ΜΕΤΑΠΤΥΧΙΑΚΟ ΠΡΟΓΡΑΜΜΑ ΣΠΟΥΔΩΝ:
''ΕΛΑΧΙΣΤΑ ΕΠΕΜΒΑΤΙΚΗ ΧΕΙΡΟΥΡΓΙΚΗ, ΡΟΜΠΟΤΙΚΗ ΧΕΙΡΟΥΡΓΙΚΗ ΚΑΙ ΤΗΛΕΧΕΙΡΟΥΡΓΙΚΗ''

ΕΘΝΙΚΟ ΚΑΙ ΚΑΠΟΔΙΣΤΡΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
ΙΑΤΡΙΚΗ ΣΧΟΛΗ

ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

ΘΕΜΑ: « Percutaneous Lithotripsy, old and new techniques that preserve it as a basic modality in modern minimal invasive urology»

ΜΕΤΑΠΤΥΧΙΑΚΟΣ ΦΟΙΤΗΤΗΣ: ΜΟΥΡΜΟΥΡΗΣ ΠΑΝΑΓΙΩΤΗΣ του Ιωάννη
ΑΜ 20120730

ΑΘΗΝΑ ΙΑΝΟΥΑΡΙΟΣ 2015

ΠΡΑΚΤΙΚΟ ΚΡΙΣΕΩΣ
ΤΗΣ ΣΥΝΕΔΡΙΑΣΗΣ ΤΗΣ ΤΡΙΜΕΛΟΥΣ ΕΞΕΤΑΣΤΙΚΗΣ ΕΠΙΤΡΟΠΗΣ ΓΙΑ ΤΗΝ ΑΞΙΟΛΟΓΗΣΗ ΤΗΣ ΔΙΠΛΩΜΑΤΙΚΗΣ ΕΡΓΑΣΙΑΣ
Του Μεταπτυχιακού Φοιτητή Μουρμούρη Παναγιώτη του Ιωάννη

Εξεταστική Επιτροπή

- Ευάγγελος Φελέκουρας, Αναπλ. Καθηγητής Χειρουργικής **(Επιβλέπων)**
- Χρήστος Π. Τσιγκρής, Καθηγητής Χειρουργικής & Επιστημονικός Υπεύθυνος του Π.Μ.Σ.

Θεόδωρος Διαμαντής, Καθηγητής Χειρουργικής

Η Τριμελής Εξεταστική Επιτροπή η οποία ορίσθηκε από την ΓΣΕΣ της Ιατρικής Σχολής του Παν. Αθηνών Συνεδρίαση της .....ης .... 20.... για την αξιολόγηση και εξέταση του υποψηφίου κ Μουρμούρη Παναγιώτη, συνεδρίασε σήμερα .../.../....

Η Επιτροπή διαπίστωσε ότι η Διπλωματική Εργασία του Κου Μουρμούρη Παναγιώτη του Ιωάννη με τίτλο: Percutaneous Lithotripsy, old and new techniques that preserve it as a basic modality in modern minimal invasive urology, είναι πρωτότυπη, επιστημονικά και τεχνικά άρτια και η βιβλιογραφική πληροφορία ολοκληρωμένη και εμπεριστατωμένη.

Η εξεταστική επιτροπή αφού έλαβε υπ' όψιν το περιεχόμενο της εργασίας και τη συμβολή της στην επιστήμη, με ψήφους .... προτείνει την απονομή του Μεταπτυχιακού Διπλώματος Ειδίκευσης (Master's Degree), στον παραπάνω Μεταπτυχιακό Φοιτητή.

Στην ψηφοφορία για την βαθμολογία ο υποψήφιος έλαβε για τον βαθμό «ΑΡΙΣΤΑ» ψήφους ...., για τον βαθμό «ΛΙΑΝ ΚΑΛΩΣ» ψήφους ...., και για τον βαθμό «ΚΑΛΩΣ» ψήφους .... Κατά συνέπεια, απονέμεται ο βαθμός «.....................».

Τα Μέλη της Εξεταστικής Επιτροπής

- Ευάγγελος Φελέκουρας (Επιβλέπων) (Υπογραφή)____________________
- Χρήστος Π. Τσιγκρής (Υπογραφή)____________________
- Θεόδωρος Διαμαντής, (Υπογραφή)____________________

Αφιερωμένο στους ανθρώπους που μου χαρίζουν τόσα χρόνια την αγάπη και την υπομονή τους

Ευχαριστώ τον Αναπληρωτή Καθηγητή Σκολαρίκο Ανδρέα και τον Επίκουρο Καθηγητή Παπατσώρη Αθανάσιο για την βοήθειά τους στην συλλογή των στοιχείων απαραίτητων για την συγγραφή της παρούσας διπλωματικής εργασίας.

ΠΕΡΙΕΧΟΜΕΝΑ- CONTENTS

Part 1

1 Introduction……………………………………………………………………..7

2 Percutaneous surgery……………………………………………………………7

2.1 Anatomical considerations……………………………………………………7

2.2 Perirenal anatomy…………………………………………………………….8

2.3 Renal collective system………………………………………………………..9

2.4 Intrarenal vessels……………………………………………………………10

3 Indication for PCNL……………………………………………………….....10

4 Special anesthetic considerations for PCNL……………………………….11

5 Organizing the operating room for PCNL…………………………………12

6 Instrumentation for performing PCNL……………………………………..12

7. Patient Positioning…………………………………………………………15

7.1 Prone and prone flexed position……………………………………………15

7.1.1 Advantages and disadvantages of prone position……………………………16

7.1.2 Lateral and lateral flexed position……………………………………...17

7.2 Supine position……………………………………………………………...19

7.2.1 New variations in supine position……………………………………...20

7.2.2 Advantages and disadvantages of the supine position…………………………20

8. Image guided percutaneous renal access…………………………………..21

8.1Ultrasound………………………………………………………………...21

8.1.1 Ultrasound guided access with needle guide…………………………...22

8.1.2 Ultrasound access without a needle guide……………………………...22

8.2 Fluoroscopy…………………………………………………………………23

8.3 Novel techniques for gaining percutaneous renal access……………………...27

8.4 Robotic assisted percutaneous access to the collective system…………………..28

9 Dilation of the nephrostomy tract……………………………………………………..29

9.1 Potential complications of tract dilation…………………………………………33

10 Rigid and Flexible Nephroscopy…………………………………………………34

11 Lithotripsy…………………………………………………………………………...36

11.1 Ultrasound Lithotripsy……………………………………………………….36

11.2 Pneumatic Lithotripsy…………………………………………………………..36

11.3 Combined ultrasonic and pneumatic lithotripsy………………………………...37

11.4 Laser lithotripsy and the Holmium: YAG laser………………………………...38

Part 2

A. Introduction…………………………………………………………………….40

B. Material and Methods……………………………………………………….....40

C. Patient positioning……………………………………………………………...40

D. Imaging technique for the puncture of pelvicalyceal system……………………..41

E. Site of puncture………………………………………………………………….43

F. Dilation of access………………………………………………………………..44

G. Lithotripsy…………………………………………………………………………..45

H. Drainage and hemostasis………………………………………………………..46

I. Combination of endoscopic techniques and PCNL………………………………..49

J. Conclusions and future perspectives……………………………………………49

Abstract……………………………………………………………………………51

Περίληψη…………………………………………………………………………….51

References………………………………………………………………………….53

PART 1

1. Introduction

The first description of percutaneous stone removal was that of Rupel and Brown (1941) of Indianapolis, who removed a stone through a previously established surgical nephrostomy. Goodwin and associates described the first placement of a percutaneous nephrostomy tube to drain a grossly hydronephrotic kidney. These researchers did not have radiographic imaging and so the drainage tube was placed without it. The first percutaneous access for removal of a renal stone was performed later by Fernstrom and Johansson[1]. Technological advances in endoscopes, imaging equipment, and intracorporeal lithotripters allowed urologists to alter these percutaneous techniques into well-established methods for removal of upper urinary tract calculi. Many papers from surgeon with big surgical experience have established Percutaneous Nephrolithotripsy (PCNL) as a routinely used technique to treat patients with large or otherwise complex calculi[2]. Because the percutaneous approach to stone removal is superior to the open approach in terms of morbidity, convalescence and cost PCNL has replaced open surgical removal of large and complex calculi at most institutions[3]

1. Percutaneous surgery

2.1 Anatomic considerations

During percutaneous surgeries guided by fluoroscopy or ultrasonography the vision of the positioning of adjacent structures and organs is limited and so understanding of the renal and perirenal anatomy is of paramount importance in order to obtain access in an effective and safe manner. Nevertheless anatomical variations make this procedure extremely challenging even in the hands of experienced surgeons.

1.2. Perirenal anatomy

The kidneys are well protected organs, situated retroperitoneally and surrounded by perirenal tissue. The mobility of the kidneys is limited by the short renal hillar vessels and the surrounding supporting structures, although nephroptosis is found in some cases. In these cases the kidney not only descends but also rotates anteriorly. This can make the puncture in prone position extremely challenging and complication rate greater.

The kidney lies adjacent to the vertebral bodies usually extending from the 11^{th} or 12^{th} thoracic to the 2^{nd} or 3^{rd} lumbar vertebrae. The right kidney is displaced a few centimeters inferior to the left kidney. The longitudinal axis of the kidneys parallels the lateral edges of the psoas muscle, about 30 degrees from vertical, with the lower poles lateral to the upper poles. The kidneys are also tilted 30 degrees off the frontal plane, with the lower poles anterior to the upper poles. Finally, the kidneys are rotated out of the frontal plane as well, with the lateral aspect of the kidney posterior to the medial aspect, such that each kidney is rotated 30 degrees posteriorly from the renal hilum.

Immediately posterior to the kidneys is the psoas muscles, except at the upper poles where the diaphragm is posterior. The pleura can be injured through an upper calyx puncture and this risk is greater in kidneys that are situated higher than usual.

Extremely useful is the knowledge of kidney relationships with adjacent organs. On the right side the liver is anterior to the upper pole of the kidneys and can extend in some individuals to cover the entire anterior surface. On the left, the spleen covers kidney anteriorly. Due to anatomical variations of the size of these organs, traumatizing them is a possible scenario and surgeon must be aware of these variations in any individual in order to plan the procedure. The colon can be lateral or even posterior to the right and left kidneys respectively. The proximity of the colon to the kidneys varies with location. It is greater on the left side and at the lower pole. Additional visceral relations to the kidneys include the adrenal glands, the duodenum and gallbladder and the tail of the pancreas. These structures can be injured with a misdirected or excessively deep puncture but this kind of injuries are extremely rare.

2.3 Renal collecting system

The renal papillae drain into the minor calyces which are the most peripheral portions of the intrarenal collective system. If only one papilla drains into a minor calyx, it is described as a simple calyx. When there are two or more papillae entering the calyx it is termed a compound calyx. The outermost wall of the calyx, into which the papilla is set, is the calyceal fornix. There are 5 to 14 minor calyces in each kidney[4]. There are three drainage zones: the upper pole, the middle pole and the lower pole. The minor calyces, either directly or after coalescing into major calyces, drain by infundibula into the real pelvis.

