Endourologic Anatomy of the Kidney

General Anatomy: The kidneys are paired organs lying retroperitoneal on the posterior abdominal wall. Each kidney is of a characteristic shape, having a superior and an inferior pole, a convex border placed laterally, and a concave medial border. The medial border has a marked depression; the hilum containing the renal vessels and the renal pelvis (Drake et al, 2007).

Position of the Kidneys: As the kidneys lie on the posterior abdominal wall, against the psoas major muscles, their longitudinal axis parallels the oblique course of the psoas (Fig. 1). Moreover, since the psoas major muscle has a shape of a cone, the kidneys also are dorsal and inclined on the longitudinal axis. Therefore, the superior poles are more medial and more posterior than the inferior poles. As the hilar region is rotated anteriorly on the psoas muscle, the lateral borders of both kidneys are posteriorly positioned. It means that the kidneys are angled 30 to 50° behind the frontal (coronal) plane (Fig. 2) (Drake et al., 2007).

Fig.(1): Anterior view of the kidneys in relation to the skeleton, shows that the longitudinal axis of the kidneys are oblique (arrows), being the superior poles more medial than the inferior poles. The dashed line marks the longitudinal axis of the body. This figure also shows that the posterior surface of the right kidney usually is crossed by the 12th rib and the left kidney by the 11th and 12th ribs (Sampaio 2000) Quoted from (Smith et al., 2006).
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Fig. (2): Superior view of a transverse section of the kidneys at the level of the 2nd lumbar vertebra shows that the kidneys are angled 30 to 50° behind the frontal (coronal) plane. FA = frontal plane of the body; RA = renal frontal (coronal) axis (Sampaio 2000) Quoted from (Smith et al., 2006).

Perirenal Coverings: The kidney surface is enclosed in a continuous covering of fibrous tissue called the renal capsule (or “true renal capsule”). Each kidney within its capsule is surrounded by a mass of adipose tissue lying between the peritoneum and the posterior abdominal wall and called the perirenal fat (Fig. 2 & 3). The perirenal fat is enclosed by the renal fascia (so-called fibrous renal fascia of Gerota’s fascia). The renal fascia is enclosed anteriorly and posteriorly by another layer of adipose tissue, which varies in thickness, called the pararenal fat (Fig. 3) (Sampaio, 2000).

The renal fascia comprises a posterior layer (a well-defined and strong structure) and an anterior layer, which is a more delicate structure that tends to adhere to the peritoneum (Fig. 2 & 3). The anterior and posterior layers of the renal fascia (Gerota’s fascia) subdivide the retroperitoneal space in three potential compartments: (1) the posterior pararenal space, which contains only fat; (2) the intermediate perirenal space, which contains the suprarenal glands, kidneys and proximal ureters, together with the perirenal fat; (3) the anterior pararenal space, which unlike the posterior and intermediate spaces, extends across the midline from one side of the abdomen to the other. This space contains
the ascending and descending colon, the duodenal loop and the pancreas (Fig. 4) (Sampaio, 2000).

Inferiorly, the layers of the renal fascia end weakly fused around the ureter (Fig. 3 & 5). Superiorly, the two layers of the renal fascia fuse above the suprarenal gland and end fused with the infradiaphragmatic fascia (Fig. 5). An additional fascial layer separates the suprarenal gland from the kidney (Fig. 5). Laterally, the two layers of the renal fascia fuse behind the ascending and descending colons. Medially, the posterior fascial layer is fused with the fascia of the spine muscles. The anterior fascial layer merges into the connective tissue of the great vessels (aorta and IVC) (Fig. 2 & 4).

These anatomic descriptions of the renal fascia show that right and left perirenal spaces are potentially separated, and therefore, it is exceptional that a complication of an endourologic procedure (eg, hematoma, urinoma, perirenal abscess) involves the contralateral perirenal space (Drake et al, 2007).

The true capsule and Gerota’s fascia are of importance when performing a percutaneous renal surgery. As the needle is passed through the skin into the kidney, two areas of resistance are felt, the first is at the lumbo-dorsal fascia, and the second is at the true capsule. The renal capsule is a firm fibrous membrane that adheres to the underlying parenchyma. Passing needle through this capsule is much like pushing a needle through cardboard in that there is some initial resistance to the needle's passage followed by sudden “give”. At this point, the needle lies within the renal parenchyma and therefore moves to and fro as the kidney moves with respiration. The renal capsule is richly innervated; accordingly, puncture or dilatation of a unanaesthized renal capsule causes considerable discomfort (Sampaio, 2000).
Fig. (3): Lateral view of a longitudinal section through the retroperitoneum, reveals the posterior (P) and the anterior (A) layers of the renal fascia. Pe = peritoneum; K = kidney. (Sampaio 2000) Quoted from (Smith et al., 2006).

Fig. (4): Superior view of a transverse section of the kidneys at the level of the 2nd lumbar vertebra shows the three compartments of the retroperitoneal space. P = posterior pararenal space, which contains only fat; I = intermediate perirenal space, which contains the suprarenal glands, kidneys and proximal ureters, together with the perirenal fat; A = anterior pararenal space, which unlike the posterior and intermediate spaces, extends across the midline from one side of the abdomen to the other, and contains the ascending and descending colons, the duodenal loop and the pancreas (Sampaio 2000) Quoted from (Smith et al., 2006).
**Fig. (5):** Anterior view of a schematic drawing of the renal fascia (Gerota’s fascia) and the kidneys. This scheme depicts that the two layers of the renal fascia fuse above *(Sampaio 2000) Quoted from (Smith et al., 2006).*

**Kidney Relationships with Diaphragm, Ribs, And Pleura:** The kidneys lie on the psoas and quadratus lumborum muscles. Usually, the left kidney is higher than the right kidney, being the posterior surface of the right kidney crossed by the 12th rib and the left kidney crossed by the 11th and 12th ribs (Fig. 1). The posterior surface of the diaphragm attaches to the extremities of the 11th and 12th ribs. Close to the spine, the diaphragm is attached over the posterior abdominal muscles and forms the medial and lateral arcuate ligaments on each side (Fig. 6). In this way, the posterior aspect of the diaphragm (posterior leaves) arches as a dome above the superior pole of the kidneys, on each side. Therefore, when performing an intrarenal access by puncture, the endourologist may consider that the diaphragm is traversed by all intercostal punctures, and possibly by some punctures below the 12th rib (Fig. 7) *(Hopper and Yakes 1990).*

Generally, the posterior reflection of the pleura extends inferiorly to the 12th rib; nevertheless, the lowermost lung edge lies above the 11th rib (at the 10th intercostal space) (Fig. 7). Regardless of the degree of
respiration (mid- or full expiration), the risk of injury to the lung from a 10th intercostal percutaneous approach to the kidney is prohibitive. Any intercostal puncture should be made in the lower half of the intercostal space, in order to avoid injury to the intercostals vessels above (Hopper and Yakes 1990).

Fig. (6): Schematic drawing of an inferior view of the suprarenal gland and end blended with the infradiaphragmatic dome. The arrows point to the diaphragmatic fascia (long arrow). Note a dependence of attachments to the extremities of the 11th and 12th ribs. The fascia separating the suprarenal gland from the kidney $M = \text{medial arcuate ligament}$, $L = \text{lateral arcuate ligament}$; (short arrow). $D = \text{diaphragm muscle}$. $ql = \text{quadratus lumborum muscle}$; $pm = \text{psoas muscle}$. (Sampaio 2000) Quoted from (Smith et al., 2006).

Fig. (7): Schematic drawing from a lateral view of the kidney and its relationships with the diaphragm, ribs, pleura, and lung. $PR = \text{posterior reflection of the pleura}$, $L = \text{lower edge of the lung}$; $K = \text{kidney}$, $X = 10\text{th rib}$; $XI = 11\text{th rib}$; $XII = 12\text{th rib}$. (Sampaio 2000) Quoted from (Smith et al., 2006).
Kidney Relationships With Liver And Spleen: The liver on the right side and the spleen in the left, may be posterolaterally positioned at the level of the suprahilar region of the kidney, because at this point, these organs have their larger dimensions (Fig. 8). Therefore, one may remember that a kidney puncture performed high in the abdomen has little space for the needle entrance) If the intrarenal puncture is performed when the patient is in mid- or full inspiration, the risk to the liver and spleen is increased. This knowledge is particularly important in patients with hepatomegaly or splenomegaly, on whom a computed tomography (CT) scan should be performed before puncturing the kidney (Drake et al., 2007).

Fig. (8): A, Inferior view of a transverse section through a cooled cadaver at the level of the suprahilar region of the kidney reveals that the liver (L) and the spleen (S) are posterolaterally positioned in relation to right (RK) and left (LK) kidneys. B, Similar section of that shown in A, performed at the level of the infrarihilar region reveals that inferiorly, the liver (L) and the spleen (S) are more laterally positioned in relation to right (RK) and left (LK) kidneys. (Sampaio 2000) Quoted from (Smith et al., 2006).

Kidney Relationships With Ascending And Descending Colons: The ascending colon runs from the ileocolic valve to the right colic flexure (hepatic flexure), where it passes into the transverse colon. The hepatic colic flexure (hepatic angle), lies anteriorly to the inferior portion of the right kidney. The descending colon extends inferiorly from the left colic flexure (splenic flexure) to the level of the iliac crest. The left colic flexure lies anterolateral to the left kidney (Hopper, et al., 1987).
Occasionally, it was observed in the course of routine abdominal CT scan examinations, that the retroperitoneal colon is lying in a posterolateral or even a post renal position. Hence, in these cases, it is at great risk of being injured during the intrarenal percutaneous approach. This event (retro renal colon) more commonly occurs with regard to the inferior poles of the kidneys (Fig. 9). In a controlled study, it was demonstrated by CT scan that, when the patient is in the supine position, the retro renal colon was found in 1.9% of the cases. Nevertheless, when the patient assumes the prone position (the more frequent position used for percutaneous access to the kidney) the retro renal colon was found in 10% of the cases. Therefore, special attention should be given, under fluoroscopy and with the patient in the prone position, to detect patients with retro renal colon prior any invasive percutaneous renal procedure. (Hopper et al., 1990).

Fig. (9): Superior view of a transverse section through a cooled cadaver at the level of the inferior poles of the kidney, reveals the ascending (AC) and descending (DC) colons lying in a posterolateral position in relation to right (R) and left (L) kidneys. S = spine (Sampaio 2000) Quoted from (Smith et al., 2006).
Pelvicalyceal System: Endourologic Implications:

**Basic Intrarenal Anatomy** The renal parenchyma consists basically of two kinds of tissue, the cortical tissue and the medullary tissue. On a longitudinal section, the cortex forms the external layer of renal parenchyma. The renal medulla is formed by several inverted cones, surrounded by a layer of cortical tissue on all sides (except at the apexes). As in longitudinal sections, a cone assumes the shape of a pyramid and the established expression for the medullar tissue is renal pyramid; the apex of a pyramid is the renal papilla. The layers of cortical tissue between adjacent pyramids are named renal columns (cortical columns of Bertin) *(Sampaio, 2000)* (Fig. 11).

The cortical tissue comprises the glomeruli with proximal and distal convoluted tubules. The renal pyramids comprise the loops of Henle and collecting ducts; these ducts join to form the papillary ducts (about 20) which open at the papillary surface (area cribrosa papillae renalis) draining urine into the collecting system (into the fornix of a minor calyx) (Fig. 12).

