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REVIEW

Status quo of percutaneous nephrolithotomy in children

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Abstract Paediatric nephrolithiasis is quite challenging in terms of management because of the smaller size of the urinary tract and the bigger risk for stone recurrence. Children bear a higher risk of metabolic and infectious causes of stone disease and a longer lifetime risk for recurrence, especially in cases of residual fragments. Complete stone clearance should become the absolute objective and clinically insignificant residual fragments should be avoided. Nowadays, percutaneous nephrolithotomy (PCNL) arises as a logical first-line treatment option for considerable paediatric nephrolithiasis as miniaturization of endoscopes and advances in energy sources for stone fragmentation have facilitated stone-free rates. In this review we present the evolution of PCNL in children and we demonstrate its safety and efficacy. As appropriate instruments are available and relevant surgical experience is accumulating, age should no longer exist as a limiting factor for performing PCNL.

Keywords Children · Lithiasis · Percutaneous nephrolithotomy

Introduction

Paediatric urolithiasis, although relatively uncommon in comparison to adult stone disease (two per million compared with two per thousand in adults) is challenging in terms of management because of the smaller size of the urinary tract and the bigger risk for recurrence [1, 2]. In particular, paediatric renal stone disease has been a management dilemma in view of the concern about the effects of the treatment modalities on the growing kidney, the long-term outcome and the significant recurrence rate [3]. Children bear a higher risk of metabolic and infectious causes of stone disease and a longer lifetime risk for recurrence, especially in cases of residual stones [2]. Previously, multiple open procedures were performed in order to treat recurrent renal stones with an obvious negative impact in renal function. Therefore, modern treatment modalities should aim to be as minimally invasive as possible and achieve a stone-free status.

In 1986, Newman et al. [4] reported the first successful use of extracorporeal shock wave lithotripsy (SWL) in 15 children. Since then, the safety and efficacy of SWL has been well established and SWL is considered as the first-choice treatment [2]. However, this may not be a preferable option in children with large stone burden, because of a high risk of failure and residual fragments. Furthermore, children with anatomical abnormalities (e.g. renal, spinal) are not the best candidates for SWL. In such cases, similar to adult patients, percutaneous nephrolithotomy (PCNL) emerges as a logical first-line treatment option. Therefore, PCNL in children is the topic of several recent reviews [5, 6], such as the present review, which updates the relevant status quo.

The dawn of PCNL in children

Although PCNL was introduced in the same period as SWL, there was a slower acceptance. Primarily, this was because of technical limitations associated with a lack of

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paediatric instruments. The small size of the kidney and the more compact collecting system necessitates the use of smaller instruments, especially in preschool children. Furthermore, the low incidence of large renal stones in children limited the opportunities to acquire experience with PCNL in such patients.

In 1985, Woodside et al. [7] reported the first series of percutaneous stone removal in children. The authors used adult instruments to successfully treat seven children. No significant complications were recorded and none of the patients required a second procedure or were discharged from the hospital with a nephrostomy tube. However, the mean age of the patients was 14 years; thus the operation was quite similar to that in adults.

The evolution of PCNL in children

Instrumentation

The introduction of miniaturized endourological instruments has reinforced the interest for PCNL in children as well as the availability of efficient energy sources for intracorporeal lithotripsy. A smaller calibre percutaneous tract and nephroscope is considered to be less injurious to the kidney. Underdilating and avoiding torturing are important considerations in preventing bleeding and renal trauma during PCNL in children [8]. Desai et al. [3] reported significant blood loss in patients with tract dilatation more than 24F in comparison with dilatation up to 22F. The potential advantages of "mini" PCNL include smaller tract and intrarenal incision, single step dilatation and sheath placement, good working access as well as lower cost. In a recent review, Lahme [9] stressed that PCNL in children should be performed as "mini" PCNL.

Jackman et al. [10] stressed the value of avoiding tract dilation to adult size of 24F to 28F, especially in preschool children. The authors used an 11F working sheath in a group of 11 patients (aged 2–6 years) with a mean stone burden of 1.2 cm^2, resulting in stone-free rate of 82%.