An important consideration for percutaneous renal surgery is determining the anterior-posterior orientation of the calyces because access (from the typical posterior or posterolateral approach) into a posterior calyx allows relatively straight entry into the rest of the kidney, whereas percutaneous puncture of an anterior calyx requires an acute angulation to enter the renal pelvis, which may not be possible with rigid instrumentation.

2.4 Intrarenal vessels

Although anatomy of the renal artery varies significantly, in general the main renal artery divides into an anterior and posterior branch. The former then divides within or before the renal sinus into segmental arteries. Once the anterior segmental arteries and the posterior branch of the renal artery enter the renal parenchyma, they divide into interlobar arteries. The fact that the final divisions of the renal arteries are "end-arteries" makes the arterial vascular injury a great complication which may lead to permanent loss of renal function. Additionally the safest place to percutaneously access the collective system is directly into the calyceal fornix because this will avoid the interlobal arteries adjacent to the calyceal infidibula.

2. Indications for PCNL

According to the EAU 2014 guidelines, the indications for PCNL are different for different positioning of the stone or even for the size of the stone. Stones that are bigger than 20mm should be treated primarily by PCNL because other modalities have greater side effects. This affects stones that are situated in renal pelvis or upper/middle calices[5,6]. For stones in the lower pole the gold standard operation is PCNL especially if the stone is >20mm and if there are anatomical differentiations such as a steep infundibular- pelvic angle, a long calyx or a narrow infundibulum.

Also indications for performing PCNL are also staghorn calculi and after many failed extracorporeal shock wave lithotripsies (ESWL).

3. Special anesthetic considerations for PCNL

Prone position and potential blood loss increases the anesthetic risks of PCNL in contrast to other endourological procedures. However PCNL has been performed safely and with low morbidity in many patients, including patients with many comorbidities and the morbidly obese[7]. The procedure is considered intermediate in cardiac risk.

Two main positions are been used in PCNL: the prone and the supine position. Prone positioning increases the complexity of the anesthesiologist work. Careful positioning and draping of the patient is required in order to maintain safe airway placing, adequate ventilation and avoidance of pressure point injuries.. Of benefit is the more uniform distribution of pulmonary blood flow improving ventilation to perfusion matching and oxygenation[8,9]. Also functional residual capacity increases (compared to the anesthetized supine position) in normal weight and less so in obese patients[8].

Larger stones will probably require more surgical time and this fact increases the likelihood of needing general or neuraxial (spinal or epidural) anesthesia. Because PCNL requires kidney puncture and manipulation blood transfusion may be expected. Many centers follow a “blood ordering schedule” to minimize the risks and the costs[10].

Longer PCNL procedures may lead to significant dependent edema to inferiorly located anatomy. If supraglottic airway edema is suspected, extubation should be delayed until the edema has resolved significantly.

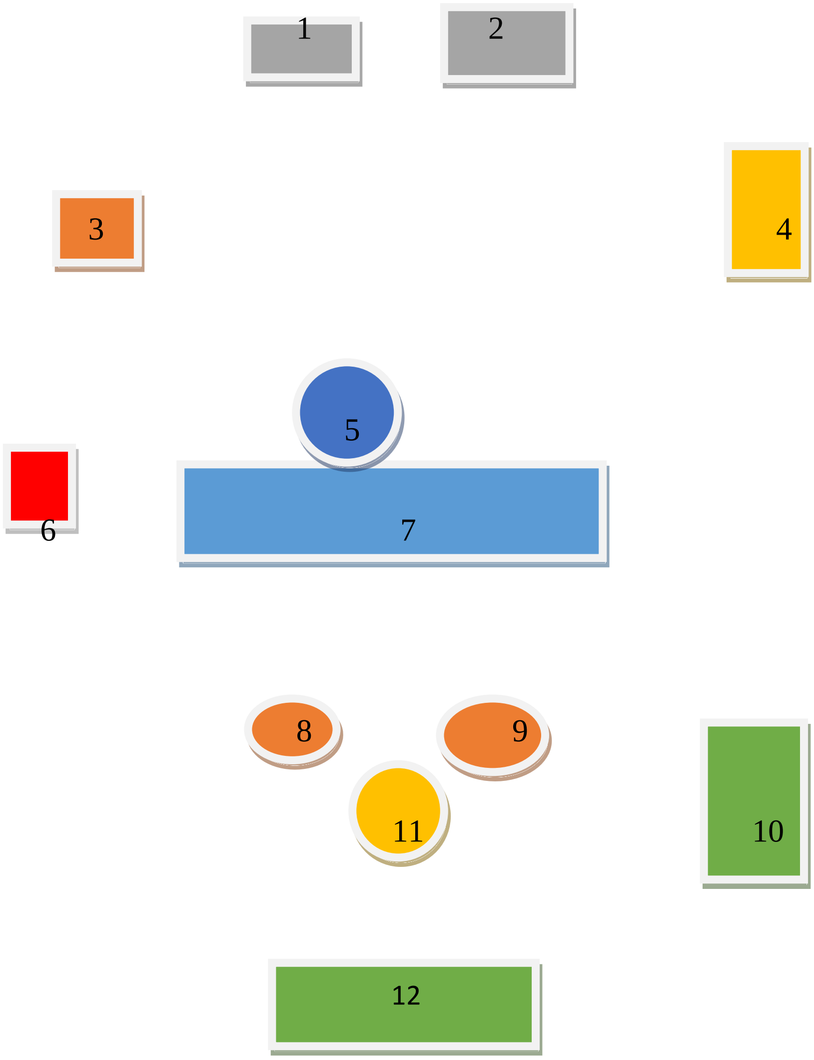
4. Organizing the operation room for PCNL.

The working of the operation room (OR) needs must serve the needs of an endourology team. A mobile C- arm unit is essential in an OR dedicated to urology. It should provide a high quality image to allow quick and precise diagnosis.

The configuration of an endourology OR is different from that of a general OR, as equipment has to be ergonomically located. This will minimize procedural time by allowing direct control and shorter changeover times. The OR should contain cameras, lights, endoscopic and anesthetic equipment, C-arm and the operating table and all should be capable of being operated easily from the surgeon and his team.

There should be display screen monitors, moveable and these monitors should be interconnected with changeable viewing between fluoroscopic image and endovision image, A strategic equipment placement in a case of PCNL is shown in figure 7

Figure 7 A strategic equipment placement 1 Display screen 2 X ray screen 3 LASER machine 4 Anesthesia trolley 5 C- Arm 6 Ultrasound machine 7 OR table 8 Assistant 9 Surgeon 10 Endoscopic equipment 11 Nurse 12 Nurse trolley



5. Instrumentation for performing PCNL

The necessary instruments are shown in Table 1.

Table 1
Surgical equipment that is used when performing PCNL
C-arm unit Xray protection equipment (gawns and goggles)
Video-Endoscopy tower
Ultrasound machine
Cystoscope with Albaran
Contrast material
5-Fr open-end ureteric catheter
18-gauge puncture needle
Guide wires: 0.035 inch guide wire 100% hydrophilic, 0.035 inch guide wire with hydrophilic end and body with PTFE hydrophilic covering, 0.035-inch guide wires Amplatz superstiff και extrastiff
5Fr angiographic catheter
5Fr angiographic catheter Cobra type
8-10-12Fr dilators with PTFE
8/10 Fr metallic dilators

Ballon Dilator with sheath 30Fr
Metallic dilators Alken type
Rigid Nephroscope diameter 24Fr (longer for obese patients – flexible nephroscope 16Fr
LithoClast
Holmium laser device and 365-200μ caliber fibers
Clamps for stone removal
Nitinol baskets
Nephrostomy tubes 8, 10, 16F
JJ stents No 4.8-6Fr 26-28 cm

6. Patient Positioning

7.1 Prone and prone flexed position

Due to the retroperitoneal location of the kidneys and their proximity to the flank, PCNL is most commonly performed in prone position with straightforward access to the collecting system. At present, the majority of PCNLs are performed with the patient in the prone position and access is obtained through a posterior or posterolateral calyx. This position offers plenty of advantages, with the main disadvantages being the time required for patient repositioning and anesthetic concerns.

To perform fluoroscopically guided access (which is the most common way to perform PCNL) a high quality retrograde pyelogram is essential. Consequently the procedure begins with the patient positioned supine (Fig 8). Once the patient has been intubated under general anesthesia, rigid or flexible cystoscopy is performed. In men this is performed supine while the frog-leg position is useful in women. Under the guidance of a Nitinol guidewire an angiographic catheter is passed into the collective system. Urine is completely aspirated and the collecting system is filled with radiographic contrast to identify all calyces (Fig 9). The guidewire is then removed and the angiographic catheter is secured externally to a folley catheter. With a folley catheter in place and the angiographic catheter secured externally, the patient is carefully repositioned prone. Prevention of pressure injury must be of great concern and it is taking place with rolls under the knees, feet and chest (Fig 10). The next step is to flex the table 30-40^{o} to open the space between the 12th rib and the posterior iliac crest. Flexion of the hips not only increases the working space on the patient flank, but also may rotate the ribs cephalad, further increasing the working space and facilitate the entry in the collective system from a more easily accessible and less traumatic calyx.

7.1.1 Advantages and disadvantages of prone position

As mentioned the majority of PCNLs are still carried out with the patient in the prone position with prior retrograde placement of an angiographic catheter under fluoroscopic control. This initial procedure prolongs OR time. Additionally, if the procedure is started prone, identification of the posterior calyces, especially in obstructed systems, may be difficult due to dilution of the contrast material in the urine. Prone positioning for PCNL allows access to the entire flank, with a wide choice of calyces to be punctured. Prone position also facilitates upper calyx puncture when and if it is needed.

The prone flexed modification provides several additional advantages over the traditional technique. One and of the most importance is that the working space is further increased and the kidneys are displaced inferiorly in the retroperitoneum making the puncture of the correct calyx much easier.

7.1.2 Lateral and lateral flexed positions

The lateral position has multiple advantages in obese patients and sometimes is the only feasible position for these patients with a BMI >50 who cannot be operated prone. This position allows the abdomen and its contents to fall laterally as occurs when the patient is supine. This maximizes diaphragmatic excursion and helps general anesthesia.

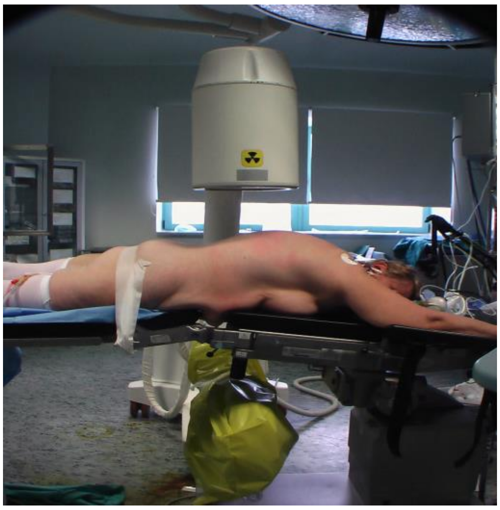
The lateral- flexed position is familiar to any urologist who performs open and laparoscopic renal surgery. This position significantly widens the space between the 12^{th} rib and the iliac crest, flattening the folds of adipose tissue and facilitating percutaneous access. The increased distance between 12^{th} rib and iliac crest produced by this flexion, is even more pronounced than the increase produced by flexion with the patient prone. Also, in this position, the use of a standard length Amplatz sheath and nephroscope is possible providing that the puncture is made from an upper calyx. Finally a relatively new modification of this position is the "Barts technique" in which patient is positioned in lithotomy with ipsilateral pelvis elevated 45^o while his shoulders are rotated to be perpendicular to the OR table and the ipsilateral leg is flexed and adducted and the contralateral leg is fully abducted.

