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Minimally invasive techniques used for treatment of urolithiasis in children

Techniki małoinwazyjne stosowane w leczeniu kamicy układu moczowego u dzieci

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Abstract

The paediatric population is a special group among patients with urolithiasis. Within the past 25 years, the prevalence of this disease in the paediatric population has increased from 6% to 10%. The causes of this higher prevalence are not entirely clear but may be associated with various factors, such as: inappropriate eating habits, inappropriate diet, particularly rich in salt and animal protein, insufficient fluid intake, obesity, hypertension, pollution, faster pace of living as well as uncontrolled intake of multivitamin preparations and dietary supplements. The mean age of a paediatric patient with urolithiasis is 7–8 years. The aim of this publication is to present minimally invasive techniques used for treatment of urolithiasis in the paediatric population. Due to a high risk of disease recurrence, the selection of a treatment method that enables removal of calculi in the least invasive and the most effective way is vital in this group of patients. The choice of management depends on various factors, such as: location, size and composition of calculi, patient's age, anatomical conditions, the degree of urinary outflow obstruction and recurring urinary tract infections. Surgical methods of urolithiasis treatment are identical in adults and in children. Minimally invasive techniques include extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), ureterorenoscopic lithotripsy (URSL; ureterolithotripsy) and retrograde intrarenal surgery (RIRS). Owing to the technical advancement, minimally invasive techniques are effective in children and help evacuate calculi fully, even with a single procedure. It must be remembered, however, that they should be performed by experienced urologists in highly specialised and well-equipped centres.

Keywords: urolithiasis, children, ESWL, PCNL, URSL, RIRS

Streszczenie

Populacja pediatryczna stanowi szczególną grupę pacjentów z kamicą układu moczowego. W ciągu ostatnich 25 lat częstość występowania tej choroby w populacji pediatrycznej wzrosła z 6% do 10%. Przyczyny zwiększonej zachorowalności nie są do końca wyjaśnione, ale na wzrost częstości kamicy moczowej mogą mieć wpływ różne czynniki: nieprawidłowe nawyki żywieniowe, niewłaściwa dieta, zwłaszcza z dużą zawartością soli i pokarmów bogatych w białko zwierzęce, niedostateczna podaż płynów, otyłość, nadciśnienie tętnicze, zanieczyszczenie środowiska, przyspieszenie tempa życia, niekontrolowana podaż preparatów wielowitaminowych i suplementów. Przeciętny wiek pacjenta pediatrycznego z kamicą wynosi około 7–8 lat. Celem pracy jest przedstawienie technik małoinwazyjnych w leczeniu kamicy układu moczowego w populacji pediatrycznej. Ze względu na wysokie ryzyko nawrotu choroby w tej grupie zasadnicze znaczenie ma wybór takiej metody leczenia, która umożliwiłaby usunięcie złogów w sposób jak najmniej inwazyjny i jednocześnie skuteczny. Wybór odpowiedniego sposobu postępowania zależy od wielu czynników, takich jak: lokalizacja, wielkość i skład złogu, wiek pacjenta, warunki anatomiczne, stopień utrudnienia spływu moczu, nawracające zakażenia układu moczowego. Procedury chirurgicznego leczenia kamicy u dzieci są takie same jak u dorosłych. Wśród technik małoinwazyjnych należy wymienić litotrypsję pozaustrojową (*extracorporeal shock wave lithotripsy*, ESWL), nefrolitotrypsję przezskórną (*percutaneous nephrolithotomy*, PCNL), litotrypsję ureterorenoskopową (*ureterolithotripsy*, URSL) i wsteczną chirurgię śródnerkową (*retrograde intrarenal surgery*, RIRS). Metody małoinwazyjnego leczenia kamicy u dzieci dzięki zaawansowanemu rozwojowi techniki są efektywne i umożliwiają całkowitą ewakuację złogów już podczas pierwszej procedury. Należy jednak pamiętać, że powinny być wykonywane przez doświadczonych urologów, w wysokospecjalistycznych i dobrze wyposażonych ośrodkach.

