable option in patients with large stone burden, owing to a high incidence of failure and the risk of leaving behind significant stone fragments in the pelviccalyceal system (PCS). Moreover, anatrophic nephrolithotomy for complex branched calculi has been shown to cause up to 6-16% deterioration in renal function after surgery.\cite{26} Therefore, PCNL can be advocated as a suitable treatment option for children with significant stone burden, to avoid numerous SWL sessions under anesthesia and the risks associated with repeated open surgery.\cite{27,28}

PCNL however, is still not widely practiced in children, especially for staghorn calculi, due to limited experience with upper tract endourology in children. The smaller size of the pediatric kidney, more compact collecting system in children and the relatively large size of currently available endourological instruments, impose problems in performing PCNL in children. In addition, there are concerns regarding the risk of hypothermia and blood loss, especially in children <5 years, where the margin for error is small. Animal studies\cite{29} and various clinical series have shown that PCNL has no adverse effect on renal structure and function.\cite{27-30} Mor et al. performed radioisotope scans on 10 children before and after PCNL and showed no change in differential function and no evidence of significant scarring.\cite{28} Dawaba et al. showed a significant increase in the GFR following PCNL, in 65 pediatric patients with no renal scarring after long term follow-up.\cite{30}

Woodside et al. reported the first pediatric PCNL in 1985,\cite{31} in 7 patients with a mean age of 14 years. Adult instruments were used and no significant complications were observed. Most reports on pediatric PCNL describe children up to 16 years of age. However, PCNL in preschool children is far more challenging than in older children, in whom the operation becomes quite similar to that in the adult and the constraints mentioned above become less limiting.

Underdilating rather than overdilating and avoiding torquing are important considerations in preventing blood loss during PCNL in children. Krovand et al. proposed a two-session approach to minimize bleeding; initially establishing percutaneous tract and a second session for calculus manipulation.\cite{32} Jackman et al. used an 11F access sheath and stressed the value of avoiding tract dilatation to adult size of 24F to 28F, particularly in preschool children.\cite{33} They opined that a smaller tract leads to less nephron injury. Desai et al. noted significant drop in hemoglobin in patients, in whom tract dilatation was increased to 24F and beyond, compared to dilatation to no more than 22F.\cite{34} In our experience, we have used essentially the same instruments as in adults, except that we brought the sheath size down to 24F and accordingly used the adult nephroscope without the outer sheath, bringing its diameter down to 19F. This allows rapid debulking of the stone and helps in pulling out larger fragments, thereby minimizing operating time. In 19 pre-school children with complete staghorn calculi, the authors achieved complete clearance with PCNL monotherapy in 89%, which increased to 94.7% with adjunctive SWL. The majority of children (68%; N = 13) required two tracts, while five children (26%) required only one tract and one child required three.\cite{35} We believe that special pediatric instruments and sheaths that are far more delicate and do not provide as much stone yield as rapidly, are not necessary in all pediatric cases. However, they would certainly assume importance for smaller.
stones in undilated systems. Hyperthermia is another potential complication of PCNL in children. Al-Shammari et al. noted a correlation between the duration of the procedure and hyperthermia. They observed no hyperthermia in patients with operating time less than 150 minutes. Warming irrigant fluids to body temperature, avoiding prolonged operating times and covering the extremities with warming blankets, should decrease the incidence of hyperthermia.

In most studies, PCNL is used as a part of combination therapy for managing complex calculi. However, liberal use of multiple tracts can achieve complete clearance with PCNL monotherapy without the need for adjuvant SWL. Using multiple tracts when necessary, prevents excessive torque to gain entry into adjacent calyces, which may cause infundibular tear and bleeding. Desai et al. reported the use of multiple tracts in 60% of the patients in their series. They observed a significant increase in blood loss in patients with multiple tracts, even though the complications in these patients are no different than those in whom single tracts were used.

Existing experience with PCNL in children is encouraging. The long-term effect on renal structure and function appear to be minimal. Since pediatric calculi are prone to recurrence that necessitates additional procedures, PCNL provides a less invasive technique than open surgery in the treatment of these stones and also makes additional procedures safer.

**PEDIATRIC URETEROSCOPIC LITHOTRIPSY**

The earliest documented report of a ureteroscopic procedure in a pediatric patient was by Young and McKay (1929), who used a pediatric cystoscope to perform ureteroscopy of dilated ureters in a 2-week old infant with posterior urethral valves. However, the technique gained wide acceptance after Ritchey and Shepherd published their experience of pediatric ureterolithotripsy in 1988. Pediatric ureteroscopy demands the use of smaller caliber endoscopes and flexible lithotripsy probes, that can be passed down small working channels. The development of flexible and semirigid ureteroscopes and improved designs of scopes with smaller outer sheath, large working channels and improved optics, have increased the ability of pediatric urologists to perform ureteroscopy even in the smallest patient.