One disadvantage of flank positioning is that percutaneous access usually requires either ultrasound guidance or the use of the triangular technique using the C-arm and so the “bullseye” technique which is simpler cannot be used.

Fig 8 Supine position for performing retrograde pyelogrm

Fig 9 Retrograde pyelogram

Fig 10 Prone position for performing PCNL



7.2. Supine position

The surgical table in an endourology OR must be radiolucent with anticulated leg supports. The patient can lie in pure supine position or with his legs separated and flexed. In both cases a suitable suspension (pillow or a bag) is situated under the lumbar fossa of the targeted kidney. Some nephroscopes are short (<20 cm) and are not recommended, as they receive light and water connections from opposite sides, and this fact obstructs the movements of the nephroscope that are needed from the surgeon in order to render the patient stone free

The patient legs may be extended (with their feet oriented upwards of slightly obliquely) or flexed on leg supports. If the latter, we prefer to set the contralateral leg lower to facilitate the ureteral access with a rigid ureterorenoscope. The ipsilateral arm of the patient is flexed and fixed above their throrax with adhesive drape.

7.2.1 New variations in supine position

Some modifications of this position have been described. Some urologists prefer to rotate the patient a little more[11] in a way that the direction of the tract is more horizontal. Some urologists prefer to maintain the oblique position of the patient in order to allow them larger nephroscope movements[12]. Others prefer the pure supine position without any element of suspension under the lumbar fossa[13]. Finally, others prefer to position the patients with their legs flexed on supports, but with the ipsilateral leg lower and more extended[14].

When there is a need to perform PCNL with simultaneous rigid ureterorenoscopy(URS), we can position the patient with their legs flexed is supports, with the contralateral more descended.

7.2.2 Advantages and disadvantages of the supine position

Supine access is safer for the urologist, because his hands are never in the X-ray beam of C- arm if this equipment is used. Calyceal puncture is easier than when the patients are in the prone position. With the supine position, the incidence of the X-ray is perpendicular to the needle and calyx axis, and displacements of the calyceal papilla are better appreciated when the tip of the needle is pushing in front of them, making it unnecessary to rotate the C-arm fluoroscope.

The iatrogenic risks are minimized, because no patient repositioning is taking place,and no time is wasted in patient maneuvers. In this pure supine position it is also possible to insert the angiograpgic catheter with utilizing of flexible endoscope.

In the supine position intervention is better tolerated by high-risk patients, especially the old and obese, because the vena cava is not compressed and the diaphragm is not pulled up. In this position the risk of puncturing the colon is less than in prone position because when the pillow elevates the lumbar fossa, the kidney and the colon are elevated too. In this prone position, the colon is pulled back, increasing the risk of damage.

One of the best technical advantages of the supine position is the ability to perform simultaneously PCNL and URS. With the two endoscopes inside the kidney manipulation of stone fragments and extraction through the Amplatz sheath is much easier.

This position has also some disadvantages. In this position there is usually a delay in the filling of inferior calyces with the contrast because the inferior renal pole is more elevated that the superior one. Also using this position means that the distention of the tract will be lesser than in prone position. In some patients, it can be more difficult or impossible in supine position to reach upper calyx with a rigid nephroscope.

7. Image guided percutaneous renal access

8.1 Ultrasound

Ultrasound has several advantages as an interventional tool. It is commonly available, relatively inexpensive and portable. It has no radiation and provides guidance for access in multiple planes. Its greatest advantage is use for realtime placement and avoidance of viscera. An added advantage is that Doppler modality helps the surgeon to avoid important vascular structures lying along the needle path. The ultrasound guided approach has proven to be safe and efficacious in the pediatric population[15], renal stones in transplanted kidneys[16] and pelvic renal ectopia[17].

8.1.1 Ultrasound guided access with a needle guide

With the use of this modality the patients lower chest and the iliac crest must be slightly elevated. Usually with the patient in prone position and with the elevation of chest and iliac crest, the bowels and viscera tend to drop down, thus minimizing the chance of bowel injury. When the kidney is scanned and posterior calyx is found, the site of needle entry is marked and the puncture preformed with an 18 G needle. It is essential to minimize respiratory and ultrasound probe movement at this point. In order to ensure an accurate puncture, the needle tip should be seen along the electronic dotted line throughout its course. The position of the needle in the desired calyx is confirmed with return of clear urine. The characteristics of a perfect renal puncture are the shortest route, a straight puncture tract, throughout skin and cortex of the kidney, through the cup of the desired calyx of puncture. Ultrasound guided access is the best modality to accomplish all of the above.

8.1.2. Ultrasound access without a needle guide

A correct puncture can be achieved without a dotted line or a needle guide. The operator places the probe and scans the relevant kidney. The probable path of the needle is marked with the help of the ultrasound transducer and the puncture is done along this path. The serious limitation of this technique is that although the ultrasound probe shows the kidney and calyces, the image does not clearly shows depth and so does not show the plane of the path that the needle passes, as a result of this the chances of visceral injury increases.

8.2 Fluoroscopy

Fluoroscopy equipment in percutaneous renal surgery typically uses radiation for image formation and guidance during all phases of this procedure. Fluoroscopy is useful during the advancement of guidewires, tract dilation, stone removal and nephrostomy placement. PCNL is performed with the combination of fluoroscopic and endoscopic visualization of the collecting system. Fluoroscopy is a 2D (two dimensional) method and unfortunately provides limited information regarding the adjacent soft structures. Nevertheless, it has proven to be an invaluable tool for the performance of PCNL.

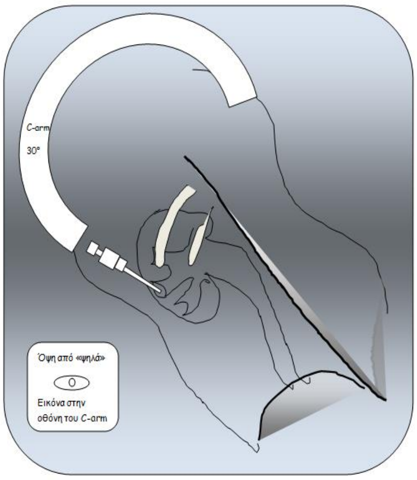
As mentioned above the most frequent calyx to be punctured is the lower and posterior one but access can be obtained through middle or upper calyx as well depending of the stone size and placement. Thorough evaluation of the renal collecting system anatomy is essential prior to definitive percutaneous puncture for access tract creation. The information provided by preoperative CT is very valuable at the time of puncture under fluoroscopic control[18], as it identifies the most suitable place to set the path of the needle from the skin to inside the calyx that has been chosen for puncturing. A CT scan can assess the presence of adjacent organs in the possible path of the needle. When deciding about the correct puncture, parenchyma should be evaluated for areas of parenchyma that are strong enough to maintain a working needle path and prevent subsequent development of a fistula. Also it is desirable to identify those calyces for which surrounding thickness of parenchyma will promote their spontaneous closure of the puncture. Areas of kidney with an extremely thin parenchyma should be avoided because of the possibility of postsurgical hematoma.

Next step is to opacify the collecting system with direct injection through the angiographic catheter of contrast material. The chosen posterior calyx is visualized with the C-arm in the posteroanterior direction initially Percutaneous access to the upper urinary tract through a calyx must meet five conditions that guarantee safe access and avoid complications: access is performed from a posterolateral position, through the renal parenchyma, towards the center of the calyx posterolaterally, and toward the center of the renal pelvis and as a result of these four conditions, the trajectory does not damage any major blood vessels.

There are two primary methods used to gain fluoroscopy-guided percutaneous renal access: the “bullseye” technique and triangular technique[19]. The use of these techniques needs opacification of the collective system with iodinated contrast that is administered retrograde via an angiographic catheter, in order to visualize the targeted calyx. A calyceal entry point is selected to avoid the larger vascular structures that are found at the level of the infundibulum.

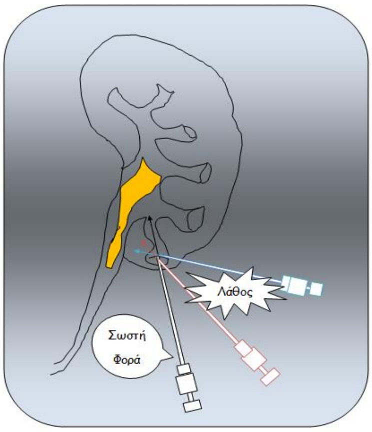
As with most percutaneous access techniques, the bullseye technique requires fluoroscopy to monitor and guide the procedure. With the C-arm in the 30^o position, an 18 G access needle is positioned, so that the targeted calyx, needle tip, and needle hub are in line with the image intensifier, giving a bullseye effect on the monitor. In effect the surgeon is looking down the needle into the targeted calyx. The needle is advanced in 1-2 cm increment. Continuous fluoroscopic imaging is performed to ensure that the needle maintains its proper trajectory. Needle depth is ascertained by rotating the C-arm to a vertical orientation. If the needle is aligned with the calyx in this view, clear urine comes from inside the needle, confirming proper positioning. (Fig 11)

Fig 11 Bullseye technique



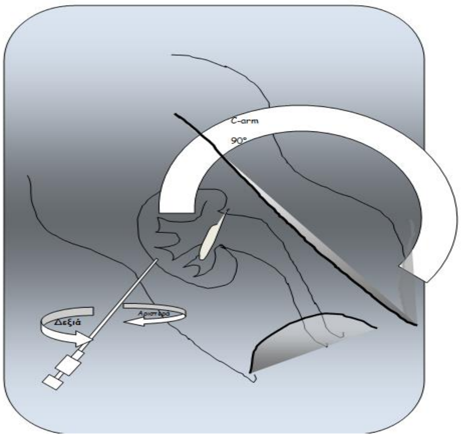
The triangulation technique is based on simple geometric principles and is guided by fluoroscopy. Under fluoroscopic control the needle is positioned in straight line with the infudibulum of the calyx that is going to be punctured. In this way we have the first dimension that we need in order to gain access to the collecting system of the kidney (Fig11).

Fig 11 Confirming the first dimension for the correct puncture for PCNL



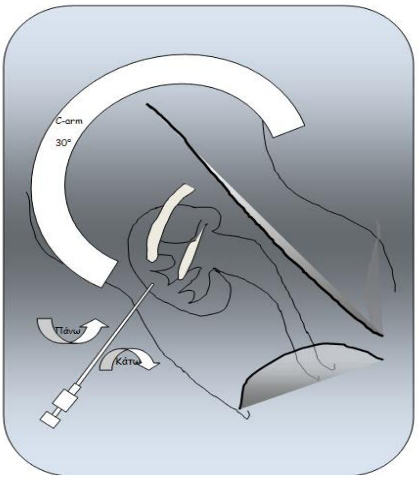
The constant movement of the C-arm unit between the different angles gives the surgeon the two dimensions of the correct proceeding of the needle tip. With the C- arm in parallel with the puncture line gives the surgeon the second of three dimensions (Fig 12)

Fig 12 Confirming the second dimension in PCNL



The surgeon then rotates the C-arm unit 30^{o} toward his place and so the fluoroscopic image gives the 3rd dimension of the triangular technique.(Fig13)

Fig 13 Confirming the 3rd dimension of the triangular technique



8.3 Novel techniques for gaining percutaneous renal access

Fluoroscopy with the use of a C-arm and ultrasound, either alone or in conjuction with fluoroscopy, are the most commonly used modalities for gaining percutaneous renal access for PCNL[19]. However, in certain scenarios, CT-guided access may be the only viable option as it provides precise control of the needle path and also gives information about the adjacent structures. This technique was first described by Haaga et al in 1977[20].