Słowa kluczowe: kamica układu moczowego, dzieci, ESWL, PCNL, URSL, RIRS

INTRODUCTION

Urolithiasis was treated as early as in the Antiquity. The evidence for this is a description of treatment methods in the Egyptian Ebers Papyrus from 1550 BC. Moreover, other documents, such as *On Diseases of the Bladder and Kidneys* written by Rufus of Ephesus and a 7-volume *De Medicina* by Aulus Cornelius Celsus, include descriptions of transperineal procedures used for urinary stone removal. In Ancient Rome, there was a speciality of lithotomists, of whom Hippocrates wrote "I will not cut, even for the stone, but I will leave such procedures to the practitioners of that craft"[1]. Despite this long history of urolithiasis treatment, we are still searching for the best method that would enable effective, safe and minimally invasive stone removal.

The paediatric population is a special group among patients with urolithiasis. Within the past 25 years, the prevalence of this disease in the paediatric population has increased from 6% to 10%[2]. The causes of this higher prevalence are not entirely clear but may be associated with various factors, such as: inappropriate eating habits, inappropriate diet, particularly rich in salt and animal protein, insufficient fluid intake, obesity, hypertension, pollution, faster pace of living as well as uncontrolled intake of multivitamin preparations and dietary supplements[3]. Moreover, improved quality of diagnosis and more frequent use of computed tomography in emergency departments for the diagnosis of abdominal and lumbar pain have significantly contributed to the increase in the detectability of urolithiasis[4]. Kidney stones may develop at any age. The literature has known cases of 4-day-old neonates with diagnosed nephrolithiasis. Nevertheless, the mean age of a paediatric patient with this disease is 7–8 years[4]. It is a recurring condition. In retrospective studies, recurrences are noted (depending on the source) in 24–50% of patients. The highest recurrence rate is observed in children with metabolic disturbances[5].

Due to a high risk of disease recurrence, the selection of a treatment method that enables removal of calculi in the least invasive and the most effective way is vital in the paediatric population. Over 80% of calculi are excreted spontaneously and require no intervention. As Van Savage indicates, stones that cause no stasis and are smaller than 4 mm should be observed and treated only conservatively. The remaining calculi require either conservative or surgical treatment. The choice of the most adequate management depends on various factors, such as: location, size and composition of calculi, patient's age, anatomical conditions, the degree of urinary outflow obstruction and recurring urinary tract infections[6].

Surgical methods of urolithiasis treatment are identical in adults and in children. Minimally invasive techniques include extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), ureterorenoscopic lithotripsy (URSL; ureterolithotripsy) and retrograde intrarenal surgery (RIRS).

EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY

The idea of using shock waves to crush stones was conceived in the 1950s. When investigating the causes of dents in wing plating of supersonic F-104 Starfighter jets, it was observed that rain drops hitting the plating of the flying aircraft with the speed of Mach 2 (Mach 1 ≈ 1,220 km/h) produced ultrasound waves that induced structural changes and corrosion. This phenomenon was used in the prototype of an ESWL device and applied for the first time in 1980[7]. The HM3 device was equipped with a bath where the patient, held on straps, was immersed. An electrohydraulic shock wave generator was positioned beneath the patient. Water in which the wave scattered was degassed and deionised; the device was therefore referred to as "the most expensive bath in the world." The procedure was painful and was conducted under general anaesthesia.

The current devices for ESWL utilise three types of generators:

- electrohydraulic – the shock wave is generated as a result of electric discharge between electrodes in the water environment; the procedure is characterised by high efficacy, but is painful[8];
- electromagnetic – the wave is generated as a result of vibration of a metal membrane or cylinder in response to the action of electromagnetic field; the energy can be broadly regulated, the procedure is less painful compared to the one with the electrohydraulic generator[8];
- piezoelectric – the wave is generated as a result of a joint effect of simultaneous stimulation of numerous spherically-arranged piezoelectric ceramic elements; the method is characterised by a greater rate of failure and a higher number of required procedures; due to a large area of wave entrance to the body, it is painless.