A minor calyx is defined as the calyx that is in immediate apposition to a papilla. The renal minor calices drain the renal papillae and range in number from 5 to 14 (mean, 8); although the number of minor calices is widely varied, it was found that; 70% of the kidneys presenting 7 to 9 minor calices. A minor calyx may be single (drains one papilla) or compound (drains two or three papillae). The polar calices often are compound, markedly in the superior pole. The minor calices may drain straight into an infundibulum or join to form major calices, which subsequently will drain into an infundibulum. Finally, the infundibula, which are considered the primary divisions of the pelvicalyceal system, drain into the renal pelvis (Fig. 11 and 12).
Fig. (10): A. Anterior view of a pelvicalyceal endocast from a left kidney, obtained according to the injection-corrosion technique. B. Schematic drawing of the endocast shown in A, indicates the essential elements of kidney collecting system. cc = compound calyx; sc = single calyx; mc = minor calyx; Mc = major calyx; f = caliceal fornix; i = infundibulum; P = renal pelvis (Sampaio 2000) Quoted from (Smith et al., 2006).

Fig. (11): Schematic drawing of a longitudinal section of the kidney depicts the intrarenal structures. c = renal cortex; rc = renal column (cortical column of Bertin); rp = renal pyramid; p = renal papilla; mc = minor calix; Mc = major calix; P = renal pelvis. (Sampaio 2000) Quoted from (Smith et al., 2006).
**Calyceal arrangement:**

Recent advances in endourology have revived interest in collecting system anatomy, since a full understanding of such anatomy is necessary to perform reliable endourologic procedures as well as uroradiologic analysis.

For the endourologist, a thorough understanding of the caliceal arrangement is essential. Brodel's description and illustration of the caliceal anatomy in 1901 is highly recommended for review. The upper and lower pole calyces are usually compound and project in polar direction. The remaining calyces are arranged into distinct rows: anterior and posterior, the anterior calyces usually form an angle of 70 with the frontal plane of the kidney, whereas the posterior calyces usually form an angle of 20 with the frontal plane, and therefore face slightly posterior to the lateral convex border of the kidney. On occasion, the converse applies (anterior calyces 20 and posterior calyces 70) as described by Hodson. *(Kim and Clayman 2006).*
The traditional teaching regarding the correlation between the actual anatomy of the pelvicalyceal system and the appearance of the collecting system on intravenous urography (IVU) is that on a standard anteroposterior view the anterior calices appear to be seen in cross section laterally, and the posterior calices appear to be more medial and are seen from a cup-like end on point of view (Kim and Clayman 2006).

Sampaio et al., studied 140 cadaver kidneys in which retrograde pyelography was correlated with the actual anatomy of the pelvicalyceal system derived from endocast. In actuality, this relationship (where the anterior calices are seen laterally and the posterior calices are seen medially) was only present in 27.8% of the kidneys studied. The posterior calices were more lateral in 19.3% of cases. The largest proportion of kidneys (52.9%) had a mixed pattern (Fig. 10).

A sample of 140 pelvicalyceal endocasts was divided into two major groups according to the drainage of the kidney polar region and of the mid (hilar) zone:

**Group A**: was composed of 87 casts (62% of the specimens) that present two major caliceal groups as a primary division of the renal pelvis and mid-zone drainage dependent on these major groups (Fig. IA, IB). Group A includes two different types of casts. In Type AI (63 casts; 45%) the kidney mid zone is drained by minor calices that are dependent on the superior or the inferior caliceal groups (Fig. IA). The drainage could also be dependent on both superior and inferior caliceal groups. In Type AII (24 casts; 17%), the kidney mid zone is drained by crossing calices, one draining into the superior caliceal group and another draining simultaneously into the inferior caliceal group.
**Group B:** was composed of 53 casts (38%) that present kidney mid-zone (hilar) drainage independent of the superior and inferior caliceal groups (Fig. I C, I D). Group B I includes two different types of casts. In Type B I (30 casts; 21 %), the kidney mid zone is drained by a major caliceal group independent of the superior and inferior groups (Fig. IC). In Type B II (23 casts; 16%) the kidney mid zone is drained by one to four minor calices entering straight into the renal pelvis (Fig. ID). Such calices are independent of the superior and inferior caliceal groups. The kidney collecting system is amply varied and showed morphologic bilateral symmetry in only 37% of the casts (26 pair of casts) (**Sampaio 2000**).
Fig. (13): Ensemble view of the four morphologic type of pelvicalyceal system. A. Type Al: Anterior view of left pelvicalyceal cast shows kidney mid zone drained by calices dependent on the superior (s) and inferior (i) caliceal groups. B. Type All: Anterior view of left pelvicalyceal cast shows kidney mid zone drained by crossing calices. * = interpelvic-caliceal region (s pace). The crossing calyx that drains into the inferior caliceal group is in ventral position (arrowhead). C. Type BI: Anterior view of right pelvicalyceal cast shows kidney mid zone drained by hilar major calyx (m). This cast shows also the existence of minor calices perpendicular to the collecting system (arrows). D. Type BII: Anterior view of left pelvicalyceal cast; kidney mid zone is drained by minor calices entering straight into renal pelvis (m) (Sampaio 2000) Quoted from (Smith et al., 2006).
**Fig (14):** Anterior view of two left pelvicalyceal casts. A. This cast shows long and thin superior caliceal infundibulum (arrow). B. The cast shows short and thick superior and inferior caliceal infundibula (arrows). *(Sampaio 2000) Quoted from (Smith et al., 2006).*

**Position of the Calices Relative to the Lateral Kidney Margin:** In 39 of 140 casts (27.8%), the anterior calices had a more lateral (peripheral) position than the posterior calices In 27 casts (19.3%) the posterior calices were in a more lateral position than the anterior calices in the majority of cases (74 casts; 52.9%) the anterior and posterior calices had variable positions; superimposed or alternately distributed. (Fig. 15, 16, 17).

**Fig. (15):** Position of the calices related to lateral margin of the kidney. A, Anterior view of right pelvicalyceal cast. This cast reveals that the anterior calices have a more lateral (peripheral) position than posterior calices (arrows). It means that the posterior calices are placed medially. B, Schematic drawing of the same case shown in A, demonstrates the peripheral calices in the anterior plane and the medial calices (arrows) in the posterior plane. *(Sampaio 2000) Quoted from (Smith et al., 2006).*
**Fig. (16):** Position of the calices related to lateral margin of the kidney. A, Anterior view of right pelvicalyceal cast. This cast reveals that the posterior calices (arrows) have a more lateral (peripheral) position than anterior calices. B, Schematic drawing of the same case shown in A, demonstrates the peripheral calices in the posterior plane (arrows) and the medial calices in the anterior plane. *(Sampaio 2000) Quoted from (Smith et al., 2006).*

**Fig. (17):** Position of the calices related to lateral margin of the kidney. A, Anterior view of right pelvicalyceal cast. This cast reveals that the calices in the anterior plane (arrows) are placed alternately relative to the lateral margin of the kidney. In one region, they are more lateral, and in another region, they are more medial. B, Schematic drawing of the same case shown in A, demonstrates the calices in the anterior plane (arrows) placed alternately relative to the lateral kidney margin. In one region, they are more lateral, and in another region, the calices in the posterior plane are more lateral. *(Sampaio 2000) Quoted from (Smith et al., 2006).*
Crossed Calices: In 17.2% of the cases, the kidney midzone (hilar) was drained by crossed calices, one draining into the superior caliceal group and the other draining into the inferior caliceal group simultaneously. On the pyelograms, the crossed calices (laterally) and the renal pelvis (medially) outlined a radiolucent region that termed the interpelvicaliceal region (Fig. 18). When the crossed calices were in the mid kidney, the calyx that drained into the inferior caliceal group was in ventral position in 87.5%.

Fig. (18): Comparative study between radiographic view of a left kidney and its corresponding three-dimensional cast. A, Anterior view of a retrograde pyelogram shows a radiographic image of the interpelvicaliceal region (arrow). B, Anterior view of the corresponding three-dimensional endocast. The asterisk demonstrates interpelvicaliceal space. The arrowhead shows a minor calyx perpendicular and superimposed to the surface of a superior major calyx, which cannot be seen on the pyelogram. Open arrow shows anterior minor calyx superimposed on the posterior minor calyx. On pyelogram, making a distinction between them can be difficult. C, Oblique view of the same cast. The arrow shows a perpendicular minor calyx into the superior caliceal group. Arrowheads demonstrate distinction between the anterior and posterior minor calices, which are superimposed on the pyelogram. (Sampaio 2000) Quoted from (Smith et al., 2006).

In the case of IVU or retrograde pyelography this should include lateral and oblique views. Similarly, at the time of planned PCNL, antero posterior as well as oblique views need to be obtained such that the targeted calyx is of a posterior nature. Similar information can also be obtained from 3-D reconstruction of CT images (Kim and Clayman 2006).
CT Analysis of Caliceal Anatomy in the Supine and Prone Positions:

Segupta et al, (2000) assessed the effect of patient positioning on the position of the kidneys and their consequent projection onto plain radiographs, thus ascertaining the need for special preoperative imaging. Fourteen patients were studied by obtaining fine (5-mm)-cut contrast-enhanced CT scans in the pyelogram phase in both the supine and prone position.

The orientation of the kidneys relative to the midsagittal plane of the body and the orientation of the anterior and posterior calices relative to the axis of the kidney were measured from hard copy images. Comparison was made between prone and supine positions for left and right kidneys separately, as well as overall.

They found that The position of the patient had a small effect on the orientation of the kidneys, with the mean angle changing from 56.6° when supine to 61.6° when prone (p 0.05). However, no significant change in caliceal orientation or the relative projection of the anterior and posterior calices occurred as a result.

Fig. (19): Measurement of angulations of kidney relative to body. (A) CT scan showing measurement. (B) Close-up of CT scan illustrating measurement of caliceal angulations' relative to axis of kidney (Segupta et al., 2000).
Renal Blood Supply:

*Intrarenal Arteries:*

Although wide variation exists, the renal arteries in general originate from the lateral margin of the aorta just below the level of the superior mesenteric artery (Fig. 20). They course posterior to the renal vein and branch on the appropriate side of the renal pelvis into an anterior and posterior division (*Kim and Clayman 2006*).

Generally, the main renal artery divides into an anterior and a posterior branch after giving off the inferior suprarenal artery. Whereas the posterior branch (retro pelvic artery) proceeds as the posterior segmental artery to supply the homonymous segment without further significant branching, the anterior branch of the renal artery provides three or four segmental arteries. The segmental arteries divide before entering the renal parenchyma into interlobar arteries (infundibular arteries), which progress adjacent to the caliceal infundibula and the minor calices, entering the renal columns between the renal pyramids. As the interlobar arteries progress, near the base of the pyramids, they give origin (usually by dichotomous division) to the arcuate arteries. The arcuate arteries give off the interlobular arteries, which run to the periphery giving off the afferent arterioles of the glomeruli (Fig. 21). (*Kim and Clayman 2006*).
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**Fig. (20):** Schematic drawing of an anterior view from a right kidney, shows the branching of the renal arteries and their official nomenclature according to kidney regions. RA = renal artery; sa = segmental artery; ia = interlobar (infundibular) artery; aa = arcuate artery. *(Sampaio 2000) Quoted from (Smith et al., 2006).*

**Fig. (21):** Schematic drawing of two adjacent pyramids and minor calices, depicts the renal vasculature from the level of the interlobar arteries to the glomerular level. ia = interlobar (infundibular artery); aa = arcuate artery; il. a = interlobular artery; af. = afferent arteriole of the glomeruli *(Sampaio 2000) Quoted from (Smith et al., 2006).*

**Intrarenal Veins:** The intrarenal veins, unlike the arteries, do not have a segmental model. Moreover, in contrast to the arteries, there is free circulation throughout the venous system, providing ample anastomoses between the veins. These anastomoses, therefore, prevent parenchymal congestion and ischemia in case of venous injury *(Sampaio, 2000).*
The small veins of the cortex, called stellate veins, drain into the interlobular veins that form a series of arches (Fig. 22). Within the kidney substance, these arches are arranged in arcades, which lie mainly in the longitudinal axis. There are usually three systems of longitudinal anastomotic arcades and the anastomoses occur in different levels: between the stellate veins (more peripherally), between the arcuate veins (at the base of the pyramids) and between the interlobar (infundibular) veins (close to the renal sinus) (Sampaio, 2000).