Indications for CT- guided access include anatomic difficulties, such as spinal dysraphism[21], morbid obesity, abnormal visceral anatomy (retrorenal colon or spleen)[21], abnormal urinary tract anatomy (urinary diversion)[22] abnormal renal anatomy (multiple cysts, angiomyolipoma)[23], ectopic/ transplant kidney and failed access using standard fluoroscopy/ultrasound.

CT guided percutaneous renal access may be undertaken in an interventional CT suite using CT fluoroscopy or using a hybrid unit that combines Ct with standard fluoroscopy[24]. It can also be performed in a standard CT unit with intermittent scans taken with the operator outside the room which minimizes radiation for the controller but it is slower[25]. Some investigators have also used laser guidance system to facilitate needle entry[26]. Access is obtained with the patient prone or supine- oblique. A scout tomogram is initially registered to help localize scans to the renal region. A non contrast acquisition of the abdomen is obtained and the kidneys assessed for dilation, presence of renal masses and relative position in relation to colon, spleen, liver and diaphragm.

A suitable calyx for entry is identified following the principle that the safest, most direct route is through the fornix of a posterior facing calyx. This reduces the risk of arterial hemorrhage. After infiltration of local anesthesia, a 18 G needle with sheath is advanced subcutaneously towards the target calyx. A further localizing scan with the needle in place helps finer adjustment on the needle trajectory. Based on this scan the trajectory of the needle is altered and either advanced or withdrawn until urine is obtained. Often it is only necessary to advance or withdraw the needle a few millimeters to hit the targeted calyx. Once urine is seen, a repeat scan confirms the position of the needle tip in the collecting system. Next move is to insert a guidewire through the plastic sheath into the collecting system. The sheath is removed, dilation is made in the way we describe and a nephrostomy tube is been placed and the patient transferred in the operating room for surgeon to perform PCNL.

8.4 Robotic assisted percutaneous entry of the collective system

Robotic percutaneous renal access systems were first proposed less than two decades ago by Potamianos et al who performed the first studies in creating a passive robot to facilitate needle placement for percutaneous surgery[27]. Since then and for the last 15 years many robotic systems were developed. One of them PAKY-RCM is a robot with three active DOF(degrees of freedom) that can remotely align the needle along a selected trajectory pathway under fluoroscopic guidance. PAKY is the needle driver and the RCM device is an active robotic arm attached to PAKY that allows the tip of the needle to pivot about a fixed point on the skin. Another robotic system Revolving needle driver helped improving targeting and reduce errors by as much as 70%. These robotic systems helped urologists acquire more experience in entering the collecting system and the patients from being re-operated for removing a renal stone. The ultimate goals in applying robotic technology in performing PCNL are to obtain an access to the collecting system of the kidney with ease, accuracy and efficiency. Robotic assistance for percutaneous access may ultimately improve surgical performance and decrease complication rates and operative times[28]. Finally robotic systems helped a new promising field telerobotics, to emerge helping new surgeons to master this technique with the help of an expert who may be thousands of miles away.

8. Dilation of the nephrostomy tract.

With the use of the above techniques gaining access to the collecting system throughout a target calyx is successful. The correct puncture is been confirmed and the fluoroscopic image (if this technique was used) is seen in Fig 15. The next step is to advance the guide wire (0, 0035 inch, Nitinol) whenever possible down to the bladder in order to reduce the chance of losing the tract due to accidental removal of the guidewire after subsequent manipulations(Fig 16). If this is impossible enough wire must be coiled in an upper calyx in order not to be damaged or interfere with the procedure. Fig 17.

Fig 15 Image of a correct access in the collecting system

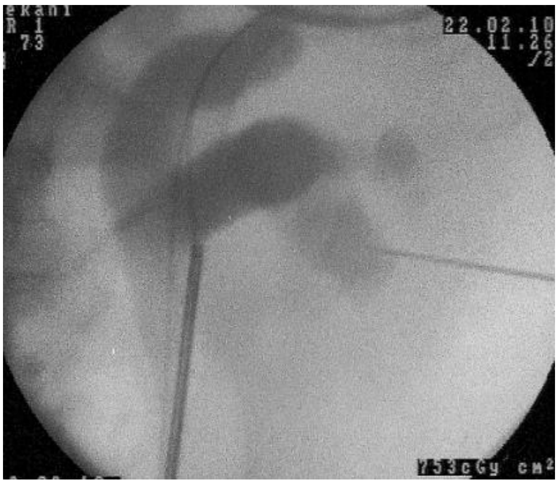


Fig 16 Advancement of guidewire down to the bladder

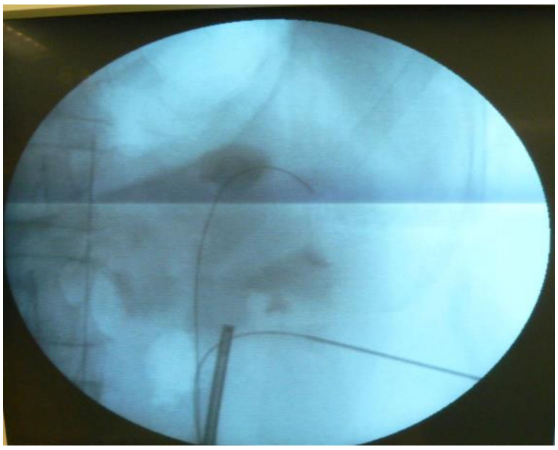
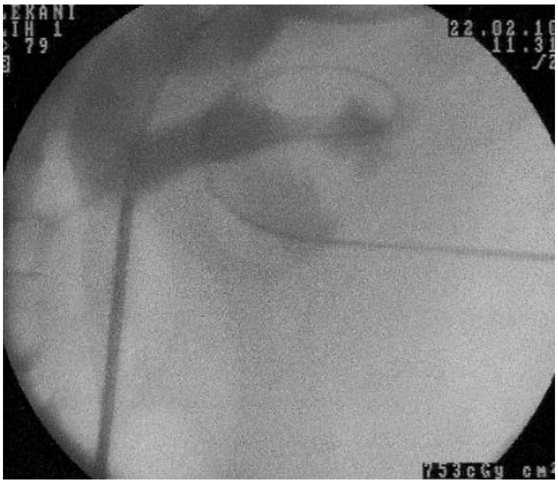


Figure 17 Guidewire coiled in the collecting system

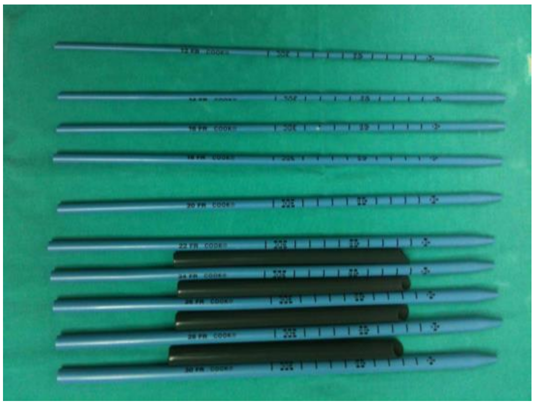


After the correct placement of the guide wire the next step is an incision 1, 5-2 cm in the skin around the wire and then the dilation instrument is advanced over this wire. There are many different types of dilators.

The fascial dilator system set is composed of Teflon cylindrical dilator of progressively larger circumference, ranging from 5F to 30 F in size. The introduction of each dilator is usually carried out in a rotational or spinning motion, under mandatory fluoroscopic guidance. This system is particularly useful when faced with the need to dilate a heavily scarred tract, following previous percutaneous surgery or in the presence of a retroperitoneal inflammatory process. The main disadvantage of this system is the potential risk of kinking of the wire following dilation failure.

The Amplatz dilator (Fig 18) set is composed of tapered-tip polyurethane cylindrical dilators of progressively increasing circumference ranging from 8 to 30 F. The main advantage of this set is conferred by the used of tapered 8F angiographic catheter. The use of this catheter provides additional stiffening and stability of the guidewire, thereby decreasing the risk of its kinking. The 8F angiographic catheter is inserted over the guidewire under fluoroscopic guidance, as an initial step. All subsequent larger dilators are inserted over the 8F angiographic catheter and guidewire, in order of increasing the diameter. The shoulders of each dilator must be advanced until entirely within the entry calyx. The working sheath is introduced last, over the largest Amplatz dilator until the leading edge of the sheath overlaps the shoulders of the Amplatz dialtors.

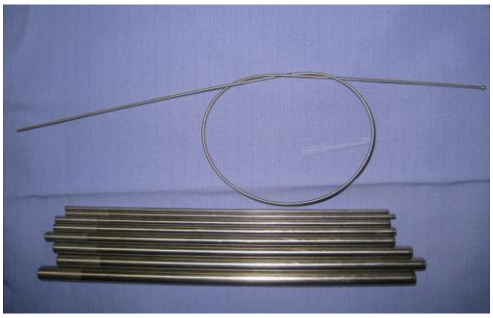
Fig 18 Amplatz dilators



Coaxial metal dilator systems

Coaxial metal dilators such as the Alken instruments (Fig 19) are composed of stainless steel rods which are mounted together in a telescopic fashion. Each dilator is designed to adapt to the lumen of the next successive dilator, starting with an 8F hollow guide rod. The initial hollow guide rod is advanced over a guidewire under fluoroscopy, until the tip is positioned within the renal pelvis. Each dilator, dilates the tract 4F and ultimately all together 24-26F. The main advantage of this system is its rigidity but it can also lead to iatrogenic trauma.

Fig 19 Alken dilator system



Balloon dilator system

Percutaneous nephrostomy tract balloon dilators (Fig 20) are intended for creation of tracts in a rapid and are performed in a single step, They are designed to be introduced into the collecting system over a guidewire and tract dilation is carried out under fluoroscopic guidance. The balloon dilator set consists of a expendable balloon, 30 F working sheath that is back- loaded before the deflated balloon is placed over the wire and syringe inflator. Pressure of up to 20 atm can be easily achieved with this system, although in general, much lower pressures are usually sufficient for tract creation(12-16). Balloon inflation allows for full expansion of the balloon, which is followed by insertion of a working sheath over the balloon, in a rotational manner. The main advantage of this system is the fact that the tract is created using lateral, rather than angular, shearing forces which in theory are less traumatic and reduce the chance of larger vessel injury. The main disadvantage is the relatively higher cost compared to other systems.