The shock wave is focussed on a calculus under digital fluoroscopy or ultrasonography (USG) guidance.

Extracorporeal shock wave lithotripsy is a method of choice in the treatment of pelvicalyceal stones measuring ≤20 mm in diameter and ureteral stones <10 mm[9,10]. Other indications include residual urolithiasis following PCNL (sandwich therapy)[11] and catheter incrustations. The efficacy of this method after a single session is estimated at 68–92%[12]. It is absolutely contraindicated in patients with an aneurysm in the abdominal aorta and renal artery, during pregnancy, active urinary tract infection, in patients with an obstacle distal to the stone (calyceal neck stenosis, ureteropelvic junction obstruction, ureteral narrowing) or with skeletal defects preventing proper patient placement on the table. Relative contraindications include haemorrhagic diathesis (a procedure is possible in collaboration with a haematologist provided that coagulation factors are supplemented prior to and after the procedure) and the use of anticoagulants.

The principal complications of ESWL include:

- renal colic;
- *steinstrasse*;
- urinary tract infection of variable character and course;

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- residual urolithiasis;
- haematuria;
- perirenal haematoma (usually treated conservatively);
- transient renal function decline; to date, no permanent effects of the procedure on kidney excretory function have been observed.

No long-term complications, such as renal function deterioration or hypertension, have been noted. Vlajković et al. evaluated glomerular filtration rate (GFR) before and after ESWL. They demonstrated that GFR normalises or increases approximately 3 months after the procedure, which makes ESWL deemed as a safe therapy[13].

There are a number of factors that may affect the efficacy of ESWL. These are:

- the number and size of calculi; if stones are >15 mm, complete evacuation is achieved in fewer than 50% of patients[14];
- stone location; the efficacy of the procedure is reduced with stones located in the inferior calyces[15];
- structure of the pelvicalyceal system; long and narrow calyces and the angle between a calyx and pelvis below 70° reduce the efficacy of the method;
- stone composition; hard stones, e.g. cystine stones are poorly crushable (if stone density in computed tomography without contrast enhancement is >1,000 Hounsfield units, it is highly likely hard[16]);
- body mass index (BMI); BMI >30 reduces the efficacy of the procedure; energy attenuation is roughly estimated at 10–20% per each 6 cm of tissue[17];
- congenital kidney malformations; unrotated kidneys, horseshoe kidneys and duplex collecting systems reduce the efficacy of ESWL.

Extracorporeal shock wave lithotripsy used as a monotherapy is much more effective in children than in adults due to softer stones, their smaller sizes, lower amount of tissue during shock wave transmission and easier spontaneous evacuation of fragmented stones[18,19].

However, attention must be paid to the fact that this procedure does require general anaesthesia. That is why, when failure is likely, an alternative method, which may eliminate calculi with a single anaesthesia, is worth considering.

PERCUTANEOUS NEPHROLITHOTOMY

Percutaneous nephrolithotomy (PCNL) was described for the first time by Goodwin in 1955. This procedure is conducted under general anaesthesia and antibiotic protection. After introduction of a catheter into the ureter and renal pelvis, under radiological or ultrasound guidance, the renal calyx is incised percutaneously, thereby creating a working canal, or, more precisely, one to three canals, depending on the need; this way complete elimination of staghorn stones from the pelvicalyceal system is possible. Subsequently, a nephroscope is introduced and, under visual control, stones are crushed into smaller fragments using pneumatic, ultrasonographic or laser lithotripters (Ho:YAG).

According to the guidelines of the European Association of Urology, PCNL is the method of choice for:

- stones ≥1.5 cm, located in the upper renal pole;
- stones ≥1.0 cm, located in the lower renal pole;
- hard stones, e.g. cystine or struvite stones;
- urolithiasis concomitant with anatomical defects that may obstruct calculus outflow.