Boormans et al. [11] performed PCNL in 23 children (mean age 7.5 years) with a mean stone burden of 6 cm^2. They used an 18F Amplatz sheath and a paediatric 16F nephroscope, resulting in a primary stone-free rate of 58%, while in the remaining cases the mean stone burden decrease was 82%. Kolla et al. [8] used successfully the adult nephroscope without the outer sheath, bringing its diameter down to 19F.

Helal et al. [12] performed PCNL by using a 15F Hickman catheter introduction kit, where the sheath was partially peeled away. Thereafter, a 10F paediatric cystoscope and grasper were inserted through the sheath to remove the renal stones. Lastly, Samad et al. [13] also reported the use of a 17 F nephroscope in children less than 5 years old, achieving a clearance rate of 90%.

Bilen et al. [14] compared PCNL in children after using different sizes of instruments via a 26F, a 20F and a 14F tract. They concluded that smaller instrument size up to 20F did not significantly increase the operative time and had the same success rates as the adult-sized devices. However, low blood transfusion rates were only reached in children operated through a 14F tract.

Recently, Nouralizadeh et al. [15] performed 26 PCNL procedures in children less than 5 years old with adult-size instruments. The mean stone size was 33 mm and average operative time was 93.2 min. Stones were completely cleared with only one tract in 79.1% of patients, the overall complication rate was 15.3% and mean hospital stay was 5.2 days.

Usually, grasper forceps, ultrasound and/or electrohydraulic intracorporeal lithotripsy are used through the Amplatz sheath to remove and/or fragment renal stones. Also, it is common practice to place a nephrostomy tube in all children postoperatively [11]. The tube is clamped once the urine is clear and removed afterwards provided there is no loin pain or fever. In such cases, if residual stones are suspected in the collecting system, an antegrade nephrostogram and a plain X-ray are performed as well. The mean postoperative stay is similar to adults (3–4 days) and is much shorter in comparison with open surgery.

Site and number of tracts

The site of puncture and the number of tracts is important for the efficacy and morbidity of PCNL in children. Subcostal lower pole access is associated with a lower risk of intra- or post-operative complications. Studies in adults have revealed that the overall complication rate for supracostal access tracts was four times more frequent (16 vs. 4%) in comparison with subcostal access [16].

Boormans et al. [11] performed all their 26 PCNLs through a lower pole calyx, including 2 cases with an additional middle pole access. Only in one case intra-operative bleeding necessitated blood transfusion. Raza et al. [17] performed 25 out of 43 PCNLs through a lower pole calyx, while 15 took place via the middle pole, 2 through a lower and middle pole and only 1 case through an upper and middle pole calyx. No pneumothorax was recorded or transfusion needed, while the overall complication rate was 6%. Lastly, Samad et al. [13] used upper pole access in 8 with congenital renal abnormalities without any need for transfusion and with a clearance rate of 90%.

Regarding the number of tracts, Desai et al. [3] assessed 116 PCNLs and found that the number of accesses was significantly ($p < 0.01$) correlated with the haemoglobin drop; but not with the serum creatinine concentrations pre- and post-operatively. However, the usage of multiple tracts in big and/or multiple stones may prevent excessive torque to gain entry into adjacent calyces, which may result in infundibular tear and blood loss. Aron et al. [18] treated 19 preschool children with complete staghorn stones by performing safely two tracts in 68% of the cases, while in one case three tracts were required.

Bilateral PCNL

The potential advantages of simultaneous bilateral PCNL could include reduced psychological stress, one cystoscopy and anaesthesia, less medication, hospitalization, convalescence and overall cost [19]. Salah et al. [19] performed simultaneous bilateral PCNL in 13 children with a mean stone diameter of 2 cm, by using a 26 F adult nephroscope. All patients were rendered stone free; there was no severe complication and in one case a second session was needed because of residual stone. Because both kidneys were operated, JJ stents were inserted and remained in situ for 6 weeks. The above encouraging results upon the safety and efficacy of simultaneous bilateral PCNL were confirmed by Samad et al. [13]; however, relevant studies are warranted.