Figure 20 Balloon dilator system

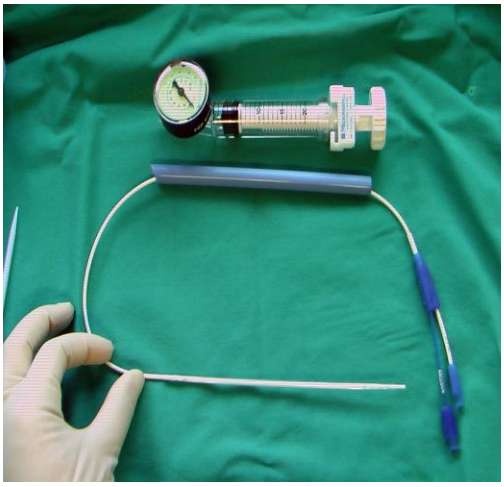
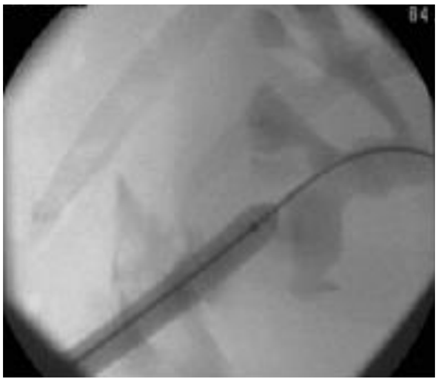


Figure 21 Correct dilation



9.1 Potential complications of tract dilation

Acute hemorrhage can originate from intercostal vessels, renal parenchymal branches of the renal vein or renal artery adjacent to the pelvicalyceal system. The most clinically significant bleeding related to percutaneous tract dilation is due to over advancement of the dilating instrument, resulting tearing of the infundibulum. Moreover the most common cause of renal pelvis perforation is the aggressive use of dilators. This perforation can be identified intraoperatively by contrast extravasation on fluoroscopy which requires termination of the operation and placement of a JJ stent or a nephrostomy tube or after the operation which requires the same procedure in the most emergency manner.

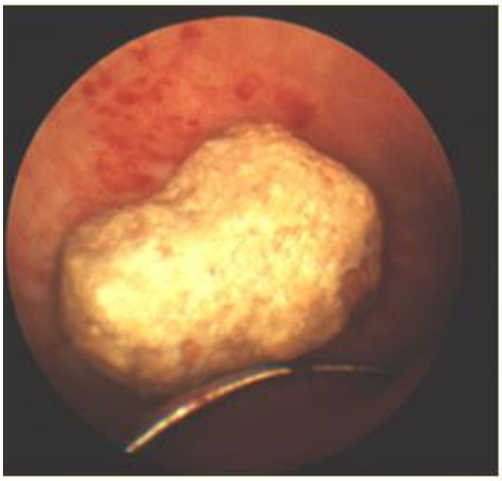
9. Rigid and Flexible Nephroscopy

Rigid nephroscopes are most commonly used to clear stones from the collecting system during PCNL. However anatomic differentiations and stone position can make these instruments unhelpful in rendering a patient stone free.

Once the desired calyx is reached with the rigid or flexible nephroscope or ureteroscope, the size of the stone(s) to be removed must be measured (Fig 21).If the stone size makes probable pulling it through the infundibulum intact, a basket or a grasper can be used. This maneuver needs special care not to traumatize the infundibulum. If the stones to be removed are too large, lithotripsy must be performed usually with a device combining mechanical and ultrasonic lithotripsy or with holmium:YAG laser. While ultrasonic lithtotripters enable concominant fragmentation and suction, they can be used solely through rigid or semi-rigid endoscopes. As for the laser it can be used either through rigid or flexible instruments and are the only available modality with small diameter flexible ureteroscopes. There are a wide variety of laser fibers each used for different kind of situations. Most urologists generally use a 200μm fiber through the flexible nephroscope as it easily fits through this instrument without affecting deflection or irrigation. The settings to be used depend on the nature and the size of the stone. If the goal is to fragment the stone in tiny fragments then the settings of the machine must be lower power at a faster frequency. If the stone is very hard then high power and lower frequency are the desired settings. The resultant pieces can then be extracted through the sheath.

Tiny fragments are often broken off by the laser if they cannot be extracted with any means. One technique is to irrigate with a syringe or a cutted Nelaton catheter through the sheath to flush out these fragments. If they are small enough they can even be aspirated with the syringe. The most effective technique also includes changing the position of the patient to maximize the drainage of these fragments. From the renal pelvis, the fragments can be easily extracted by the rigid nephroscope using atraumatic forceps.

Fig 21 Estimation of the size and type of the stone



The need for postoperative drainage is evaluated intraoperatively. If the patient is a candidate for a “tubeless” procedure a JJ stent is places antergradely with stich closure on the puncture site. If not a re-entry percutaneous nephrostomy can be used for rapid re-access to the ureter.

10. Lithotripsy

11.1 Ultrasonic lithotripsy

Ultrasound waves can be created through a number of different mechanisms. In the devices that are currently used a current is applied from a separate generator, to a piezoceramic plate. This plate generates vibrational energy in the form of ultrasonic waves at a frequency between 23 and 25 kHz. This energy is transmitted through the hand piece to a solid or hollow probe that is placed in contact with the stone. The vibrations of the probe transmit the energy to the calculus, resulting in a drilling effect. Ultrasonic probes are manufactured in a variety of sizes from 2,5F to 12F. The largest probes incorporate a hollow channel through which suction is applied.

11.2 Pneumatic Lithotripsy

Another example of a direct contact lithotripter is ballistic lithotripsy. Although any number of driving forces can initiate the movement of the projectile of this device the most notable and most widely utilized is compressed air. As in ultrasonic lithotripsy, the mechanism of action in pneumatic lithotripsy increases the chances for potential injury of the collecting system especially perforation. One of the limitations of pneumatic over ultrasonic lithotripsy is the solid nature of the probe without however existence of suction channel. Technically the use of pneumatic lithotripsy is facilitated by the use of nondeflected working channel. Direct vision is mandatory to ensure the safety as well as to facilitate adequate fixation of the calculus against the urothelium.

11.3 Combined ultrasonic and pneumatic lithotripsy

In an attempt to combine the benefits of these two technologies, the Lithoclast Ultra was developed. This device uses a combination of ultrasonic and pneumatic lithotripsy to accomplish calculus fragmentation and evacuation. A single control unit is activated via a foot pedal and enables the surgeon to use either of the lithotripters individually or in combination. Suction is incorporated into the ultrasonic portion of the device. (Fig 22). Combining the pneumatic lithotripter's ability to successfully fragment hard stones with the disintegration and suction capabilities of ultrasonic lithotripsy help to minimize stone retropulsion, facilitate stone clearance and decrease operative times.

Fig 22 Lithoclast®(EMS) system

11.4 Laser lithotripsy and the holmium: YAG laser

Laser amplification by stimulated emission of radiation (L.A.S.E.R.) is a mechanism for emitting electromagnetic radiation through stimulated emission of protons. The holmium laser operated at a wavelength of 2100 nm. Its fibers are available in diameters ranging from 200-1000 μm. Both the 200 μm and 365 μm fibers can be used with semi-rigid and flexible ureteroscopes and their flexible nature allows for preservation of flexion capabilities which is a great advantage of this modality. The ability to effectively fragment all stone compositions makes HoL lithotripsy a valuable tool in the hands of an endourology surgeom. In addition the flexible nature of the laser fiber makes it helpful in flexible renoscopy. The relatively small penetration of this laser provides a high margin of safety as long as care is taken to keep the fiber at least 1 mm from the urothelium. The disadvantages of Hol lithotripsy lie within its potential ability to perforate the urothelium if activated within close proximity to the wall of collecting system. In addition the cost of the fibers combined with their relatively small life span may be a major drawback.

Technically the Hol fiber should be kept at least 2 mm beyond the end of the scope to avoid damage to the lens system. The most efficient technique to fragment the stone with the laser is the painting technique. In this way the lithotripsy allows vaporization of the stone and helps avoid large fragments. While performing laser lithotripsy it should be kept in mind that laser has the capability of cutting through metals (guidewires, baskets).

Part 2

A. Introduction

According to most recent guidelines of EAU, percutaneous nephrolithotripsy (PCNL) is the gold standard procedure for stones> 2 cm, in stones situated inside a diverticulum of the lower calyx, in staghorn calculi, in failed extracorporeal shockwave lithotripsy (ESWL) and in stone situated in a lower calyx and ureteropelvic junction stenosis[29].With the development of new endoscopic modalities, novel imaging techniques and robotic technologies that can be combined with the standard PCNL, this relatively old surgery technique can play a distinctive role in the era of minimal invasive urology and possibly augment it. The purpose of this article is to review the literature for all the novel aspects of this procedure and their effectiveness.

B. Materials and Methods

We reviewed the literature for articles concerning percutaneous lithotripsy (PCNL). The search was limited in articles which had at least abstract written in English and were indexed in PubMed from 1980- 2014. The keywords that were used were percutaneous lithotripsy, techniques, patient positioning, imaging modalities, dilation, puncture site, drainage and novel aspects.

C. Patient positioning

Valdivia et al were the first researchers ever published their experience in 557 patients which were operated in the supine position in an attempt to overcome the limitations of the most widely used so far, prone position. In this study authors conclude that the risk for colon perforation is significantly lesser in the supine than in prone position due to the position of the bowel which is far from the kidney and the puncture tract[30]. There are studies conducted in a large number of patients which are in favor of supine position while explaining its advantages, including decreasing operating time, evacuation of stone fragment, a more tolerable position for high-risk patients, and sitting position for the surgeon[31]. The other major complication of PCNL, which is bleeding, is the field of study of a recent review which demonstrates an overall transfusion rate of 4, 6% with supine PCNL[32]. But the most important results come from the direct comparison of prone and supine positioning during performance of PCNL by the same surgeon. There are three studies in the literature that give us the answer in the above question. Unfortunately those papers are underpowered due to small sample sizes, but nevertheless no significant difference in transfusion rate was noted by any group. When considered together the transfusion rate for PCNL performed in the supine position was 8, 4% versus 4, 3% when performed prone (p=0.07)[32,33,34]. More recently de la Rosette et al when they examined the effect of patient positioning, they concluded that the prone position was associated with similar bleeding rates, but decreased operative times, and slightly improves stone free rated compared to the supine position in patients with increased BMI and with staghorn stones[35]. Other possible positions are the supine Valdivia- Galdakao, the modified supine position and the "Barts" position, especially in obese patients or patients with cardiac or respiratory problems[36,]. Recently Daels et al[37] studied 75 patients in which they performed PCNL in Valdivia-Galdakao position. The study proved that this position has significantly lesser complications from the cardiovascular and the respiratory system and also provides better access to the airway. The study also concluded that there are lesser complications from the gastrointestinal tract due to the position of the colon. In similar results reached Amon Sesmero et al[38] who studied 50 patients who were operated in Valdivia- Galdakao position vs 50 patients in prone position, with similar stone free rates.