The main complications of this procedure are fever, urosepsis and intensive bleeding requiring transfusion. Other possible complications are: pneumothorax, haemothorax, urothorax and injury to organs adjacent to each of the kidneys. As revealed by experience of authors from different centres, the risk of the need for transfusion is very low[18,20,21]. Dawaba et al. monitored renal function using dynamic renal scintigraphy. They demonstrated that renal function either improved or remained unchanged in 64 of 65 patients after PCNL[22]. The efficacy of PCNL used in monotherapy ranges from 87% to 98.5%[23,24]. To increase the efficacy, various centres started implementing a so-called sandwich therapy, i.e. ESWL performed after PCNL. This management helps reach even 100% efficacy.

Since the first use of PCNL, this procedure has been continuously modernised. Contemporary modifications include: standard PCNL (S-PCNL), mini-PCNL (mini-perc), ultra-mini-PCNL, (UM-PCNL) and micro-PCNL (Tab. 1).

Mini-perc is conducted with the use of miniaturised equipment and the technique itself also differs from standard PCNL. In mini-PCNL, the canal with the diameter of 11 Charr is formed with the use of single-step Alken or Amplatz dilators[25]. The stone fragmentation procedure is conducted with the use of holmium laser. Minor fragments of a crushed stone are flushed from the pelvicalyceal system. Drainage is not required after the procedure. In some, special cases, nephrostomy is retained. The frequency of complications and the need for blood transfusion in patients after mini-PCNL is lower compared with standard PCNL. Mini-PCNL may potentially become an effective way of crushing pelvicalyceal stones reaching 1–2 cm[26]. The method is particularly recommended for urolithiasis in calyces with neck stricture of with long and narrow necks.

Percutaneous nephrolithotomy and its modifications are minimally invasive procedures that require considerable experience and skill. Despite this, they are an effective and good alternative to surgery.

Type of surgery	Standard PCNL	Mini-PCNL
Size of the device	26–28 Charr	12–15 Charr
Forming the passage	Under US or fluoroscopy guidance	Under US or fluoroscopy guidance
Lithotripsy device	Ultrasonographic, ballistic, laser	Holmium laser
Evacuation of stone fragments	With forceps	By flushing