![Fig. (22): A anterior view of left kidney endocast of the pelvicalyceal system together with the venous vascular tree shows the three systems of longitudinal anastomotic arcades; from lateral (periphery) to medical (hilar): stellate veins (curved arrow), arcuate veins (short arrow) and interlobar veins (long arrow). RV = renal vein. B, Schematic drawing shows the three orders of arcades: 1 = first order arcade; 2: second order arcade; 3 = third order arcade (Sampaio 2000) Quoted from (Smith et al., 2006).](image)

The junction between the anterior and posterior divisions of the renal artery results in a relatively a vascular plane (Brodel's line). There are no marks on the surface to demonstrate this area, however it usually located 1-2 cm posterior to the lateral margin of the kidney (Hopper et al., 1990).
From this, it can be seen that the safest way to enter the collecting system percutaneously is end-on through the fornix of a calyx, usually the lowermost calyx. An approach through infundibulum, especially the superior infundibulum may be dangerous because of the large vessels and major branches that cross the infundibular surfaces. The superior pole infundibulum for example, may almost be encircled by the upper segmental artery anteriorly and the posterior segmental artery posteriorly. It can be also seen that the safest place to puncture the kidney is just posterior to the line of maximal convex curvature (Brodel's line) (Hopper et al., 1990).

The safety and efficacy of all endourologic procedures are dependent on the understanding of practical renal anatomy. It is this knowledge that truly enables the physician to "see" inside the kidney (Sampaio 2000).
Imaging for Percutaneous Renal Access

PCNL is an image-driven treatment modality that relies heavily on: Preoperative imaging to define stone burden and delineate the relational anatomy of the kidney, Intraoperative imaging to facilitate percutaneous puncture, endoscopic inspection, and pleural screening, and Postoperative imaging to detect residual stones and assure antegrade drainage (Park et al, 2006).

i. Preoperative imaging:

Pre-operative imaging studies define the renal or ureteral stone burden and delineate renal anatomy and the relationship of the kidney to surrounding organs. Selecting the optimal preoperative imaging study depends on the patient’s renal function, body habitus, and renal anatomy. Contrast studies may be unsafe in patients who have renal insufficiency, and consequently, detailed collecting system anatomy may be unattainable except at the time of surgery. In patients who have renal anomalies such as horse-shoe kidney, or with an unusual body habitus caused by severe scoliosis or meningomyelocele, the relationship of the kidney to surrounding organs that are potentially in the line of percutaneous puncture may be atypical, and consequently cross-sectional imaging studies are needed to determine a safe line of access (Park et al, 2006).

a. Plain abdominal radiography:

Most calcium-containing stones are visible on (KUB) provided they are sufficiently large, not obscured by overlying stool or bowel gas, and not overlying the spine or bony pelvis. Brushite and calcium oxalate monohydrate stones are the most radio-opaque of calcium-containing stones, followed by calcium apatite and calcium oxalate dihydrate stones. Cystine and struvite stones are faintly opaque and uric acid stones are radiolucent, although they may be faintly visible when mixed with
calcium, or when they reach a large size. Although KUB has the advantage of being rapidly acquired, readily available, and relatively inexpensive, its use is limited by a fairly low sensitivity for the detection of renal calculi. Indeed, published sensitivity and specificity rates for KUB in the detection of renal and ureteral calculi range from 58% to 62% and 67% to 69%, respectively (Jackman et al., 2000). Furthermore, the lack of anatomic detail with regard to the kidney and surrounding organs limits its usefulness in pre-operative planning for PCNL. KUB, however, is useful in determining if a stone is radio-opaque and can be identified on fluoroscopy at the time of percutaneous renal access. For no opaque stones, opacification of the renal collecting system with retrograde injection of contrast, or use of ultrasound guidance, may be necessary to obtain percutaneous access (Jackman et al., 2000).

b. Intravenous urogram (IVU):

Historically, the (IVU) was the study of choice for evaluating patients with suspected stones and for planning therapy. IVU demonstrates detailed collecting system anatomy, particularly when appropriate oblique and anteroposterior views are obtained. In addition, it shows the relation of the kidney and collecting system to the ribs, which determines the need for supracostal access. On the other hand, IVU typically is performed in the supine position, and the relation of the collecting system to the pleural space and ribs may change when the patient is prone (Mutazindwa and Husseini, 1996).

Nevertheless, the IVU can assist in selecting the appropriate calyx for percutaneous puncture based on the location of the stone, the infundibulopelvic angle, and the spatial anatomy of the collecting system. In many cases, direct access into the stone-bearing calyx is optimal. In other cases, such as a complete staghorn calculus, or a partial staghorn calculus occupying the renal pelvis and multiple lower pole calyces, an
upper pole posterior calyx may serve as the site of optimal access (Fig. 23) (Thiruchelvam et al., 2005).

IVU is important in planning the percutaneous approach to stone-bearing calyceal diverticula, as it delineates the calyx with which the diverticulum is associated and shows the size and location of the diverticulum (Fig. 23). Because non enhanced, helical CT is superior to IVU for detecting renal and ureteral calculi, IVU is no longer available at some institutions. Nevertheless, the detailed depiction of collecting system anatomy with IVU remains an important adjunct in the evaluation of patients considered for PCNL. Whether CT urography with three-dimensional reconstruction will prove to be as good or superior to IVU and ultimately replace IVU for the delineation of collecting system anatomy remains to be seen (Thiruchelvam et al, 2005).

**Fig. (23):** (A) Noncontrast CT demonstrates a left renal calculus (arrow). (B) Scout film from intravenous urogram demonstrates that the left renal stone seen on CT is composed of multiple small stones (arrow). (C) Ten-minute film from intravenous urogram shows that the stones are located within a calyceal diverticulum (arrow). Noncontrast CT alone was not sufficient to reveal the caliceal diverticulum. (D) Oblique film shows that the stone-bearing diverticulum (arrow) projects posteriorly from the upper pole calyx (Park et al, 2006).
c. Computed tomography (CT):

With the introduction of unenhanced helical CT, detection of renal and ureteral calculi has been enhanced greatly. Indeed, CT has been shown to be superior to IVU for evaluating patients with acute flank pain (Thiruchelvam et al., 2005).

The benefits of CT imaging before PCNL, however, surpass just the accurate detection of renal calculi. CT delineates the extent, orientation, and location of renal calculi, which can facilitate the selection of an appropriate calyx for percutaneous access. Furthermore, CT provides detailed information on the relational anatomy of the kidney that may impact selection of an appropriate calyx for safe puncture (Raj et al., 2003).

Enhanced computing power and sophisticated three-dimensional CT software have led to the capability of creating detailed three-dimensional CT urography images depicting the renal parenchyma and pyelocaliceal system (Fig. 24) With the use of three-dimensional CT imaging, the collecting system and its relational anatomy to adjacent structures can be viewed readily, and an optimal and safe access site selected. Initially, Three-dimensional CT (Fig. 25) was used to produce surface-rendered models, but the time required for data acquisition was prohibitive, and reconstruction was unreliable. Moreover, once contrast was administered, the stone was indistinguishable from the collecting system (Leder and Nelson 2001).
**Fig. (24):** CT urogram reconstructed with delayed contrast-enhanced images. The three-dimensional relationship of the collecting system to the ribs, pleura, and colon can be delineated (*Park et al, 2006*).

*Fig.(25):* Three-dimensional reconstruction of a left complete staghorn calculus. The superior border of the stone (arrowhead) lies just at the level of the 12th rib, and up-per pole access likely would require a supracostal puncture (*Park et al, 2006*).
d. Magnetic resonance image (MRI):

MRI has assumed a very limited role in the diagnosis and management of renal calculi because of unreliable identification of stones in the collecting system or ureter. Because it avoids ionizing radiation, MRI may be considered an alternative to ultrasound in the pregnant patient with suspected stones, but the greater availability, lower cost, and greater accuracy of ultrasound in the diagnosis of stones and obstruction make MRI a rarely used modality. The use of open configuration MRI to facilitate percutaneous nephrostomy placement (PCN) has been described, but this application is considered investigatory, and its future potential is unclear. At the current time, MRI is not considered a first-line imaging modality for preoperative planning for PCNL (McAleer and Loughlin, 2004).

ii. Intraoperative imaging:

The most critical step in performing successful PCNL is establishing safe and effective percutaneous access. The ideal site of percutaneous puncture should be selected to maximize the use of rigid instruments, minimize the risk of complications, and achieve stone-free status. For optimal outcomes, it is necessary to outline criteria for proper patient selection, preoperative planning, and postoperative management (Park et al., 2006).

Intraoperative imaging is necessary for obtaining percutaneous access, but it also facilitates endoscopic inspection of the collecting system. Percutaneous puncture can be guided by ultrasound (US) or fluoroscopy. Although ultrasound guidance is sufficient for percutaneous puncture into the collecting system, passage of a guide wire and dilation of the tract requires the use of fluoroscopy (Park et al., 2006).
a. Ultrasound (US):

Ultrasound has made a significant impact in the field of urinary interventions, with the principle role being imaging guidance. US guidance has made procedures safer and shorter, limiting the number of needle punctures required and decreasing or sometimes eliminating radiation. In most of its applications it is complementary to fluoroscopy for providing image guidance for different urinary procedures (Preet and Raj, 2007).

Ultrasound before performing PCN helps to plan the procedure and Access site. The particular renal calyx and the skin puncture site can be selected before prepping the patient. The depth of the target and angulations of needle access can be planned, keeping in mind the a vascular Brodel’s line. Usually the posterior calyx is selected and ultrasound can provide radiation-free real-time imaging guidance for the needle puncture. It decreases the procedure time and the number of needle punctures, thereby decreasing the chance of potential complications (Preet and Raj, 2007).

Ultrasound eliminates the need for intravenous contrast administration, which is at times used during fluoroscopic-guided urinary access. In a poorly functioning kidney intravenous contrast may not even be feasible because of limited excretion, in which case ultrasound is valuable for single needle puncture access. US also helps to avoid cysts during access for PCN because they may cause confusion attributable to the aspirated fluid. Once antegrade access is obtained into the urinary system, fluoroscopy is generally better for guide wire manipulation (Preet and Raj, 2007).

Ultrasound guidance can be used to direct percutaneous puncture into the collecting system. Limitations of this modality include limited targeting ability in a non distended collecting system, poor image quality
in an obese patient, and limited ability to identify fine details of collecting system anatomy, such as a calyx with a stenotic infundibulum. Ultrasound, however, is the modality of choice for percutaneous access in select patient populations, such as pregnant patients or renal transplant patients in whom fluoroscopy is contraindicated or ill-advised or when retrograde passage of a ureteral catheter for opacification of the collecting system is precluded (Preet and Raj, 2007).

The principles of a successful US-guided puncture do not differ from those of the fluoroscopic approach. However, monographic identification of the needle may be technically demanding. There are a variety of transducers with lumens designed to accommodate the needle to help guide the puncture more easily. Because the tip of the needle is difficult to visualize, successful puncture of the collecting system is ultimately confirmed by the return of urine through the needle. Porcine experiments on US-guided nephrostomy with the aid of a magnetic field–based navigation device have addressed this limitation, allowing for accurate puncture needle placement in plane or out of plane from any direction, independent of transducer position (Lu et al, 2002).

Among transplant patients, US guidance offers the advantage of identifying overlying bowel that must be avoided when puncturing the transplant kidney. Although US is attractive because it minimizes exposure of the patient and surgeon to ionizing radiation; it is strongly operator-dependent. Furthermore, although large intrarenal stones and hydronephrosis are readily evident, smaller stones and those in the ureter may be difficult to identify by US. In addition, US is unable to differentiate nephrocalcinosis from nephrolithiasis, mandating further imaging modalities (Lu et al, 2002).
b. Fluoroscopy:

Fluoroscopy is the most common imaging modality used to obtain percutaneous renal access, although the choice between fluoroscopy and US is dependent on surgeon preference and experience. Regardless of the imaging modality used to gain access, intraoperative fluoroscopy is indispensable for the successful completion of PCNL (Park et al, 2006).