D. Imaging technique for the puncture of pelvicalyceal system

The most widely utilized imaging modalities for obtaining percutaneous access to the collecting system is fluoroscopy and ultrasound. Access to the collective system with fluoroscopy is more challenging that with ultrasound guidance[39]. In a clinical trial 100 patients with no abnormality of the upper urinary tract were selected from among candidates for PCNL and randomly assigned to two groups (of 50 patients each): group 1 that ultrasound guided access was utilized versus group 2 that fluoroscopy guided access was used. Duration of the access procedure was 11+- 3,5 mins and 5,5+-1,7 mins in groups 1 and 2 respectively (p=0.001). Duration of radiation exposure, on average was 0,69 and 0,95 min respectively (p=0,001). They concluded that ultrasound guidance for accessing collective system in PCNL is an acceptable alternative to fluoroscopy and also decreases radiation hazards[40]. In another study Zegel et al compared 55 patients with ultrasound access with 33 patients with fluoroscopy access and found that the use of either sonographic method for the initial needle puncture significantly reduced the number of puncture attempts (p = 0.000004) and potential iatrogenic risk, eliminated the need for intravenous administration of contrast material, allowed initial safe introduction of a large caliber needle, and decreased the length of time needed to perform the procedure[41]. Ultrasound-guided access has also been described in the nondilated system and researchers found that under B-type ultrasound guidance, severe complications did not occur during nephrolithotripsy and stones were cleared in 114 out of 132 cases

(86.4%) during immediate phase I lithotripsy this operation and so this operation appears to be efficacious and safe[42] but this approach needs significant experience[43] .On the other hand there are studies that performed a combination of these two techniques and found this combination efficient and safe method in PCNL and they conclude that it should be the first option in PCNL[44]. Finally in a recent study, Andonian et al studying a matched sample with 453 patients in each group from the CROES database concluded that there is a greater risk of hemorrhage when fluoroscopy is used in contrast with the use of ultrasound 13.1% (p=0.001) and 11.1% (p=0.001) respectively but they remark that this must be related to a greater access sheath size (≥ 27F) and multiple puncture[45].

Novel techniques like CT or MRI guided puncture for performing PCNL are basically needed in few selected patients but more recent studies tend to alter this conclusion and augment the role of these modalities in performing PCNL[46]. The need for reducing the number of punctures lead to the development of new techniques like all seeing needle. Bader et al[47] studied 15 patients who underwent PCNL with the use of this technique and published very good results.

Trying to achieve the same goal led to the development of novel modalities such as the use of robotic system for percutaneous renal puncture. LARS (Laparoscopic Assistant Robotic System) was used by Cadeddu et al[48] who described accuracy in vitro 0,43 mm and ex vivo success with the first attempt 83%. A more recent developed robotic system called PAKY (percutaneous access to the kidney) helped in performing PCNL in 9 patients and authors described in the in vitro study, successful puncture with the first time in all 70 attempts, including 10 attempts at the 3-mm balls. Clinically, percutaneous access to the desired calix was attained on the first attempt in each case. The mean targeted calyx was 14,7 mm I diameter and the mean time required to gain access was 8,2 mm with no complications[49]. PAKY-RCM (percutaneous access to the kidney with the remote center of motion device) which is the evolution of the PAKY system accomplished even better results when compared with the standard manual access. In a study comparing 23 patients in a group with robotic assistance and 23 in a group with the standard manual access the results, no significant difference was found in time to access with the mean number of attempts 2.2 +/- 1.6 v 3.2 +/- 2.5 (P = 0.14), a mean of 1 10.4 +/- 6.5 minutes v 15.1 +/- 8.8 minutes (P = 0.06) in the manual needle puncture. The PAKY-RCM was successful in obtaining access in 87% (20 of 23) of cases. The authors conclude that Robotic PAKY is a feasible, safe, and efficacious method of obtaining renal access for nephrolithotomy[50]. Nevertheless these modalities are still in infancy and larger studies are needed in order to prove their efficacy and cost-effectiveness.

E. Site of puncture

The most commonly used site for entering the collective system is a rear posterior calyx due to lack of vessels in this area. Nevertheless the puncture of an upper calyx may be mandatory due to the position or the size of the stone. This puncture has higher complication rates which range between several studies in the literature from 10-26%. Munver et al.[51] studied 240 patients and found that the overall complication rate irrespective of percutaneous approach was 8.3% (16.3% for supracostal and 4.5% for subcostal access). More specifically the three major complications categories that typically are of concern in PCNL are pulmonary complications, adjacent organ injuries and postoperative pain. For the first category it is well documented that supra costal access is associated with increased occurrence of pulmonary injuries. From the same study seven out of 8 intrathoracic complications (87.5%) developed in supracostal cases. As for organ injury, which is less common than pulmonary complications, include injury of liver, spleen and intestines. A similar study shows that PCNL with supracostal access can damage the liver in 4% of patients and the spleen in 3% of patients especially during aspiration, whereas the primary risk from a posterior 11th-12th rib intercostal approach to the upper renal collecting system of intervening lung can be expected to occur in from 14% to 29% of patients[52]. Because these injuries and especially colon perforation may result in an important morbidity and even mortality the use of preoperative CT to determine the relationship of adjacent structures is of great importance[53]. Another study mentions that patients undergoing PCNL with supracostal approach can exit the operating room without the need of drainage resulting in less analgesia (P = 0.000) and discharging at a mean of 19 hours earlier (P = 0.000) than those in the control group (with drainage)[54]. Finally the main conclusion about puncture site is that familiarity with basic renal anatomy is essential to obtain access safely. Adherence to basic principles allows the establishment of percutaneous access in a straightforward and efficient manner. Of course certain clinical situations may require special access techniques[55].

F. Dilation of access

There are a wide variety of dilators in order to perform PCNL. Every one of them has its advantages and disadvantages with the balloon dilator to be the most commonly used. The most important complication of dilation remains hemorrhage and varies between the dilators with balloon dilator having the better rates, ranging from 0%- 15,5%[56,57,58]. Other common complication of dilation is renal pelvis perforation. This complication can be minimized using the one step dilation which is provided by the balloon system dilator.

G. Lithotripsy

The two most commonly used modalities in PCNL for lithotripsy is the combined ultrasonic and pneumatic lithotripsy and the Holmium YAG: laser (HoL) lithotripsy. The clinical utility of the combined (ultrasonic and pneumatic) lithotripter has been evaluated in several studies[59,60,61]. In the first of these studies, 68 patients were treated for staghorn calculi over a 2 year period. From these thirty-five patients had complete and 33 patients partial staghorn calculi. Clinically, complete stone free rate (KUB and ultrasound) was 66% after the first PNL whereas sixteen out of 68 patients had a second look PNL with an overall stone free rate of 89.7% by dismission[59]. In the second study, 20 patients with symptomatic renal stone were randomized to receive stone fragmentation and removal using a standard ultrasonic device or a new combination pneumatic/ultrasonic. The combination device required significantly less time for complete stone clearance (21.1 versus 43.7 minutes, p = 0.036) as well as a greater rate of stone clearance (39,5 vs 16,8 mm2/min, p = 0.028)[60] . Finally in the third study, in which 30 patients were enrolled, stone ablation and clearance rates were similar for both the combined pneumatic and ultrasonic device and the standard ultrasonic device (46 and 66,7% p=0,26). When stratified with respect to stone composition, the combined device was more efficient for harder stones, and the standard device was more efficient for softer stones[61].

Hol has been extensively used for PCNL, with success rates after a single session ranging from 61,4% to 89% and their result have shown that using a high-power holmium-YAG laser is safe and effective in the treatment of large renal stones[62]. A relevant study compared Hol and pneumatic lithotripter in 60 patients who underwent PCNL for 2,5 cm stone and found more operating time in the laser group, more complications with pneumatic lithoclast group and a high initial cost of laser, with similar stone free rates.[63]. One of the largest studies so far in the literature was published by Li et al and presented a novel technique for PCNL called MPCNL. The authors published 4760 minimal invasive PCNLs (MPCNLs) in 3610 kidneys including 240 kidneys with staghorn calculi and 85 ureteral stones. They published a stone free rate of 89% and a significant complication rate of 0,86%. Their conclusion was that MPCNL is a safer approach which minimizes the risk of vessel injury but much time is needed for the surgeon to master this technique[64]. Finally for stone fragment extraction a technique using a Nelaton catheter to wash out these fragments has been published with very good results[65].

H. Drainage and hemostasis

There are three main techniques for ending a PCNL procedure: placement of a nephrostomy tube, placement of a ureteral stent and without any drainage (total tubeless surgery). Pietrow et al randomized thirty consecutive patients to receive either a 10F pigtail catheter or a 22F Council-tip catheter for their percutaneous drainage after PCNL. They authors demonstrated that those patients with the smaller nephrostomy tube noted significantly lower pain scores at 6 hours (3.75 v 5.3; P=0.03). Although the pain scores were lower on POD 1 and 2 for the 10F catheter group, the difference was not statistically different (1.9 v 2.9 and 1.25 v 1.9, respectively; both p>0.05) without reporting any adverse effects with the smaller tube[66]. Not many papers exist in the literature to compare PCNL with tube drainage and stented PCNL. In one of these Feng et al compared 27 patients that underwent traditional PCNL with tract dilation to 30F for passage of a 34F working sheath versus “mini-PCN” in which tract dilation was performed up to 22F for passage of a 26F sheath versus tubeless PCN which involved the use of a double-J stent for internal drainage without the use of a nephrostomy tube for external drainage at termination of the procedure (stented PCNL). The researchers found that the tubeless PCNL group required less morphine use, had a decreased length of hospitalization, and had a smaller total procedural cost compared with the other two groups, but this study has the disadvantage of small number of patients[67]. A much larger randomized study was conducted by Agarwal et al who reported 222 patients underwent standard PCNL versus tubeless PCNL In this study superior outcomes in terms of postoperative pain(59 +/- 5.1 vs 31 +/- 4.8 p < 0.01) and hospital stay (21.8 +/- 3.9 hours vs 54.2 +/- 5 hours p < 0.01) and incidence of urinary leakage from the nephrostomy site (0/101 vs, 7/101) were found in the tubeless PCNL[68]. In the same pace a prospective randomized trial of 85 patients found lesser surgery time and lesser postoperative pain in the stented group, with no significant difference in bleeding or leakage complications observed.[69]. Same results in a large meta-analysis of 14 randomized trials including 776 that showed that there were statistically significant differences in hospital stay, postoperative analgesic requirement and urine leakage between tubeless and standard PCNL but no statistically significant differences in terms of stone-free rate, postoperative fever, and blood transfusion between tubeless and standard PCNL[70]. The results of relevant studies are in favor of totally tubeless PCNL[71]. The first randomized trial concerning this subject of debate came from

Instanbulluoglu et al in forty-five patients who underwent totally tubeless PCNL (Group 1) vs 45 patients in which a 14F malecot nephrostomy catheter was used for drainage (Group 2). When comparing the two groups they found the same results in the stone free status and complication rates with lesser postoperative pain in the tubeless group[72]. Totally tubeless PCNL is a safe method in a well selected group of patients but larger studies are needed to prove the safety and efficacy of this procedure in a larger cohort of patients needing PCNL. Clearly the postoperative drainage is mandatory in the case of serious bleeding, perforation or injury of the adjacent organs[73]. The complication rate between the different modalities in every step of the procedure is shown in Figure 1.