Renal congenital abnormalities

Stone disease is more common in children with congenital abnormalities (i.e. ureteropelvic junction obstruction, horseshoe and ectopic kidney) in comparison with the general population. Percutaneous access in horseshoe and pelvic ectopic kidneys is optimally obtained through the most superior calyx requiring anterior approach [20]. However, in such cases fear of injury to abdominal viscera makes PCNL a technically challenging procedure.

The percutaneous approach facilitates the simultaneous management of renal stones and ureteropelvic stenosis by performing PCNL and antegrade endopyelotomy in the same session. Choong et al. [21] performed successfully such a procedure without any complications. Reports in adults reveal that PCNL in cases with renal congenital abnormalities is safe and effective, but relevant literature in children is scant.

Efficacy of PCNL

Usually, PCNL is used as mono-therapy in most cases but it can be used as part of a multimodal approach, especially in children with large stone burden. There is a significant correlation between stone size and the stone-free rate after PCNL, but they did not record influence of the stone type on the stone-free rate [3, 8, 21].

The reported stone-free rates of PCNL mono-therapy in the recent literature are 86 to up to 98% [3, 8, 17, 21, 22]. Even in staghorn stones, a clearance rate of 89% has been reported following a single session of PCNL [8]. These rates increase with adjunctive procedures such as second look PCNL, SWL and ureteroscopy. Furthermore, Aron et al. [18] used flexible nephroscopy as an adjunct whenever necessary. Raza et al. [17] recorded that after 46 PCNLs in 35% of the cases ancillary procedures were required.

Desai et al. [3] reported a complete clearance rate of 89.8%, after treating 116 children, aged <15 years. With subsequent SWL, the clearance rate increased to 96%. After 188 consecutive PCNL, Samad et al. reported a clearance rate of up to 90%, which increased with adjuvant SWL [14]. Badawy et al. [23] performed PCNL in 60 children (mean age 6 years old) and reported that 83.3% were rendered stone-free at one session.

Although PCNL success rates are higher in adults, caution should be exercised in children, in whom diligent attempts at stone clearance in one session may be made at the expense of safety [23].

Complications of PCNL

Bleeding

Bleeding is a significant intra-operative complication not only because of blood loss, but also because vision is impaired and the procedure can be abandoned. Blood loss requiring transfusion is reported in 0.4–24% and is associated with stone burden, sheath size, number of tracts and operative time [2, 3, 8, 13, 18, 21, 22]. In order to minimize bleeding when using adult-sized instruments Kroovand et al. [24] and recently Desai et al. [3] proposed a two-session technique, by first establishing the percutaneous tract and second performing the stone disintegration. Bleeding during PCNL is usually of venous origin and can be managed with the placement of nephrostomy tubes or tamponade catheters [25].

Desai et al. [3] reported an average haemoglobin drop of 1.9 g/dl in 116 cases of PCNL. The authors reported that the number and size of tracts were significantly ($p < 0.01$) correlated with the haemoglobin drop. Sahin et al. [26] reported a mean haemoglobin drop of 1.16 g/dl after treating 14 children and in 1 case blood transfusion was necessary. The average haemoglobin drop was less than 1 g/dl in a study by Kapoor et al. [27] in 31 children. Samad et al. [13] recorded a blood transfusion rate of 0–7.7% during 188 consecutive PCNLs. Mahmud et al. transfused 2 out of 29 children that underwent PCNL; however none of the procedures were abandoned or required conversion to open surgery [27].

Hypothermia

Hypothermia is related to the temperature of the irrigation fluid that is used intra-operatively and to the operative time of the PCNL. Al-Shammari et al. reported that no hypothermia was recorded when the procedure took place in < 150 min [29]. Also, Mahmud et al. did not report any case of hypothermia because they made special efforts to drape and cover the child [28]. Therefore, warming irrigation fluid to body temperature, avoiding prolonged operative times and covering the extremities with warming blankets is advisable [8].