To facilitate fluoroscopic-guided percutaneous puncture, diluted contrast or air is instilled by means of a retrograde ureteral catheter or occlusion balloon catheter placed cystoscopically at the time of PCNL. Opacification of the collecting system delineates and distends the collecting system, further facilitating access. The instillation of air to create an air pyelogram has an advantage over instilling contrast in that air can identify the posterior calyces and avoids obscuring the stone. (Park et al, 2006).

The location of the stone-bearing calyces and their relation to the overlying ribs allows the surgeon to target the appropriate calyx, taking into account the risk of pleural violation. Upper pole percutaneous puncture provides optimal access to large or complex renal calculi, to
stones isolated in the upper pole calyces, to lower pole partial staghorn calculi, and to large ureteropelvic junction stones (Munver et al., 2001).

Lower pole access is favored for a primarily lower pole stone burden or for renal pelvic stones. Mid pole access generally is reserved for direct puncture onto isolated midpole stones, because access into these calyces may not allow inspection of either the upper or lower pole calyces (Munver et al., 2001).

After debulking the stone with rigid nephroscopy. Correct nephrostomy tube placement also is ensured with intraoperative antegrade nephrostogram (Sakurai et al., 2004).

The introduction of CT fluoroscopy, whereby CT live can be performed in the operating room, has the potential to allow percutaneous access to be performed under CT guidance with real-time visualization. CT fluoroscopy also has the potential to allow more accurate detection of residual fragments intraoperatively, thereby precluding the need for second-look flexible nephroscopy. Although CT fluoroscopy has not reached wide-spread use, and there are no reports of intraoperative use for PCNL, application of this modality to percutaneous brachytherapy for rectal cancer and radiofrequency ablation of pulmonary masses has been reported (Sakurai et al., 2004).

The last step of PCNL is fluoroscopic inspection of the chest to assess for hydrothorax. Intraoperative chest fluoroscopy has the advantage of reliably identifying pleural fluid that can be drained intraoperatively, while the patient is anesthetized because the fluid usually is composed primarily of irrigant, placement of a small bore (8 to 10 F) thoracostomy tube is generally sufficient for drainage, and can be placed with the same equipment and technique used to obtain percutaneous access (Munver et al., 2001).
iii. Postoperative imaging:

Post-PCNL imaging is aimed at identifying residual stones and establishing adequate antegrade drainage from the collecting system.

a. Plain abdominal radiographs and nephrotomograms:

Traditionally, KUB or plain nephrotomograms were used to identify residual stones post-PCNL and determine the need for second-look flexible nephroscopy. Although these modalities are inexpensive and quick, their sensitivity in detecting residual calculi is marginal (Denstedt et al., 1991).

b. Computed Tomography (CT):

With the widespread use of nonenhanced helical CT to identify renal and ureteral calculi, recent investigators compared the sensitivity of noncontrast CT with flexible nephroscopy in detecting residual stones after PCNL. Pearle and Colleagues (1999); prospectively compared KUB, non-contrast CT, and flexible nephroscopy for their ability to detect residual stones in 36 patients with 41 renal units undergoing PCNL for large or complex renal calculi. Using flexible nephroscopy as the gold standard reference, CT had a sensitivity of 100% and specificity of 62%, compared with 46% and 82%, respectively, for KUB. Thus, in their series, selective use of flexible nephroscopy based on CT findings would have resulted in only 12% of patients undergoing an unnecessary operation compared with 32% of patients if flexible nephroscopy was performed in all patients, as was their routine.
c. Antegrade nephrostogram:

Because of the potential for edema of the ureter or ureteropelvic junction as a result of previous stone or ureteral manipulation, antegrade nephrostogram is performed after most PCNL procedures to assure adequate antegrade drainage. In addition, opacification of the collecting system can delineate calyceal anatomy and along with noncontrast CT imaging, precisely localize residual stone fragments, thereby facilitating second-look flexible nephroscopy. If antegrade drainage is confirmed, the nephrostomy tube can be removed safely (Park et al, 2006).
TECHNIQUES OF PCNL

PCNL can be in short for nephrolithotomy or nephrolithotripsy, 'lithotomy' meaning removal of stone, and 'lithotripsy' meaning shearing or fragmentation of stone. Different urologists may have their own preferences and variations of the basic operative technique (Wong 2009).

In the past 3 decades, percutaneous nephrolithotomy (PCNL) has been performed with the patient in various positions. These positions include standard prone, semi supine, flank, supine with a pad under the leg or buttock, and complete supine (Falahatkar and Allahkhah 2010).

❖ Indications of PCNL:

Stone factors:
  a. Nonstaghorn calculi >2 cm.
  b. Stag horn calculi.
  c. Composition (brushite, cystine, calcium oxalate monohydrate).
  d. Impacted proximal ureteral calculi.
  e. Failure of URS and/or ESWL.

Renal anatomy factors:
  a. Lower pole calculi >1 cm.
  b. Caliceal diverticular calculi.
  c. Surgical correction of ureteropelvic junction obstruction and concurrent large stone burden. (Miller et al., 2007).
 Contraindications of PCNL:

Absolute:

a. Uncontrolled coagulopathy.
b. Active urinary tract infection.

Relative:

a. Ectopic kidney.
b. Fusion anomalies.
c. Severe dysmorphism.
d. Morbid obesity (Miller et al., 2007).

 Preoperative Preparation:

Urine sterility is mandatory for all elective procedures. This should be achieved by urine culture followed by sensitivity-specific antibiotics for 5 to 7 days before the procedure. Documented follow-up sterile urine is preferable but may not always be feasible (e.g., indwelling nephrostomy or urethral catheter, struvite stone). Consideration should be given for 1 to 2 days or more of preoperative intravenous antibiotics in select patients with a history of urosepsis, struvite calculi, or indwelling tubes. In patients with indwelling tubes, urine should be obtained directly from the catheter lumen, not from the drainage bag. Percutaneous entry in the setting of untreated urinary tract infection risks sepsis and death. (Gupta et al., 2007) and a temporary percutaneous nephrostomy can be inserted to drain an obstructed and infected pelvicalyceal system beforehand (Wong 2009)
**Anaesthesia and Positioning:**

Intravenous analgesia and sedation combined with local anesthetic injection may be sufficient for patients undergoing drainage procedures. Patients having more extensive percutaneous renal surgery require spinal blockade or general anesthesia. Because patients will most likely be in the prone position, airway access is poor and endotracheal intubation is necessary if general anesthesia is being administered. In patients receiving spinal blockade, a higher level than usually utilized for lower urinary tract procedures is desirable, but not to the detriment of pulmonary function (Gupta et al., 2007).

Percutaneous puncture could be the most difficult step, especially when the pelvi-calyceal system is not dilated and/or the anatomy is distorted. Careful positioning of patient facilitates correct puncture of the collecting system, while at the same time protects the anaesthesised patient from inadvertent injury. The positions generally preferred for puncture are:

1- Prone oblique with affected side tilted 30 degrees up, so that the Posterior lower pole calyx is directed posteriorly on the vertical Sagittal plane (Fig. 27);

2- Completely prone, with puncture performed from posterolaterally. *(Wong 2009)* (Fig. 28)
(Fig. 27) Posterior lower pole calyx in prone oblique position \textit{(Wong 2009)}.

(Fig. 28): Completely Prone positioning for percutaneous access. Two bolsters are placed on each side of the chest to facilitate ventilation; additional bolsters are placed under the knees and ankles. The head is carefully supported by an additional bolster \textit{(Gupta et al., 2007)}

3- The modified supine position in which the patient is tilted about 30°. \textit{(Chang, et al, 2007)}

4- Complete supine position:
a- With no towel under the patient's flank (Falahatkar and Allahkhah, 2010).

b- With a towel under the patient's flank (Steele and Marshall, 2007)

**Surgical Technique**

The standard operative technique of PCNL consists of three main steps:

1. Percutaneous puncture of pelvi-calyceal system.
2. Development of track.
3. Fragmentation and/or removal of stone (Wong, 2009).

1. **Percutaneous puncture of pelvi-calyceal system**

   After induction of anesthesia, cystoscopy can be performed with the patient in lithotomy or prone position with spreader bars for placement of a uretral catheter. Bladder drainage should be provided by means of an indwelling urethral catheter (Gupta et al., 2007).

   Options for ureteral catheterization include a 5- or 6-Fr open-ended catheter, an occlusion balloon catheter, a dual-lumen catheter, or a ureteral access sheath. Each has its advantages and disadvantages. *Simple open-ended catheters* are generally nonobstructive, thereby preventing high intrarenal pressure. In addition, they generally are least likely to cause ureteral injury. They may not prevent stone fragments from migrating down the ureter during the procedure, however. *A dual-lumen catheter* has the advantage of allowing simultaneous retrograde injection of more than one medium (e.g., contrast medium and/or indigo carmine), allowing simultaneous guide wire access and contrast agent or saline injection, providing drainage via one lumen and injection through the other to prevent high pressure, and preventing stone fragment migration. It does dilate the ureter, however, and may result in ureteral edema or injury requiring stent placement. *An occlusion balloon catheter* prevents
fragment migration but can cause ureteral injury and high intrarenal pressure. A ureteral access sheath facilitates fragment passage and prevents high pressure while allowing for injection via the inner dilator but significantly dilates the ureter (thereby mandating stent placement), can cause ureteral injury, does not provide adequate remaining urethral lumen for bladder drainage, and requires a makeshift drainage apparatus at its distal end (Gupta et al., 2007).

Percutaneous puncture of the pelvi-calyceal system is done with precision under the guidance of one of the following imaging techniques:

1. Radiographic contrast medium, coloured blue with methylene blue, can be injected via a pre-inserted retrograde ureteral catheter to outline the pelvi-calyceal system. This provides an additional advantage of slight distension of the collecting system that may facilitate percutaneous puncture, and can be repeated as often as is necessary without any dose limitation. With a single stone in the renal pelvis or when the anatomy is unclear, the use of contrast material is recommended to precisely delineate the intra-renal anatomy. In general, anterior calyces are more laterally located and posterior calyces are more medially located (mnemonic LAMP: Lateral-Anterior, Medial-Posterior)

2. Hydronephrotic collecting system can be punctured easily under real-time ultrasonographic guidance.

3. Intravenous injection of contrast medium produces a pyelogram for targeting the puncture. However delineation of the collecting system may not be optimal due to poor kidney excretion, and there is a dose limit due to nephrotoxicity of the contrast medium (Wong, 2009).
4. Alternatively, a small amount of air may be injected to provide an air pyelogram. The advantage of air is that it is lighter than urine or contrast material and therefore identifies the posterior calyces first, with the patient in the prone position. (*Gupta et al., 2007*).

**- Site Selection of Percutaneous puncture of pelvi-calyceal system:**

It is very important to select the percutaneous nephrostomy tract that is most suited for a particular procedure. The preferred approach is by way of a posterior calyx because major vascular structures surrounding the renal pelvis are avoided and the transparenchymal route stabilizes the nephrostomy catheter in an appropriate position. However, puncture of anterior calyces may be required for some stones or a calyceal diverticulum but is used only if access from posterior calyces is not possible. In addition, access from an anterior calyx to the renal pelvis is technically demanding because it requires directing the wire backward (in prone position). Direct puncture of the renal pelvis should be avoided because it carries a significant risk of injury to the posterior branch of the renal artery. In general, the risk of injuring larger branches of the renal artery increases with progressively more medial punctures. In addition, the tract created from such a medial puncture provides no stability for the nephrostomy tube because it lacks parenchymal support (*Niles and Smith, 1996*).