In patients who are eligible for stented or tubeless PCNL, adjunctive techniques can be utilized to establish hemostasis and aid parenchymal closure. Various options like sealants and thermoablative techniques can be utilized for this cause. These techniques are not very well known to a large portion of the urologic society and so studies like the one of Choe et al give a detailed review of the available sealants and their characteristics[74]. A relatively large randomized trial of Shah et al followed 32 patients who underwent uncomplicated stented PCNL and 31 patients in the control arm. The study showed lesser postoperative pain and analgesic requirements in the study group but no statistically significant difference in the blood transfusion rate or in the length of hospital stay whereas complete stone clearance was achieved in 87.5% of patients in the experimental group and in 90.32% of control[75]. Due to the possible effect of these hemostatic agents when in contact with urine[76] and the little follow up of the patients involved in the relevant studies due to the limited use of these factors no safe conclusions can be extracted regarding their effectiveness.

In the same manner sparse data in the literature exist concerning thermoablative techniques that give a possible new field of study[77] but their effectiveness is far from proven.

I. Combination of endoscopic techniques and PCNL

The combination of flexible ureteroscopy (URS) and PCNL for the treatment of staghorn calculi can decrease the number of kidney puncture and accomplish better stone free results[78,79]. Scoffone et al[80] studied 127 patients who underwent combined URS and PCNL in Valdivia- Galdakao position accomplished stone free rates up to 82%. In this combination technique efforts have been made to use smaller instruments and this procedure is known as mini-PCNL, in which the tract is dilated only in 13-20 Fr[81].

J. Conclusions and future perspectives

PCNL was widely used in the past but it is still a valuable procedure and will be an important technique for the future. It is the gold standard technique for treating big and staghorn stones. Big multicenter randomized trial concerning PCNL and its efficacy in a wide variety of different factors are ongoing. Their results are expected with great concern[82].

Figure 1 Comparison of complication rates between the most popular modalities used in each step of the procedure

Step of the procedure	Complication type	Complication rate
Patient Position (supine vs prone)	Blood transfusion	8,4% vs 4,3 % (p=0,07) [4,5,6]
Imaging(fluoroscopy vs ultrasound)	Risk of hemorrhage	13,1% vs 11,1% (p=0,001) [17]
Site of puncture(subcostal vs supracostal)	Overall complications	4,5% vs 16,3%[23]
Tract dilation(Amplatz vs balloon)	Blood transfusion	15% vs 10% (p = 0.048)[28]
Drainage (standard vs tubeless)	Leakage	7% vs 0%[40]

Abstract

Percutaneous nephrolithotripsy is one of the most important surgical options in the treatment of renal calculi. This article presents the stages of the technique of percutaneous nephrolithotripsy and the advantages and disadvantages of each method. In particular, analyzes the prevailing and new data in patients position, renal access, dilation of the nephrostomy tract and the type of renal drainage and lithotripsy as well as the possible future perspectives that make this intervention a key member of minimally invasive urological surgery

Περίληψη

Η διαδερμική νεφρολιθοθρυψία αποτελεί μια από τις σημαντικότερες χειρουργικές επιλογές στην αντιμετώπιση της λιθίασης του νεφρού. Στο παρόν άρθρο παρουσιάζονται τα στάδια της τεχνικής της διαδερμικής νεφρολιθοτριψίας αλλά και τα πλεονεκτήματα και τα μειονεκτήματα της κάθε μεθόδου.. Ειδικότερα, αναλύονται τα επικρατούντα και τα νεότερα δεδομένα στη θέση του ασθενή, της

νεφρικής προσπέλασης, στους τρόπους διαστολής της οδού νεφροστομίας αλλά και το είδος της νεφρικής παροχέτευσης και της νεφρολιθοτριψίας και των πιθανών μελλοντικών προοπτικών που καθιστούν αυτήν την επέμβαση βασικό μέλος των ελάχιστα επεμβατικών ουρολογικών χειρουργείων.

References

1. Fernström I, Johansson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol. 1976;10(3):257-9
2. Alken P, Hutschenreiter G, Günther R, Marberger M Percutaneous stone manipulation. J Urol. 1981 Apr;125(4):463-6.
3. Matlaga BR, Assimos DG. Changing indications of open stone surgery. Urology. 2002 Apr;59(4):490-3; discussion 493-4.
4. Barcellos Sampaio FJ1, Mandarim-de-Lacerda CA. 3-Dimensional and radiological pelviocaliceal anatomy for endourology. J Urol. 1988 Dec;140(6):1352-5.
5. Albanis S, Ather HM, Papatsoris AG, et al. Inversion, hydration and diuresis during extracorporeal shock wave lithotripsy: does it improve the stone-free rate for lower pole stone clearance? Urol Int 2009;83(2):211-6.
6. Kosar A, Ozturk A, Serel TA, et al. Effect of vibration massage therapy after extracorporeal shockwave lithotripsy in patients with lower caliceal stones. J Endourol 1999 Dec;13(10):705-7.
7. Patel SR1, Haleblian GE, Pareek G. Percutaneous nephrolithotomy can be safely performed in the high-risk patient. Urology. 2010 Jan;75(1):51-5. doi: 10.1016/j.urology.2009.06.064. Epub 2009 Sep 25.
8. Edgcombe H, Carter K, Yarrow S. Anaesthesia in the prone position. Br J Anaesth. 2008 Feb;100(2):165-83. doi: 10.1093/bja/aem380. Review.
9. Nyrén S, Radell P, Lindahl SG, Mure M, Petersson J, Larsson SA et al Lung ventilation and perfusion in prone and supine postures with reference to

anesthetized and mechanically ventilated healthy volunteers. Anesthesiology. 2010 Mar;112(3):682-7

10. Vibhute M1, Kamath SK, Shetty A. Blood utilisation in elective general surgery cases: requirements, ordering and transfusion practices. J Postgrad Med. 2000 Jan-Mar;46(1):13-7.
11. Daels F., González MS, Freire FG, Jurado A, Damia O. Percutaneous lithotripsy in Valdivia-Galdakao decubitus position: our experience. J Endourol. 2009 Oct;23(10):1615-20. doi: 10.1089/end.2009.1526.
12. Cormio L, Annese P, Corvasce T, De Siati M, Turri FP, Lorusso F et al Percutaneous nephrostomy in supine position. Urology. 2007 Feb;69(2):377-80.
13. Melchert E1, De Farias Junior JO. New techniques to perform percutaneous nephrolithotripsy total dorsal decubitus Actas Urol Esp. 2010 Sep;34(8):726-9.
14. Ibarluzea G1, Scoffone CM, Cracco CM, Poggio M, Porpiglia F, Terrone C et al Supine Valdivia and modified lithotomy position for simultaneous anterograde and retrograde endourological access. BJU Int. 2007 Jul;100(1):233-6.
15. Kukreja R, Desai M, Patel S, Bapat S, Desai M. Factors affecting blood loss during percutaneous nephrolithotomy: prospective study. J Endourol. 2004 Oct;18(8):715-22.
16. Francesca F1, Felipetto R, Mosca F, Boggi U, Rizzo G, Puccini R. Percutaneous nephrolithotomy of transplanted kidney J Endourol. 2002 May;16(4):225-7.
17. Desai MR1, Jasani A. Percutaneous nephrolithotripsy in ectopic kidneys. J Endourol. 2000 Apr;14(3):289-92.

18. El-Nahas AR1, Abou-El-Ghar M, Shoma AM, Eraky I, El-Kenawy MR, El-Kappany H. Role of multiphasic helical computed tomography in planning surgical treatment for pelvi-ureteric junction obstruction BJU Int. 2004 Sep;94(4):582-7
19. Miller NL, Matlaga BR, Lingeman JE. Techniques for fluoroscopic percutaneous renal access. J Urol. 2007 Jul;178(1):15-23. Epub 2007 May 11. Review
20. Haaga JR, Zelch MG, Alfidi RJ, Stewart BH, Daugherty JD. CT-guided antegrade pyelography and percutaneous nephrostomy. AJR Am J Roentgenol. 1977 Apr;128(4):621-4.
21. Matlaga BR, Shah OD, Zagoria RJ, Dyer RB, Streem SB, Assimos DG. Computerized tomography guided access for percutaneous nephrostolithotomy. J Urol. 2003 Jul;170(1):45-7
22. Davis WB, Trerotola SO, Johnson MS, Patel NH, Namyslowski J, Stecker MS et al Percutaneous imaging-guided access for the treatment of calculi in continent urinary reservoirs. Cardiovasc Intervent Radiol. 2002 Mar-Apr;25(2):119-22. Epub 2002 Jan 17.
23. Eiley DM1, Ozsvath B, Siegel DN, Smith AD. Percutaneous nephrolithotomy with renal angiomyolipomas: a rare challenge. J Endourol. 1999 Feb;13(1):27-30.
24. Barbaric ZL, Hall T, Cochran ST, Heitz DR, Schwartz RA, Krasny RM et al Percutaneous nephrostomy: placement under CT and fluoroscopy guidance. AJR Am J Roentgenol. 1997 Jul;169(1):151-5
25. Thanos L, Mylona S, Stroumpouli E, Kalioras V, Pomoni M, Batakis N Percutaneous CT-guided nephrostomy: a safe and quick alternative method in

management of obstructive and nonobstructive uropathy. J Endourol. 2006 Jul;20(7):486-90

26. LeMaitre L, Mestdagh P, Marecaux-Delomez J, Valtille P, Dubrulle F, Biserte J. Percutaneous nephrostomy: placement under laser guidance and real-time CT fluoroscopy. Eur Radiol. 2000;10(6):892-5.
27. Cadeddu JA, Bzostek A, Schreiner S, Barnes AC, Roberts WW, Anderson JH et al A robotic system for percutaneous renal access. J Urol. 1997 Oct;158(4):1589-93.
28. Cadeddu JA1, Stoianovici D, Kavoussi LR. Robotic surgery in urology. Urol Clin North Am. 1998 Feb;25(1):75-85.
29. Turk C., Knoll T., Petrik A., Sarika K., Straub M., Seitz C: members of the European Association of Urology (EAU) Guidelines Office. Guidelines on Urolithiasis. In: EAU Guidelines, edition presented at the 27th EAU Annual Congress, Paris 2012. ISBN 978-90-79754-83-0.
30. Valdivia Uría JG, Valle Gerhold J, López López JA, Villarroya Rodriguez S, Ambroj Navarro C, Ramirez Fabián M, et al Technique and complications of percutaneous nephroscopy: experience with 557 patients in the supine position. J Urol. 1998 Dec;160(6 Pt 1):1975-8.
31. Falahatkar S1, Allahkhah A, Soltanipour S. Supine percutaneous nephrolithotomy: pro. Urol J. 2011 Fall;8(4):257-64.
32. De Sio M1, Autorino R, Quarto G, Calabrò F, Damiano R, Giugliano F, Modified supine versus prone position in percutaneous nephrolithotomy for renal stones treatable with a single percutaneous access: a prospective randomized trial. Eur Urol. 2008 Jul;54(1):196-202