Fever

Postoperative fever has been reported in up to 30-40% of the cases and is the commonest postoperative complication [3, 8, 13]. The origin of the fever is not thought to be the infection as urine and blood cultures are usually negative and patients are haemodynamically stable. The postoperative white blood cell count usually does not predict pyrexia and fever alone does not prolong hospitalization [28].

Samad et al. reported transient postoperative fever in 31% of 188 consecutive PCNLs [14]. Raza et al. recorded transient high grade fever (> 38º C) in 3 out of 33 children after the PCNL [17]. It has been suggested that children with postoperative pyrexia of > 38º C should be treated with intravenous gentamicin and amoxicillin [21].

Infection

The commonest presentation of children with urolithiasis is a urinary tract infection [21]. In a study by Boormans et al. in 23 children that underwent PCNL, urinary tract infections were found in 65% [28]. The high incidence of these infections could be attributed to the relatively high percentage of vesicoureteric reflux. In the same study, stone analysis revealed struvite stones or a struvite component in all cases with *P. mirabilis* infection. In one of these cases urosepsis developed, for which admission in the intensive care unit was required. On the other hand, postoperative infection has been reported in nearly 5% of the cases [8].

Rare complications

Bowel injury is a rare intra-operative complication because of the retroperitoneal access through the prone position of the child [23]. Potentially, the risk of visceral injury is bigger in cases of horseshoe or ectopic kidneys.

An unusual postoperative complication is lower ureteric steinstrasse due to dislodgement of residual stone fragments. Steinstrasse can cause obstructive uropathy and is usually successfully managed with SWL [10].

Lastly, tubeless PCNL in children has the advantages of being less painful, less troublesome and shortening the hospital stay [30]. The decision to use this procedure is best made intra-operatively and depends on the experience of the surgeon.

Effects of PCNL on renal function

Animal studies and several clinical series have revealed that PCNL has no adverse effect on renal function [8]. Mahmud et al. [28] performed ^{99m}Tc-DMSA in 17 children <5 years old, 6 week after the PCNL, without detecting any new scarring or loss of renal function. Mor et al. [31] assessed renal function with radioisotope scans in ten children before and after PCNL. The scans revealed unchanged differential function in nine cases. Significant renal scars and a 30% decrease in renal function were revealed in 1 child who underwent three 3 PCNLs within 4 years.

Interestingly, Dawaba et al. [32] reported a statistically significant ($p < 0.01$) improvement of the GFR in 65 children, from a mean value of 28.8–36.1 ml/min before and after PCNL, respectively. In the same study the authors did not detect any case of renal scarring. However, Samad et al. [33] demonstrated that there is a 5% risk of focal damage to renal parenchyma from the formation of the nephrostomy tract. Lastly, studies with long-term follow-up have not revealed that PCNL can result in hypertension [28].

Epilogue

Nowadays, open surgery for the treatment of paediatric urolithiasis has been limited in bladder lithiasis [34]. As appropriate instruments are available and relevant surgical experience is accumulating, age is no longer a limiting factor for treating renal stones with PCNL. Miniaturization of endoscopes and advances in energy sources for stone fragmentation, have facilitated stone-free rates. Complete stone clearance is the absolute objective and clinically insignificant residual fragments should not be accepted as a success. As stone disease in children is prone to recurrence, close follow-up is recommended. Furthermore, as two-thirds of infant stone patients have an underlying metabolic disorder, close cooperation of urologists, nephrologists and radiologists is necessary in order to achieve optimal results.

A vast disparity in the access to resources worldwide continues to individualize rather than standardize stone treatment in children [6]. The main indications for PCNL in children include stones refractory to SWL, large and complex stones where multiple SWL sessions are necessitated and anatomical (e.g. spinal, renal) abnormalities. PCNL is primarily indicated in staghorn stones, pelvic stones > 20 mm and lower pole stones > 10 mm (level of evidence: 2b). Further randomized studies as in adults are warranted in children in order to confirm and update the above indications.

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