**A- Percutaneous puncture of pelvi-calyceal system in prone position:**

**Subcostal Approach:**

With the C-arm in the vertical position, the collecting system is inspected and the appropriate calyx is identified. The ideal site provides the shortest tract to the calyx from below the 12th rib (Fig. 29). Examination with the C-arm at 90 degrees defines the medial vertical
plane for entry into the calyx. The C-arm is then rotated approximately 30 degrees toward the surgeon. This places the axis of the C-arm in the same central posterior plane of the kidney, providing a direct end-on view of the posterior calyces. After the calyx has been identified, the overlying skin site is marked with a curved hemostat (Niles and Smith, 1996).

(Fig. 29): The ideal site for percutaneous puncture is one that provides the shortest tract to the calyx from below the 12th rib. In this particular case, although an intercostal approach would provide the shortest tract, it would also greatly increase the risk of injury to the pleura or lung (Gupta et al., 2007).

An 18-gauge translumbar angiography needle is advanced in the plane of the fluoroscopic beam with the C-arm in the 30 degrees position. The diamond tip prevents deflection by sharply cutting through muscle and fascia while causing minimal shearing. The appropriate direction for needle advancement is determined by obtaining a “bull's-eye sign” on the fluoroscopic screen. This effect can be observed only when the needle hub is superimposed on the needle shaft and is evident when the plane of the needle is the same as that of the x-ray beam. If the axis of the needle advancement is not parallel to the axis of the C-arm beam, a segment of the needle shaft is visible (Fig. 30) (Gupta et al., 2007).
(Fig. 30): The use of two-plane fluoroscopy to achieve accurate needle entry. With the C-arm rotated 30 degrees from the vertical position (A), the “bull's eye” sign confirms passage of the needle at the proper angle. The depth of needle penetration can be checked by intermittently rotating the C-arm to the vertical position (B) (Gupta et al., 2007).

After determination of the appropriate plane, the needle is advanced in 1 to 2 cm increments using a hemostat to minimize radiation exposure to the surgeon. The needle should approximate the avascular line of Brödel, because this provides the safest access to the posterior calyceal system. A transparenchymal route avoids the hilar vessels and seals the nephrostomy tract from urine leakage. The depth of needle penetration is monitored by rotating the C-arm back to the vertical position. With the C-arm in the vertical position, the approximation of the tip of the needle to the predetermined calyx can be seen and guided fluoroscopically. For example, the needle is too deep if it appears to be past the calyx on the fluoroscopic screen. Periodically, it is important to evaluate the correct direction of needle advancement by rotating the C-arm 30 degrees toward the surgeon and observing for the bull's-eye effect.
Both the appropriate axis and the needle depth are prerequisites for a successful percutaneous access. The needle has reached its intended target when its tip is in the desired calyx on both planes of fluoroscopy (Gupta et al., 2007).

When the needle appears to be in a calyx, the stylet is removed and the correct needle position is verified by aspiration of urine. A 0.038-inch floppy-tip J-shaped guide wire is inserted into the needle and either advanced across the UPJ or coiled within the renal pelvis. With the needle left in place, a 1 cm skin incision is made. The needle is then removed and the tract is dilated over the wire (Gupta et al., 2007).

- Another technique of subcostal approach done by Wong, 2009:

Initial exploratory puncture is performed with a 21G or 22G skinny needle from below the 12th rib, targeting a posterior calyx preferably of the lower pole, aligning the direction of access with the axis of the targeted calyx and its infundibulum, aiming to traverse the minimum thickness of cortical parenchyma possible, and entering the calyx through the papilla. The depth of the advancing needle point and its relationship to the target calyx can be confirmed using C-arm fluoroscopic imaging. Rotation of the C-arm enables biplanar imaging and guidance, or the C-arm can simply be kept in the vertical plane and one judges the relative position of the needle point to the target calyx by applying the principles of parallax. Successful puncture or entry into the target calyx can be ascertained when a stream of blue-coloured fluid flows out from the needle upon withdrawal of the stylet. A second definitive puncture is then performed with a larger 18G needle. Insertion of this needle into the target calyx enables subsequent introduction of a 0.038 or 0.035 working guidewire into the pelvi-calyceal system. It can
be achieved under fluoroscopic guidance, by parallel puncture beside the initial skinny needle; this technique is particularly useful to a novice urologist.

- Subcostal approach to upper pole calyx:

  There are multiple techniques that can be done to puncture the upper pole calyx subcostally.

  (1) Displacement of the kidney caudally by placing an Amplatz sheath through a central or lower pole calyx and rotating the back of the dilator cranially, which causes caudal displacement of the kidney that can be viewed fluoroscopically. A second distinct puncture or a Y-tract is created into the upper pole. This method was successful 84% without complications (Fig. 31).

  (2) An occlusion balloon catheter can be used to apply gentle caudal traction and displace the kidney downward and below the costal margin during the initial access approach.

  (3) The needle can be advanced gradually only when the kidney is at its lowest excursion point, either incrementally during consecutive end-inspirations or while the patient is made to perform a Valsalva maneuver by the anesthesiologist (Karlin and Smith, 1989).

(Fig. 31): Caudal mobilization of the kidney using an Amplatz sheath in a middle calyx presents a lower position for superior calyceal puncture (Karlin and Smith, 1989).
(4) Triangulation technique: The C-arm is placed over the patient in the vertical position. A retrograde pyelogram is obtained, and the skin over the desired calyx is marked with a hemostat while the C-arm is maintained in the vertical position. This plane defines the medial extent of needle penetration for access to the desired calyx. The C-arm is then rotated 30 degrees toward the surgeon for an end-on view of the posterior group of calyces. With the C-arm at 30 degrees, the skin site over the calyx is marked lateral to the first site. The surgeon uses this point on the skin surface to move in a vertical line inferiorly until a site 1 to 2 cm below the 12th rib is reached. This third site is marked and serves as the site of needle entry. From this point, the needle is advanced to the junction of the vertical plane and the 30 degrees plane. Access is achieved at the junction of all three axes, hence the term triangulation (Niles and Smith, 1996) (Fig. 32).

(Fig. 32): The triangulation technique can be used to avoid intercostal needle puncture. The vertical (90-degree) plane defines the medial extent of needle penetration, and the 30 degrees plane provides an end-on view of the posterior calyces. In the triangulation technique, the needle is advanced from a point 1 to 2 cm below the 12th rib to the junction of the vertical and 30 degrees planes (Niles and Smith, 1996).
In this technique, the bull's-eye sign does not exist; and thus the axis for needle advancement is based on the surgeon's appreciation of the principles of two-plane fluoroscopic viewing, especially regarding the needle tip and calyceal position. It is also very important to be familiar with the perception of the angle of advancement of the needle as it relates to the depth of penetration along the medially defined plane described previously. This approach is technically more demanding and requires more experience with percutaneous punctures (Fig. 33). This procedure can place some torque on the renal parenchyma and should only be used when the normal renal excursion allows the superior calyces to be close to the level of the 12th rib (Niles and Smith, 1996).

(Fig. 33): Percutaneous puncture of the superior pole calyx (by triangulation technique). (A) Sub-costal point of entry with the tip of the needle puncturing the superior pole calyx. (B) After aspiration of urine confirms the correct position, the guide wire is advanced into the ureter (Niles and Smith, 1996).

**Intercostal Approach:**

The risk of hydrothorax and hemothorax is increased when percutaneous access to the calyces is performed above the 12th rib. (Irby et al, 1999). Direct percutaneous access to an upper pole calyx can be difficult by a subcostal approach, and the endourologist needs to be familiar with the intercostal approach. Many urologists favor this approach for gaining access to the upper pole and suggest that it provides
direct and optimal access to most staghorn calculi, even though it carries
a slight and acceptable increase in morbidity (Golijanin et al, 1998).

2. Development of track

Needle entry into the desired location of the pelvicalyceal system
represents the first step of a successful percutaneous intervention (Gupta,
et al., 2007). The second step is to dilate a track from the skin through the
renal parenchyma into the collecting system, and to place a working sheath (Wong, 2009). The tract also must be secured and dilated to allow
for the passage of nephroscopic equipment or drainage catheters. In the
early experience with percutaneous techniques, dilation of existing
nephrostomy tracts was carried out gradually using sequentially larger
telescopic dilators over a period of 8 days. Castañeda-Zúñiga et al.,
(1982) first described acute dilation of the nephrostomy tract in a single
session with no untoward effects. Since then, multiple techniques have
been developed that allow for safe and rapid nephrostomy tract dilation,
so that percutaneous access and intrarenal surgery now can be routinely
performed during the same setting.

Guide Wire Introduction

The main principle of acute tract dilation is that, it must always
be performed over a guide wire. After needle entry into the collecting
system is confirmed by return of urine after removal of the stylet, the
Seldinger technique is used to advance a guide wire through the needle
into the collecting system. The wire should be stiff enough to support the
subsequent dilation. Passage of the wire down the ureter into the bladder
should be attempted to minimize the risk of wire dislodgement during
fascial dilation. In situations in which this is not possible (e.g., impacted
ereteral stone, narrow UPJ), the wire should be positioned in a calyx that
is distant from the initial nephrostomy tract to prevent dislodgement during dilation. In patients with complete staghorn calculi, the guide wire may coil within the punctured calyx because it cannot pass into the renal pelvis. In this case, dilation must be performed very gently because the guide wire can be easily displaced. In addition to the initial working guide wire, a second safety guide wire may also be used (Press and Smith, 1995).

The safety wire is inserted immediately adjacent to the working wire and serves to protect access to the nephrostomy tract in case the working wire becomes kinked or displaced. Insertion of the safety guide wire requires the use of a double-lumen catheter or a coaxial system to accommodate two wires. This coaxial system consists of an inner dilator tapered to the size of the guide wire and an outer sheath. After the inner dilator is removed, the external sheath allows the safe insertion of the second guide wire, ensuring its correct positioning within the ureteral lumen. Various safety guide wire introducers are available (Press and Smith, 1995).

**Types of Dilators**

A variety of techniques exist for acute dilation of the nephrostomy tract. The most commonly used systems include *progressive fascial dilators, malleable dilators, metal coaxial dilators, and high-pressure balloon dilators*. The decision of which type of dilation system is used varies among urologists on the basis of personal preference and experience. Multiple investigators have found no differences in renal parenchymal damage among the various dilation methods (Stoller et al, 1994). It should be noted however that, when comparing balloon dilators and malleable dilators, several groups of investigators observed lower
Review of Literature

renal hemorrhage rates and lower transfusion rates in patients undergoing balloon dilation (Safak et al, 2003).

(1) Fascial Dilators.

The fascial dilator system consists of progressively larger polytetrafluoroethylene (Teflon) tubes designed to slide over a 0.038-inch guide wire. They range in size from 8 to 36 Fr and are inserted in a rotating, screw-type fashion with the entire dilation procedure performed under fluoroscopic control. The main advantage of this system is that it is safe. The stability conferred by the firm polytef composition also makes fascial dilators ideal for dilation of fibrous tracts such as may be seen in patients with a history of retroperitoneal surgery, percutaneous surgery, or inflammatory processes of the kidney (Press and Smith, 1995). The main drawback of this system is its dependence on the integrity of the guide wire (LeRoy, 1996). In addition, despite their purported safety, caution must be exercised when introducing fascial dilators because their tips can perforate the renal pelvis medially, causing excessive blood loss or extravasation of irrigating fluid into the retroperitoneum (Gupta, et al., 2007).

(2) Malleable Dilators:

Malleable dilators were developed in 1982 by Kurt Amplatz to improve upon some of the weaknesses of the older fascial dilators and are now widely referred to as Amplatz dilators (Rusnak et al, 1982). A tapered 8-Fr angiographic catheter is initially inserted down the ureter over the working guide wire, and progressively larger polyurethane catheters are serially passed over the catheter/guide wire combination. The additional stability conferred by the tapered 8-Fr catheter facilitates the entire dilation process by preventing the guide wire from kinking and by allowing the larger dilating catheters to slide more easily. These
dilating catheters range in diameter from 12 to 30 Fr in increments of 2 Fr (Gupta, et al., 2007).