Tab. 1. Comparison of PCNL with mini-PCNL

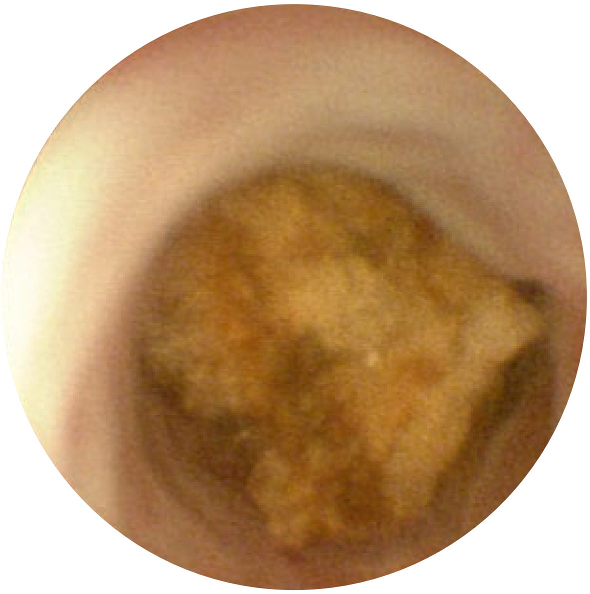

Fig. 1. A calculus in the middle part of the ureter

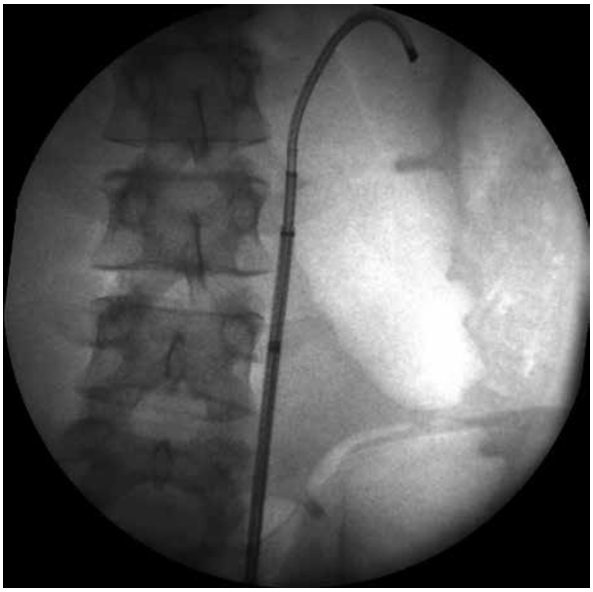

Fig. 2. fURS positioning with fluoroscopy guidance

URETERORENOSCOPIC LITHOTRIPSY

Ureterorenoscopic lithotripsy (URSL) is a procedure that enables ureteroscopy of the entire ureter up to the ureteropelvic junction and, owing to miniaturisation of flexible ureteroscopes, also of the entire pelvicalyceal system (RIRS). This procedure is indicated when calculi are located in the ureter, especially in its lower segment, and in the kidneys, and may be effectively treated with flexible ureteroscopy (fURS). This procedure is conducted under general anaesthesia and antibiotic protection. A ureteroscope is introduced into the urinary bladder and then to the ureter, reaching the calculus (Fig. 1). Stones are crushed with pneumatic or laser lithotripters. Stone fragments may be removed with forceps or baskets, but they are usually left for spontaneous evacuation in the paediatric population due to a very slight diameter of the ureter. Depending on the duration of the procedure, number of ureteroscope insertions and visible ureteral mucosa injuries, the ureteral catheter is either retained and removed after approximately 2 weeks or removed immediately. The time for which a DJ catheter is retained depends on the level of ureteral injury during the procedure, severity of other complications or indications for retaining it for a longer period of time. In the case of fURS, so-called ureteral access sheaths (UAS) are used. They shorten the procedure duration as they facilitate multiple fURS insertions and crushed stone removal, improve visibility, ensure low intrarenal pressure during the procedure owing to constant outflow of the flushing fluid, and protect the delicate equipment against mechanical damage. Fluoroscopy is used for better control of the fURS tip location, which facilitates the assessment of the orientation and angle of the tip (Fig. 2). The use of fURS within the kidney is referred to as retrograde intrarenal surgery (RIRS). The efficacy of this method is high. Corcoran et al. noted 88% efficacy after a single procedure with Ho:YAG lithotripters based on a study among 47 children with calculi in the proximal part of the urinary tract[27]. In the study of Cannon et al., the efficacy of URSL for treatment of 12.2 cm stones located in the inferior renal calyces was 76%[28]. Complications after URSL include: ischaemia, subcapsular haematoma, ureteral injury, including mucosal tear, formation of so-called false passage, ureteral perforation as well as partial or complete ureteral detachment and renal colic (not necessarily due to residual stones, sometimes due to mucosal oedema). Long-term complications include ureteral narrowing and vesicoureteral reflux. However, the analysis of the available literature suggests that the risk of complications is low. In 100 procedures, Smaldone et al. noted only 4 cases of perforation and 1 case of distal ureteral narrowing that required an open surgery[29].

The development of minimally invasive techniques has led to even more effective endoscopic procedures with robotic technology. Avicenna Roboflex is a robot used for support during RIRS for improved efficacy and safety. However, there are only few reports on this technique in children.

CONCLUSION

Owing to the technical advancement, minimally invasive techniques are effective in children and help evacuate calculi fully, even with a single procedure. It must be remembered, however, that they should be performed by experienced urologists in highly specialised and well-equipped centres.

Conflict of interest

The authors do not report any financial or personal affiliations to persons or organisations that could adversely affect the content of or claim to have rights to this publication.

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