Concerns have been raised over the risk of damaging the ureterovesical junction during ureteroscopy, as a consequence of dilating the ureteric orifice and intramural ureter. Such dilatation can result in postoperative vesico-ureteric reflux (VUR) or lower ureteral stricture. Caione et al. reported no postureteroscopy VUR in 7 children after rigid ureteroscopy. Shepherd et al. have shown that dilating the ureter up to 12F, did not result in VUR postoperatively. Voiding cystograms done on pediatric patients after ureteroscopic procedures, have shown the incidence of low grade VUR to be as high as 15%. Raza et al. suggested that dilatation of the vesicoureteral junction is usually not necessary with ureteroscopes <8F. Dilatation allows safer passage of larger ureteroscopes with less potential for ureteral perforation and improved visualization and also allows removal of larger stone fragments. Jayanthi et al. suggested that postoperative screening for reflux is not required for all patients and should be reserved for symptomatic patients only. In almost all patients, the VUR resolves spontaneously with conservative management and rarely is symptomatic.

Calculus extraction may be performed using a basket or forceps, electrohydraulic (EHL), ultrasonic, or laser lithotrips. EHL is associated with a higher risk of injury to the urothelium. The size of ultrasonic lithotripters limits its use in children. Holmium-Yttrium Aluminium Garnet (Ho-YAG) laser fibres are small and flexible with a short depth of penetration (0.4 mm), allowing it to be used safely with pediatric endoscopes. Further, laser fragmentation produces 2-3 mm fragments that can pass very easily down the ureter, making Ho-YAG laser the lithotripter of choice for most pediatric urologists. Most series have employed ureteral stent placement, following ureteroscopic lithotripsy in pediatric patients. However Kurzrock et al. used stents in only 29% patients for the following indications: hydronephrosis, edema of ureteric orifice and large stone burden. Rationale for stent placement, is to decrease postoperative stricture formation and pain, but however, the stent itself can sometimes be the cause of pain and requires another anesthesia for its removal. Having a stent with a suture exiting urethral meatus, obviates the need for anesthesia for stent removal. Overall, it is reasonable to stent the ureter if the procedure is prolonged (>90 min), ureteral trauma occurs, the stone is impacted, the stone burden is large, or if the ureteric orifice is balloon dilated.

The most dreaded complication of ureteroscopy in pediatric patients is ureteral perforation. Reported incidence of ureteral perforation in published studies is 1.4%, similar to that seen in adult patients. The most common complication following pediatric ureteroscopic lithotripsy, is postoperative urosepsis and pain. A review of series of pediatric ureteroscopic lithotripsy, reveals a
stone free rate of 77-100% after one procedure, comparable with the published stone free rates with SWL. [43,46,48-49] Stone location was predominantly in the distal ureter, in most of these series. Raza et al. reported their experience with ureteroscopy in the treatment of pediatric urinary tract calculi in 35 patients aged 11-months to 15-years (mean 5.9 years). [44] They used a 6.8 F semirigid ureteroscope and fragmentation was done using pulsed-dye laser, EHL, Ho-YAG laser and basket extraction. Ho-YAG laser was the only modality that achieved 100% stone free rate without any complications. Stenting or ureteral dilatation was not performed routinely. Tan et al. reported 95% stone free rate with ureteroscopy, in 23-patients aged less than 14 years. [50] They used a 6.9 F semirigid ureteroscope and Ho-YAG laser was used predominantly for stone fragmentation and observed no intraoperative complications. Ureteral stent was placed in 95% of patients after the procedure.

To conclude, ureteroscopy is a safe and effective means of treating the majority of pediatric ureteral calculi. Dilatation of the vesicoureteral junction is usually not necessary with small caliber ureteroscopes (<8F) and ureteral stenting can be avoided after uncomplicated ureteroscopy. The holmium laser is the most effective and safest method of stone fragmentation. With increasing experience, ureteroscopy rivals SWL as a first line therapy for the management of upper urinary tract calculi, in the pediatric population.

**LAPAROSCOPIC STONE MANAGEMENT**

Role of laparoscopic surgery in management of renal calculi, is still in a state of evolution. Currently, laparoscopy does not provide an edge over PCNL. Laparoscopic pyelolithotomy takes a longer time to perform, requires considerable skill and has a steeper learning curve, although it has similar hospital stay and similar or slightly inferior stone-free rates. [51-55]

However, laparoscopy-assisted PCNL has been utilized in cases of renal calculi in ectopic kidneys, which allows a safe transperitoneal access to the kidney, by reflecting the overlying bowel. [54] The adaptation of laparoscopy to perform procedures such as concomitant pyeloplasty and stone retrieval or nephrectomy, is well established and has replaced open surgery, for such procedures. Casale et al demonstrated the feasibility of pediatric transperitoneal laparoscopic pyelolithotomy in cases of failed percutaneous access, in which open pyelolithotomy was being contemplated. [55]

**REFERENCES**

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