Once the tract is adequately dilated, an outer sheath is passed in coaxial fashion over the polyurethane dilator. The external sheath secures access to the kidney and allows the repeated introduction and withdrawal of endourologic equipment. The sheaths range in size from 28 to 34 Fr, and the outer diameter exceeds the inner diameter by 4 Fr; thus, the 34-Fr sheath is designed to slide over the 30-Fr dilator. The sheaths are impregnated with polytef to reduce the coefficient of friction and to minimize buckling (Gupta, et al., 2007).

(3) Metal Coaxial Dilators.

Metal coaxial dilators are made of stainless steel and are mounted together in a telescopic fashion, mimicking a collapsible radio antenna. Progressively larger dilators are added until the tract is dilated to the desired size (Alken, 1985). The metal telescopic dilators consist of an 8-Fr hollow guide rod that slides over a guide wire and a set of six metal tubes ranging in diameter from 9 to 24 Fr. Each dilator adapts exactly to the lumen of the next dilator. A bulge at the end of the rod represents the endpoint for the progression of the dilators, ensuring that they cannot be advanced farther. After all dilators have been advanced, their tips are in the same horizontal plane, close to the tip of the guide rod (Gupta, et al., 2007).

The metal coaxial dilation system is rigid and theoretically is excellent for patients with previous surgery and associated perirenal fibrous tissue. However, several notable drawbacks have limited its use. The main disadvantage is that it is difficult to control the pressure exerted during dilation. The central core of the apparatus must be held firmly while the outer dilator is advanced to avoid untoward events such as
perforation of the renal pelvis and the resultant risks of extravasation and hemorrhage (*Seeman and Alken, 1995*).

(4) **Balloon Dilation Catheters:**
For the fascial, malleable, and metal coaxial dilation systems, the major risk of injury stems from the uncontrolled repetitive passage of progressively larger dilators. In an attempt to minimize the morbidity of nephrostomy tract dilation, balloon dilation catheters capable of achieving tract dilation in a single step were developed (Fig. 34) (*Gupta, et al., 2007*)

![Balloon dilation catheter and preloaded sheath](image)

(Fig. 34): Balloon dilation catheter and preloaded sheath (*Gupta, et al., 2007*).

Before inserting the balloon catheter, a 30-Fr polytef working sheath is backloaded behind the uninflated balloon. The catheter is then inserted over the guide wire until the inflatable segment traverses the nephrostomy tract. The tip of the balloon, indicated by the radiographic marker, is advanced just inside the calyx. Passing the balloon tip beyond the calyx or stone may result in infundibular tears or urothelial injury from the impaction of the stone. Once appropriately positioned, the balloon is inflated to acutely dilate the tract. Pressures of 15 to 20 atmosphere (atm) can easily be reached with the balloon catheter. In patients with no previous renal surgery, pressures of 4 to 5 atm are usually enough to dilate a nephrostomy tract. In those who have had surgery, higher pressures are required to achieve the final dilatation. As the balloon is inflated, a characteristic “waist” appears in areas of high
resistance, such as the renal capsule or a previous operative scar (Fig. 35). With persistent inflation, the balloon expands fully and the waist disappears, allowing the backloaded sheath to be advanced into the collecting system in a rotating fashion. This sheath is advanced into the tract to the end of the balloon, not the end of the catheter. The balloon is then deflated and retrieved from the tract. The working sheath provides the access for further endourologic manipulations (Gupta, et al., 2007).

The balloon dilator seems to be safer, faster, and with reduced X-ray exposure of the patient and surgeon. Thus, it is regarded as the gold-standard, but it is associated with a higher cost (Miller et al., 2007).

(Fig. 35): During balloon dilation of the nephrostomy tract, a waist can be seen at areas of high resistance such as the renal capsule and previous operative scar. In this instance, the waist (arrow) corresponds to dilation of the renal capsule (Gupta, et al., 2007).

3. Fragmentation and/or removal of stone

The third step is to introduce a nephroscope via the Amplatz sheath into the pelvi-calyceal system to locate the stones. The standard 26 Fr rigid rod-lens nephroscope with off-set eyepiece provides excellent optics and allows the use of strong rigid instruments to deal with the stones. Continuous irrigation with warm normal saline is set up to fill the pelvi-calyceal system with fluid, with inflow via the endoscope and outflow simply via the Amplatz sheath. This allows a very rapid flow to clear stone fragments and blood, and thus enables good endoscopic view. It dissipates the heat energy of mechanical lithotripsy and so minimises
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its potential injury. Last but not least, the importance of an effective irrigation system is to maintain a low pressure in the pelvi-calyceal system that reduces the risks of pyelo-renal reflux and its resultant fluid absorption and sepsis (Wong, 2009).

A: Nephroscopy and extraction of stones in prone position (Wong, 2009)
B: Nephroscopy and extraction of stones in supine position (Falahatkar and Allahkhah, 2010).

Smaller stones can be retrieved with rigid stone forceps directly via the Amplatz sheath. Commonly preferred instruments are tripod graspers or forceps with strong alligator jaws (Wong, 2009). Larger stones have to be fragmented first, using either one of the following energies:

1. Ultrasonic lithotripsy
2. Pneumatic lithotripsy
3. Holmium laser lithotripsy
4. Electrohydraulic lithotripsy (EHL)

And lastly inspection by flexible nephroscopy

1. Ultrasonic lithotripsy:

Ultrasonic energy is the most commonly used method for intracorporeal lithotripsy owing to its demonstrated safety and efficacy. The piezoelectric effect creates vibrational ultrasonic energy which is transmitted down the shaft of the probe. These probes are always rigid, therefore rigid nephroscopy is required and its use is limited to calices which can only be safely reached without undue torquing of the kidney. Although solid probes are available, hollow ultrasonic probes are preferred because of the ability to suction simultaneously. They range from 3 to 12 Fr in size, with the hollow designs being larger in diameter.
Under direct vision, the surgeon gently presses the tip of the probe against the stone. As the surgeon activates the probe, the assistant or activation pedal modulates the suction, thereby balancing visibility by hydrodistending the system with evacuation of broken fragments. Stone graspers are used intermittently to remove fragments less than 1 cm (Pietrow et al., 2003).

2. Pneumatic lithotripsy:

Another major energy source is the pneumatic lithotrite, or Swiss Lithoclast. This device has a generator, hand piece, and foot pedal. When activated, compressed air propels a metal projectile inside the hand piece into the base of the probe producing a “jackhammer” effect. Pressures of up to 3 atm are generated, and this ballistic energy is transmitted along the probe into the stone. (Kuo et al., 2004).

Advantages of ballistic lithotripsy include relatively inexpensive equipment with reusable components and a high margin of safety because very little heat is generated at the probe tip. Disadvantages include the inability to remove fragments simultaneously, and stone retropulsion. In an effort to improve simultaneous fragment removal, ballistic lithotripsy was combined with a suction device that can be used only with rigid probes (Delvecchio et al, 2000).

3. Holmium laser lithotripsy:

The Holmium: YAG laser generates a beam with a wavelength of 2100 nm and pulse duration of 250 µs. This wavelength is highly absorbed by water, thus the laser fiber must be placed directly on the stone. Fibers range in size from 200 to 1000 microns, and the power generated by the machine is controlled by modulating the energy (Joules) and frequency (Hertz) of each pulse. The benefits of using Holmium laser are that very hard stones can be broken, and that flexible nephroscopy can
be used with these energy sources. However, a significant downside compared to ultrasonic lithotrities is that suctioning cannot be performed simultaneously. However, one recent report used an innovative suctioning device together with the Holmium laser (Cuellar and Averch 2004).

4. Electro-hydraulic lithotripsy (EHL):

EHL utilizes electrical energy that overcomes the insulative gap of an electrode to produce a spark and an ensuing cavitation bubble (Yang and Hong, 1996). Symmetrical collapse of the cavitation bubble results in a secondary shockwave or high-speed microjets if the bubble collapses asymmetrically. Both the secondary shockwave and microjets are responsible for stone fragmentation (Denstedt and Clayman, 1990). An advantage of EHL is its low capital cost compared with laser units. EHL probes are a disposable component and depending on stone hardness, more than one probe may be required to achieve complete stone fragmentation. The probes are more flexible than laser fibers. The most important disadvantage of EHL is that some stones are resistant to fragmentation and that high peak pressures are generated at a distance from the probe tip, producing a narrow margin of safety (Vorreuther, 1993).

Drainage after Percutaneous Nephrolithotomy:

At the end of the operation, a percutaneous nephrostomy catheter is inserted along the track and left in place for one to two days. This temporary catheter nephrostomy provides monitoring for haemorrhage and diverts urine in case drainage down the ureter is not functioning well due to temporary obstruction by inflammatory swelling or blood clot (Wong, 2009), and maintains renal access if second look nephroscopy is required, and tamponades any bleeding points. There are multiple choices in nephrostomy drainage, and the final choice is dictated by surgeon
experience and discretion. Self-retaining tubes (balloon-Foley, Malecot, Cope loop) are preferred over simple, non self-retaining tubes such as red rubber Robinson catheters or modified chest tubes because the latter can be easily dislodged. Patient discomfort is greatest with large supracostal nephrostomy drainage tubes (Kim et al 2005).

- Standard versus tubeless PCNL:

External drainage of the pelvicalyceal system after percutaneous procedures of the upper urinary tract (i.e., percutaneous nephrolithotomy) has been routine practice among endourologists. (Goh and Wolf, 1999) This technique has translated into the modality of “tubeless percutaneous renal surgery” in selected patients at some institutions (Limb and Bellman, 2002). In addition, use of hemostatic sealants at the renal parenchymal defect after tubeless percutaneous procedures (i.e., nephrolithotomy) has shown some benefit in limiting postoperative urine extravasation and aiding in hemostasis (Lee et al, 2004). Nevertheless, postoperative drainage with a nephrostomy tube after percutaneous renal surgery remains a safe and standard practice (Gupta et al., 2007).

- Post-operative Care

The patient is only left with a wound of the size of the working sheath that is no more than 1 cm. However, the patient may still have some pain albeit moderate, and nausea is not uncommon. It is advisable on the first day post operation to limit oral intake to fluids, give intravenous fluid infusion, prescribe appropriate analgesic as required, and to continue antibiotic therapy (Wong, 2009).

Twelve to 48 hours after the percutaneous procedure, ante grade nephrostograms are typically performed. Complete scout radiographs should be performed to exclude residual stone fragments. Contrast should delineate upper tract anatomy and drain freely into the bladder. Hopefully
there are no stones noted and there is free drainage into the bladder. In these situations the nephrostomy may be clamped and removed after a few hours or removed immediately after the study. If there are fragments large enough to be of clinical concern, the surgeon has the option of recommending shock-wave lithotripsy or second-look nephroscopy (Park et al., 2006).
Complications of PCNL

PCNL is an established urologic procedure that is used to treat patients with nephrolithiasis. Refinements in technology and increasing surgical experience with PCNL have generally resulted in its safe and effective execution. Prompt recognition of such complications and institution of appropriate treatment will generally limit morbidity. The various complications associated with PCNL, their treatment, and methods of prevention are herein reviewed (Shah and Assimos 2006).

i. Hemorrhage:

a. Intra-operative transfusion-dependent hemorrhage has been reported to occur in 0.6-1.4% of individuals subjected to PCNL. It may manifest during the procedure or in the postoperative period. Patients are certainly concerned about receiving a blood transfusion. The risks for this have been linked to surgical technique, surgical experience, preoperative anemia, and older patient age (Stoller, et al., 1994).

Certain measures can be taken to limit this complication. The collecting system should be accessed through a posterior calyx along the direction of the infundibulum to avoid blood vessels coursing adjacent to the infundibulum. The tract should only be dilated up to the peripheral aspect of the collecting system. The renal pelvis may be perforated and hilar vessels lacerated if dilation is directed too far medially (Soble and Streem, 1998).