33. Shoma AM1, Eraky I, El-Kenawy MR, El-Kappany HA. Percutaneous nephrolithotomy in the supine position: technical aspects and functional outcome compared with the prone technique. Urology. 2002 Sep;60(3):388-92
34. de la Rosette JJ1, Tsakiris P, Ferrandino MN, Elsakka AM, Rioja J, Preminger GM. Beyond prone position in percutaneous nephrolithotomy: a comprehensive review Eur Urol. 2008 Dec;54(6):1262-9
35. Kumar P, Bach C., Kachrillas S, Papatsoris AG, Buchholz N, Masood J. Supine percutaneous nephrolithotomy (PCNL): 'in vogue' but in which position? BJU Int. 2012 May 7 [Epub ahead of print]
36. Papatsoris AG, Zaman F, Panah A, Masood J, El- Husseiny T, Buchholz N, Simultaneous anterograde and retrograde endourologic access: "the Barts technique". J Endourol 2008, 22: 2665- 2666
37. Daels F, Gonzales MS, Freire FG, Jurado, Damia O. Percutaneous lithotripsy in Valdivia- Galdakao decubitus position: our experience. J Endourol 2009, 23: 1615-1620
38. Amon Sesmero JH, Del Valle Gonzales N, Conde Redondo C, Rodriguez Toves A, Cepeda Delgado M, Martinez Saggara Comparison between Valdivia position and prone position in percutaneous nephrolithotomy. Actas Urol Esp 2008, 32: 424-429
39. Marcovich R1, Smith AD. Percutaneous renal access: tips and tricks BJU Int. 2005 Mar;95 Suppl 2:78-84.
40. Basiri A, Ziaee AM, Kianian HR, Mehrabi S, Karami H, Moghaddam SM Ultrasonographic versus fluoroscopic access for percutaneous nephrolithotomy: a randomized clinical trial. J Endourol. 2008 Feb;22(2):281-4

41. Zegel HG, Pollack HM, Banner MC, Goldberg BB, Arger PH, Mulhern C et al Percutaneous nephrostomy: comparison of sonographic and fluoroscopic guidance. AJR Am J Roentgenol. 1981 Nov;137(5):925-7.
42. Li JX, Tian XQ, Niu YN, Zhang X, Kang N. Percutaneous nephrolithotripsy with pneumatic and ultrasonic power under B-type ultrasound guidance for treatment of renal calculi in non-dilated collecting system. Zhonghua Wai Ke Za Zhi. 2006 Mar 15;44(6):386-8.
43. Gupta S, Gulati M, Suri S. Ultrasound-guided percutaneous nephrostomy in non-dilated pelvicaliceal system J Clin Ultrasound. 1998 Mar-Apr;26(3):177-9.
44. Chi Q, Wang Y, Lu J, Wang X, Hao Y, Lu Z et al Ultrasonography combined with fluoroscopy for percutaneous nephrolithotomy: an analysis based on seven years single center experiences. Urol J. 2014 Mar 3;11(1):1216-21.
45. Andonian S, Scoffone C, Louie MK, Gross AJ, Grabe M, Daels F. Does imaging modality used for percutaneous renal access make a difference? A matched case analysis. J Endourol 2012 Jul 26. [Epub ahead of print].
46. Cracco CM, Scoffone CM, Scarpa RM. New developments in percutaneous techniques for simple and complex branched renal stones. Curr Opin Urol 2011, 21: 154-160
47. Bader MJ, Gratzke C, Seitz M, Sharma R, Stief CG, Desai M,. The "all-seeing needle": initial results of an optical puncture system confirming access in percutaneous nephrolithotomy. Eur Urol 2011, 59: 1054-1059
48. Cadeddu JA, Stoianovici D, Kavoussi LR. Robotic surgery in urology. Urol Clin North Am. 1998 Feb;25(1):75-85.

49. Cadeddu JA, Stoianovici D, Chen RN, Moore RG, Kavoussi LR Stereotactic mechanical percutaneous renal access. J Endourol. 1998 Apr;12(2):121-5.
50. Su LM, Stoianovici D, Jarrett TW, Patriciu A, Roberts WW, Cadeddu JA et al Robotic percutaneous access to the kidney: comparison with standard manual access J Endourol. 2002 Sep;16(7):471-5.
51. Munver R, Delvechio F, Newman G, Preminger G. Critical analyses of supracostal access for percutaneous renal surgery. J Urol 2001, 166: 1242-1246
52. Hopper KD, Yakes WF The posterior intercostal approach for percutaneous renal procedures: risk of puncturing the lung, spleen, and liver as determined by CT. AJR Am J Roentgenol. 1990 Jan;154(1):115-7
53. LeRoy AJ, Williams HJ Jr, Bender CE, Segura JW, Patterson DE, Benson RC. Colon perforation following percutaneous nephrostomy and renal calculus removal. Radiology. 1985 Apr;155(1):83-5.
54. Shah HN, Hegde SS, Shah JN, Bansal MB. Safety and efficacy of supracostal access in tubeless percutaneous nephrolithotomy. J Endourol. 2006 Dec;20(12):1016-21.
55. Miller NL, Matlaga BR, Lingeman JE Techniques for fluoroscopic percutaneous renal access. J Urol. 2007 Jul;178(1):15-23. Epub 2007 May 11. Review.
56. Davidoff R, Bellman G. Influence of technique of percutaneous tract creation on incidence of renal haemorrhage. J Urol 1997, 157: 1229-1231
57. Kurtulus FO, Fazlioglu A, Tandogdu Z, Aydin M, Karaca S, Cek M. Percutaneous nephrolithotomy: primary patients versus patients with history of open renal surgery. J Endourol. 2008 Dec;22(12):2671-5

58. Joel AB, Rubenstein JN, Hsieh MH, Chi T, Meng MV, Stoller ML Failed percutaneous balloon dilation for renal access: incidence and risk factors. Urology. 2005 Jul;66(1):29-32

59. Hofmann R, Weber J, Heidenreich A, Varga Z, Olbert P Experimental studies and first clinical experience with a new Lithoclast and ultrasound combination for lithotripsy Eur Urol. 2002 Oct;42(4):376-81.

60. Pietrow PK, Auge BK, Zhong P, Preminger GM Clinical efficacy of a combination pneumatic and ultrasonic lithotrite. J Urol. 2003 Apr;169(4):1247-9

61. Lehman DS, Hruby GW, Phillips C, Venkatesh R, Best S, Monga M et al Prospective randomized comparison of a combined ultrasonic and pneumatic lithotrite with a standard ultrasonic lithotrite for percutaneous nephrolithotomy. J Endourol. 2008 Feb;22(2):285-9

62. Jou YC, Shen CH, Cheng MC, Lin CT, Chen PC High-power holmium:yttrium-aluminum-garnet laser for percutaneous treatment of large renal stones. Urology. 2007 Jan;69(1):22-5; discussion 25-6

63. Malik HA, Tipu SA, Mohayuddin N, Sultan G, Hussain M, Hashmi A et al Comparison of holmium: Yag laser and pneumatic lithoclast in percutaneous nephrolithotomy. J Pak Med Assoc. 2007 Aug;57(8):385-7

64. Li X, He Z, Wu K, Li SK, Zeng G, Yuan J et al Chinese minimally invasive percutaneous nephrolithotomy: the Guangzhou experience. J Endourol. 2009 Oct;23(10):1693-7.

65. Panah A, Masood J, Zaman F, Papatsoris AG, El-Husseiny, Buchholz N. A technique to flush out renal stone fragments during percutaneous nephrolithotomy. J Endourol 2009, 23: 5-6
66. Pietrow PK, Auge BK, Lallas CD, Santa-Cruz RW, Newman GE, Albala DM et al Pain after percutaneous nephrolithotomy: impact of nephrostomy tube size. J Endourol. 2003 Aug;17(6):411-4
67. Feng MI, Tamaddon K, Mikhail A, Kaptein JS, Bellman GC Prospective randomized study of various techniques of percutaneous nephrolithotomy Urology. 2001 Sep;58(3):345-50
68. Agrawal MS, Agrawal M, Gupta A, Bansal S, Yadav A, Goyal J A randomized comparison of tubeless and standard percutaneous nephrolithotomy. J Endourol. 2008 Mar;22(3):439-42
69. Marchant F, Recabal P, Fernandez MI, Osorio F, Benavides J. Postoperative morbidity of tubeless versus conventional percutaneous nephrolithotomy: a prospective comparative study. Urol Res. 2011 Dec;39(6):477-81. doi: 10.1007/s00240-011-0367-9. Epub 2011 Feb 20.
70. Yuan H, Zheng G, Liu L, Han P, Wanh J, Wei Q. The efficacy and safety of tubeless percutaneous nephrolithotomy: a systematic review and meta-analysis. Urol Res 2011, 39: 401-410
71. Aghamir SM, Hosseini SR, Gooran S Totally tubeless percutaneous nephrolithotomy. J Endourol. 2004 Sep;18(7):647-8
72. Istanbulluoglu MO, Ozturk B, Gonen M, Cicek T, Ozkardes H. Effectiveness of totally tubeless percutaneous nephrolithotomy in selected patients: a prospective randomized study Int Urol Nephrol. 2009;41(3):541-5

73. Kim SC, Tinnouth WW, Kuo RL. Using and choosing a nephrostomy tube after percutaneous nephrolithotomy for large or complex stone disease: a treatment strategy. J Endourol 2005, 19: 348–352

74. Choe CH, L'Esperance JO, Auge BK The use of adjunctive hemostatic agents for tubeless percutaneous nephrolithotomy. J Endourol. 2009 Oct;23(10):1733-8

75. Shah HN1, Hegde S, Shah JN, Mohile PD, Yuvaraja TB, Bansal MB A prospective, randomized trial evaluating the safety and efficacy of fibrin sealant in tubeless percutaneous nephrolithotomy. J Urol. 2006 Dec;176(6 Pt 1):2488-92

76. Uribe CA, Eichel L, Khonsari S, Finley DS, Basillote J, Park HK et al What happens to hemostatic agents in contact with urine? An in vitro study. J Endourol. 2005 Apr;19(3):312-7

77. Borin JF, Sala LG, Eichel L, McDougall EM, Clayman RV Tubeless percutaneous nephrolithotomy using hemostatic gelatin matrix. J Endourol. 2005 Jul-Aug;19(6):614-7; discussion 617.

78. Landman J, Venkatesh R, Ragab M, Rehman J, Lee DL, Morrissey KG et al Comparison of intrarenal pressure and irrigant flow during percu� taneous nephroscopy with an indwelling ureteral catheter, ureteral occlusion balloon, and ureteral access sheath. Urology 2002, 60: 584-587

79. Landman J, Venkatesh R, Lee DL, Rehman J, RagabJ J, Ragab M, Darcy M et al Combined percutaneous and retrograde approach to staghorn calculi with application of the ureteral access sheath to facilitate percutaneous nephrolithotomy. J Urol 2003, 169: 64-67

80. Scoffone CM, Cracco CM, Cossu M, Grande S, Poggio M, Scarpa RM. Endoscopic combined intrarenal surgery in Galdakao-modified supine Valdivia position: a new standard for percutaneous nephrolithotomy? Eur Urol 2008, 54: 1393-1403
81. Lahme S, Zimmermanns V, Hochmuth A, Janitzki A, Janitzki V. Minimally invasive PCNL (mini-perc). Alternative treatment modality or replacement of conventional PCNL? Urologe A 2008, 47: 563-568
82. Preminger GM, Alken P, Habuchi T, Wijkstra H, Skolarikos A, Yin CJ.. The clinical research office of the endourological society audit committee. J Endourol 2011, 25: 1811-1813