Stoller et al., (1994); reported that renal pelvic perforation is a risk factor for excessive blood loss during PCNL. If a working sheath is used, it must be kept in the collecting system to limit parenchymal bleeding. Angulation/torquing of the working sheath and instruments may damage blood vessels and renal parenchyma and thus should be avoided. Flexible
nephroscopy or creation of an additional nephrostomy tract should be performed instead.

Lam et al., (1992); found that use of multiple access tracts and improved flexible endoscopic skills decreased transfusion requirements in their patients with staghorn calculi subjected to PCNL. When visibility is significantly diminished because of bleeding, one should assess for malpositioning of the working sheath. If the sheath is malpositioned and bleeding persists after redirecting the sheath into the targeted portion of the collecting system, or if the tube is properly positioned and hemorrhage continues, the procedure should be terminated.

Most intraoperative bleeding is thought to be from venous sources. Heavy venous bleeding should be suspected when a high volume of dark-colored blood drains from the tract after fluid irrigation is stopped. Injection of contrast into the collecting system in this setting will sometimes demonstrate opacification of the renal venous system (Kerbl, et al., 1994).

There are various approaches for managing this problem. Inflation of a 30 French dilating balloon in the tract for 10 to 20 minutes with subsequent placement of a large nephrostomy tube is usually successful. An alternative is initial placement of a large nephrostomy tube that is subsequently clamped for 1 to 2 hours. This allows the blood to clot and tamponade the injured vein. If these measures are not successful, the use of a specialized nephrostomy tamponade catheter should be considered (Kaye, Cook Urological) Fig (36). The peripherally located balloon is inflated in the tract while urine drains through the inner core of this device. It is typically left inflated for 2 to 4 days (Fuchs, et al., 2001).
Fig. (36): (A) The Kaye tamponade nephrostomy tube can be inflated for compression of the nephrostomy tract in cases of severe hemorrhage. (B) Dual lumen of Kaye tamponade nephrostomy, allowing placement under wire guidance, antegrade nephrostograms, and hemostatic compression of nephrostomy tract (Shah and Assimos 2006).

High-volume arterial bleeding should be suspected if the effluent is bright red or has a pulsatile flow. The aforementioned approach can be utilized, but angiography and selective or super-selective embolization may be necessary if these measures are not successful.

b. Postoperative Bleeding can occur in the immediate postoperative period, at the time of percutaneous nephrostomy tube removal, or several days to weeks later. Serious preoperative bleeding, requiring intervention other than tamponade occurs in approximately 1% of patients. If high-volume bleeding from the tract is present, initial management should include finger tamponade of the tract site and subsequent placement of a tamponade catheter or the largest nephrostomy catheter that the tract will permit. The latter catheter should then be occluded. These maneuvers are optimally done under fluoroscopic guidance. The patients are placed on bed rest and administered blood transfusions as necessary. Renal arteriography
should be performed when bleeding persists, especially with the continued need for blood transfusion or hemodynamic instability due to hemorrhage \((Fuchs\ et\ al.,\ 2001)\).

c. **Delayed bleeding** the most common causes of delayed bleeding are laceration of segmental renal vessels, and development of an arteriovenous fistula or pseudoaneurysm. Superselective or selective angiographic embolization of such lesions, using coils, absorbable gelatin sponges, or platinum microcoils, is generally quite successful (Figure 37). The bleeding site may sometimes be obscured by the nephrostomy catheter, which can be removed to allow angiographic localization \((Fuchs\ et\ al.,\ 2001)\).

Open surgical exploration with partial or total nephrectomy may be necessary if the aforementioned measures are unsuccessful.

\[\text{Fig. (37): A, Delayed film of a renal arteriogram demonstrating a pseudoaneurysm (arrows), B, Renal arteriogram performed after embolization of injured vessel with coils (Shah and Assimos 2006).}\]
d. **Perinephric hemorrhage** can also occur intraoperatively and postoperatively, difficulty in accessing the kidney and malpositioning of the working sheath outside the renal parenchyma or capsule may lead to this problem. This should be suspected if the patient has a decreasing postoperative hemoglobin level while urine from the bladder and nephrostomy tube appears relatively clear. Sandwich therapy with extracorporeal shock wave lithotripsy (ESWL) and subsequent second-look PCNL is a potential risk factor since subcapsular or perinephric hemorrhage from ESWL may increase with further tract and collecting system manipulation. CT scan should be performed if this diagnosis is suspected *(Fuchs et al., 2001)*.

**ii. Extravasation:**

Extravasation occurs with perforation of the collecting system or ureter when the access sheath is outside the collecting system. *Lee et al.*, *(1987)* reported radiographic demonstration of extravasation in 7% of 582 cases. Perforation should be suspected if retroperitoneal fat and other perirenal structures are visualized, or if the patient’s abdomen or flank becomes distended. If the treatment is almost completed, it may be possible to finish the procedure with low flow irrigation, providing the patient is stable. Most perforations will heal with antegrade ureteral stent placement and nephrostomy tube drainage. Some larger rents may not heal, and open surgery may be necessary.

Management depends on the amount of extravasation. Small amounts of extravasation will resolve spontaneously with nephrostomy tube drainage. Large fluid collections (or urinomas) may develop, which usually resolve spontaneously. CT or ultrasound-guided drainage, however, may be necessary if persistent ileus, fever, respiratory compromise, or excessive abdominal distention develop. Open surgical drainage is reserved for the extremely rare cases in which the aforementioned measures are unsuccessful *(Shah and Assimos 2006)*.
iii. Stricture:

The development of ureteral stricture after PCNL is quite rare; the reported incidence is less than 1%. The proximal ureter and UPJ are the areas most susceptible. Strictures may result from inflammation due to stone impaction or from procedural trauma, including intracorporeal lithotripsy (*Shah and Assimos 2006*).

The majority of patients developing ureteral strictures can be managed successfully with an endourologic approach. Open surgical reconstruction may be required, however, for those failing the former or having extensive strictures (*Shah and Assimos 2006*).

iv. Infundibular Stenosis:

Infundibular stenosis can also rarely occur after PCNL. Prolonged operative time, a large stone burden requiring multiple procedures, and extended postoperative nephrostomy tube drainage were independent risk factors for this occurrence. This problem usually manifests within one year after PCNL (Fig.38). An endourologic approach for management of such patients should initially be considered. Observation is a consideration for asymptomatic patients without evidence of renal functional impairment of the involved kidney (*Buchholz, 2001*).

*Fig. (38):* A. Postoperative computed tomography scan demonstrates dilated right upper pole calyx. B. Subsequent retrograde pyelogram reveals no communication to the upper pole collecting system caused by infundibular stenosis. (*Shah and Assimos 2006*).
v. Retained Foreign Bodies:

Electrohydraulic lithotripsy (EHL) electrode, stent, stone basket, guide wire, laser fiber, or other instrument may become dislodged in the collecting system and should be removed because infection, a granulomatous reaction, or new stone formation may otherwise occur. Fluoroscopy can be used to help identify the foreign body, which can then be extracted with a rigid or flexible nephroscope. Replacing instruments before instrument fatigue develops helps to limit this occurrence. If the retained object is recognized after nephrostomy tube removal, retrograde ureteroscopic extraction should be initially considered. Percutaneous extraction may be required if the former is unsuccessful (*Koolpe and Lord 1990*).

vi. Extrarenal Stone Fragment Migration:

The consequences of extrarenal stone fragments are generally not of clinical significance provided the urine and stone are not infected, and the stone material does not become embedded in the submucosa. Retrieval should usually not be attempted because this may enlarge the perforation (*Evans and Stoller, 1993*).

vii. Ureteral Avulsion:

Ureteral avulsion is an extremely rare complication, occurring in less than 0.2% of cases, which usually results from attempts at an antegrade basketing of large, impacted ureteral stones. This complication mandates prompt open surgical exploration. Percutaneous nephrostomy drainage may be used as a temporizing measure to allow patient stabilization (*Shah and Assimos 2006*).

viii. Nephrocutaneous Fistula:

Fistula formation between the renal collecting system and the skin is rare. Prolonged postoperative drainage from the nephrostomy tract is usually caused by distal obstruction secondary to ureteral edema, an obstructing stone, blood clot, or stricture. Fistula drainage will usually
cease after stone removal, placement of an indwelling Double-J stent in cases of ureteral edema, or treatment of the stricture. Very rarely will it be necessary to induce healing of the fistula tract by electrocautery in addition to the aforementioned measures (Shah and Assimos 2006).

ix. Injury To Adjacent Structures:

a. **Lung and Pleura** the lung and pleura are the perirenal structures at greatest risk for injury during PCNL, although lung parenchymal injury is rare. Most of these injuries occur when a supra-costal approach is used because of the proximity of the ribs with these structures. Pneumothorax has been reported in (0 to 4%) and hydrothorax in (0 to 8%) of individuals subjected to supracostal access (Pearle et al., 2000).

Routine intraoperative chest fluoroscopy is recommended at the termination of PCNL to evaluate for obvious hydrothorax or pneumothorax. Routine postoperative chest radiography is not necessary when fluoroscopy is normal and the patient has no signs of pulmonary compromise (Pearle et al., 2000).

Patients with a small-volume pneumothorax or hydrothorax can be observed when there are no signs of pulmonary compromise. Aspiration or tube thoracostomy may be required for large pneumothoraces or patient instability (Pearle et al., 2000).

b. **Colon Perforation** is an extremely rare complication of PCNL; reported in less than 1% of cases this low incidence is attributed to the colon rarely being retrorenal (Figure 39). Patients at higher risk for colonic injury are those with congenital anomalies such as horseshoe kidney and other forms of renal fusion and ectopia, and those with colonic distention due to jejunoileal bypass, partial ileal bypass, neurologic impairment, and CT should be considered in high-risk groups to detect the presence of postrenal colon, and CT-
guidance can be used in these patients to direct percutaneous access.

**Fig. (39):** Ascending colon injury of PNL performed in patient with retrorenal colon. Extravasated contrast medium is seen in transverse and descending colon (*Shah and Assimos 2006*).

Colonic perforation can cause serious infectious complications when the perforation occurs intraperitoneally, or if diagnosis and management are delayed. Colonic penetration should be suspected if the patient has intraoperative diarrhea or hematochezia, signs of peritonitis, or passage of gas or feculent material through the nephrostomy tract. This complication may remain undetected, however, until a postoperative nephrostogram demonstrates contrast entering the colon (*Matlaga et al., 2003*).

The majority of colonic injuries can be managed conservatively if the penetration is retroperitoneal and the patient does not have signs of peritonitis or sepsis. An indwelling double-J ureteral stent is inserted, and the nephrostomy tube is pulled back into the colon. The patient is given broad-spectrum antibiotic therapy and placed on a low-residue diet. A contrast study is performed through the colostomy tube after 7 to 10 days and the tube is removed if there is no evidence of a nephrocolic fistula. Open surgical management is required in patients with trans-peritoneal perforation, peritonitis, or sepsis and in those who fail conservative management (*Matlaga et al., 2003*).
c. **Duodenum:** The second and third portions of the duodenum are retroperitoneal and are somewhat anterior to the lower pole and pelvis of the right kidney. This structure may be injured during access if a needle, guide wire, or dilator perforates the renal pelvis or lower pole collecting system and penetrates the duodenum. Very few cases of this complication have been reported, and its occurrence is rarer than colonic perforation (*Matlaga et al.*, 2003).

It is usually diagnosed when communication with the duodenum is demonstrated on an intraoperative or postoperative nephrostogram. Open surgical management may be required if the perforation is large or if the patient has sepsis or peritonitis. Success with nonoperative management has been reported in less compromised settings. Patients are treated with antibiotics, placed on nasogastric suction, and administered parenteral hyperalimentation. The nephrostomy tube is positioned correctly to ensure adequate drainage. A nephrostogram and upper gastrointestinal radiographic study are performed 10 to 14 days later to determine whether the fistula has closed (*Matlaga et al.*, 2003).

d. **Liver And Spleen Injury:** *Kondas et al., (1994)*, noted that the spleen should not be traversed if an 11th to 12th rib supracostal approach to the upper pole collecting system is undertaken during expiration; there is a 13% risk if performed during inspiration. The risk increases to 33% if a 10th to 11th rib approach is used. The risk is also increased in patients with splenomegaly, and CT should be performed in these cases to determine whether safe access is possible and to assist with nephrostomy tube placement.
Splenic injury can cause significant internal bleeding and hypovolemic shock. The diagnosis is established with US or CT. Although some patients with splenic laceration can be managed non-operatively, the majority will require splenectomy secondary to significant hemorrhage (Kondas et al., 1994).

The liver is far less susceptible to injury than the spleen. Hopper and Yakes (1990) reported the risks of injury during an 11th to 12th rib intercostal approach was minimal and would occur in only 14% of patients if a 10th to 11th rib route was taken during inspiration. Hepatomegaly places the patient at increased risk for this complication. Therefore, such patients should be evaluated with a preoperative CT scan. CT-guided access may help prevent this injury in select patients with hepatomegaly. If this is diagnosed postoperatively, the nephrostomy tube should be left in place (7 to 10) days to allow for tract maturation. The tube can be carefully removed at this interval but immediately reinserted if there is high-volume bleeding from the tract. Retrograde placement of an internalized ureteral stent at the time of nephrostomy tube removal has been recommended by some in an effort to avoid a reno-biliary fistula.

x. Medical Complications Of PCNL:

a. Infection And Sepsis It is mandatory that patients with urinary tract infections (UTI) be treated with appropriate antibiotic therapy before PCNL. The risk of sepsis from intravasation of bacteria via pyelovenous or pyelolymphatic backflow during PRS in the setting of inadequate antibiotic therapy is significant. Antibiotic therapy for patients with UTI is generally started at least one week before PCNL. The antibiotic agent employed should have activity against the cultured urinary organism and have a broad spectrum to increase the likelihood of effectiveness against the usually unknown urease-producing stone organism. Stone culture is recommended in these cases since it will aid in the choice of postoperative antibiotic therapy.
Prophylactic antibiotic therapy has been recommended by some investigators to further limit the risk of sepsis (Shah and Assimos 2006).

Purulent urine may sometimes be unexpectedly encountered at the time of accessing the collecting system. If this occurs, treatment should be postponed, the renal collecting system drained, urine from the targeted kidney cultured, and appropriate antibiotic therapy administered (Shah and Assimos 2006).

b. **Sepsis** has been reported to occur in 0.6% to 1.5% of patients undergoing percutaneous stone removal. Antibiotic therapy, fluid resuscitation, and the administration of steroids and pressors may all be required in treatment of the septic patient. Evaluation of the patient with a CT scan should be considered if the aforementioned measures are unsuccessful to assess for complications that may be contributing to the septic event (Shah and Assimos 2006).

c. **Fluid Overload** Irrigating fluid is used in PCNL, and patients may absorb high volumes of fluid if extravasation or venous injury occurs. Careful intraoperative patient monitoring helps detect this problem. A discrepancy in input and output of irrigation fluid, unexpected hypertension, and hypoxemia are signs and manifestations of this problem. Sterile normal saline solution should be used as an irrigant, except when electrocautery and electroresection are undertaken, to limit the development of hyponatremia. Using the lowest irrigating pressure that will permit adequate visualization, discontinuing the procedure when perforation of the collecting system is encountered, and limiting the duration of PCNL can limit this occurrence. The administration of diuretics and other agents may be required for managing the hypervolemic patient (Shah and Assimos 2006).
d. **Hypothermia:** Core body temperature decreases during percutaneous renal surgery (PRS). Hypothermia may occur as a result of intraoperative heat loss from vasodilation related to anesthesia, length of the procedure, exposed body surface, low ambient room temperature, and use of room temperature irrigant. The potential consequences are impaired platelet function, altered enzymatic drug clearance, and postoperative shivering causing up to a 400% increase in oxygen consumption. The latter problem places patients with compromised cardiac reserve at risk for myocardial ischemia and cardiac arrhythmia. The use of warmed irrigating fluid and proper coverage of patients (blankets, heat-preserving surgical drapes,) helps to limit hypothermia *(Roberts et al., 1994).*

xi. **Positioning Related Complications:**

Brachial plexus damage, shoulder dislocation, other forms of peripheral nerve injury, and cutaneous trauma can occur with PCNL. It is essential that appropriate positioning and padding be employed to prevent these complications. Prompt neurologic evaluation should be obtained if neuropraxia is suspected. These injuries usually resolve over time, and physical therapy plays a major role in the management of such patients *(Shah and Assimos 2006).*

xii. **Air Embolism:**

An extremely rare complication that may occur after injection of air or carbon dioxide in the collecting system to identify a posterior calyx or if there is reversal of airflow in an ultrasonic lithotriptor. Patients may manifest with hypoxemia, cardiac instability, or circulatory arrest. A machinery type of cardiac murmur may also be present. Management consists of placing the patient in a left lateral decubitus position with the head and thorax tilted downward. A central venous access line is placed through which the air can be aspirated *(Cadeddu et al., 1997).*
xiii. Deep Venous Thrombosis (DVT) and Pulmonary Embolism:
The incidence of DVT after PRS is 1 to 3%. Prevention is directed toward identifying patients at risk, taking appropriate preventive measures with thromboembolic disease prevention stockings and sequential compression devices, and encouraging early postoperative ambulation. If postoperative DVT does occur, management is aimed at preventing extension of the thrombus and embolic events (Patel et al., 1996).

xiv. Mortality:
Postoperative death is extremely rare and has been reported in 0.1 to 0.3% of patients subjected to PRS. The majority of these deaths have resulted from myocardial infarction and pulmonary embolism occurring in high-risk patients. Careful preoperative screening, invasive monitoring, and avoidance of hypotension, excessive hemorrhage and hypothermia may aid in preventing mortality in such patients (Shah and Assimos 2006).

xv. Renal Parenchymal Damage/Deterioration Of Renal Function:
Patients with staghorn calculi may be at increased long-term risk of renal functional deterioration. Teichman et al., (1995), reported that 25% of such patients subjected to PCNL had renal functional deterioration. Factors associated with this outcome included solitary kidney, recurrent calculi, hypertension, complete staghorn stone, urinary diversion, and neurogenic bladder. Loss of a kidney is exceedingly rare with PCNL. Acute renal loss is usually the result of uncontrollable hemorrhage.

xvi. Contrast Allergy:
Contrast reactions occur in less than 0.2% of percutaneous renal surgery. Patients with known contrast allergies can be treated with preoperative steroids. If a reaction develops during a procedure treatment includes antihistamines, steroids and epinephrine if needed (Shah and Assimos 2006).
To avoid complications associated with percutaneous endourologic procedures and to ensure optimum outcomes for patients; urologists must consider a number of factors when planning or performing PCNL. Therefore, training and experience of the urologist are critical, as is careful patient selection, accurate positioning, and use of the best available instruments. Most important factors to prevent complications in PCNL:

- Preoperative radiologic/sonographic evaluation.
- Optimal puncture through the calyx.
- Ultrasound control if possible.
- A traumatic dilation under continuous X-ray control.
- Minimal angulation of nephroscope.
- Use of a flexible pyeloscope for stone parts in upper calices.
- Know when to stop and when to retreat.

(Shah and Assimos 2006)
Staghorn stones

Staghorn calculi are defined as branched stones in the renal collecting system. However, there are several different arrangements within this entity. This was considered in the more complex definition by Rocco et al 1984 & Griffith et al 1987. In the modern management of such stones three factors are of major importance to decide the optimal treatment (Fig. 40):

1-The overall stone burden;

2-The location of the stone burden (i.e. which and how many calyces are involved);

3-The anatomy of the collecting system (i.e. a dilated collecting system).

Based on this, several authors have introduced a relatively simple definition, distinguishing between borderline stones, partial and complete staghorn calculi. Obviously, the stone burden can be calculated more closely using the area on a plain film of the kidney, ureter and bladder (KUB), as proposed by Lam et al. (Lam et al 1992). This was very useful in evaluating different therapeutic approaches, but in daily routine the simple classification was sufficient.
Fig. (40). Criteria determining the choice of treatment in the management of staghorn renal stones. a, top, stone size ($\geq$3 cm); middle, location (branched); bottom, anatomy (calyceal neck stenosis) and radio-density. b, top, borderline (filling the pelvis and one calyx); middle, partial (filling more than two calyces and the pelvis); bottom, complete (filling the entire renal calyceal system (or $\geq$80%)). (Rocco et al 1984 and Griffith et al 1987).
Treatment options

Staghorn where as previously only modifications of open renal surgery i.e. anatrophic vs radial nephrolithomy, currently a multimodal approach is used to minimize the morbidity of treatment and optimize the long-term results. This may include:

1) ESWL with or without indwelling catheter.
2) Percutaneous nephrolithotomy (PCNL) using different devices for stone disintegration.
3) A combination of both techniques as a planned procedure.
4) Retrograde ureteroscopic stone disintegration using a holmium laser.
5) Open surgery (i.e. anatrophic or radial nephrolithotomy, sinusoidal pyelolithotomy.

Staghorn stones are unquestionably an indication for interventional therapy, as all reports of conservative treatment show a substantially increased rate of nephrectomy (up to half) and an increase in associated morbidity (i.e. dialysis); in many cases (up to 28%) the disease resulted in death. The choice of the listed treatments mainly depends on the specific finding of a staghorn stone (i.e. stone classification. However, other factors, e.g. the age of the patient or the function of the stone-bearing kidney, may be important (Di Silverio et al 1990).

Criteria of success

The goal of any of the procedures is to render the patient stone-free, but with the introduction of ESWL, particularly for larger calculi or those in the lower calyx, >40% of persisting fragments have been accepted (Kohrmann et al 1993 and Renner et al 1999) as still being
successful, because in most cases (90%) these are clinically insignificant residual fragments defined as:

- Residual fragments of ≤4 mm after ESWL.
- Calcium oxalate/phosphate calculi.
- Normal anatomy of the upper urinary tract.
- No UTI.
- No symptoms after ESWL.
- No adjuvant therapy required.

These fragments are insignificant because they do not induce early stone recurrence, differing from the residual stones in the era of open surgery, particularly when infected. This may be attributable to improved antibiotics, but also possibly because the fragmented calculi are easier to treat, resulting in some residual sterile fragments after ESWL (Kohrmann et al 1993 and Renner et al 1999). Nevertheless, any patient with a treated staghorn stone requires a close follow-up (Segura et al 1994).

**Guidelines for the treatment of staghorn calculi**

In this situation, particularly for staghorn stones, urologists have to define the indications to select the best procedure for treating each stone. The Nephrolithiasis Clinical Guidelines Panel of the AUA reviewed 110 articles concerned with staghorn calculi, resulting in the following guidelines (Kohrmann et al 1993). The committee considered that a newly diagnosed staghorn stone was an indication for active treatment. Percutaneous stone removal, followed by ESWL or repeat PCNL, should be used for most patients with struvite staghorn stones. Neither ESWL monotherapy nor open surgery should be used as a first-line treatment for staghorn stones in most patients. As options, PCNL and ESWL are
equally effective in treating small-volume staghorn stones when the renal anatomy is normal or nearly normal. Also as an option, open surgery is appropriate therapy when the staghorn cannot be managed by any reasonable number of PCNL and ESWL sessions, i.e. if it is a giant staghorn. (Kohrmann et al 1993)

**Indications for ESWL monotherapy**

ESWL should be used in patients with a minor stone burden, peripheral stone load (i.e. multiple stone-filled calyces) and a narrow renal collecting system. (Renner et al 1999)

Patients with enhanced risk (i.e. atherosclerosis, respiratory problems) or other difficulties related to percutaneous surgery (i.e. in children, or those with urinary diversion) must undergo ESWL alone. (Renner et al 1999)

**Indications for PCNL monotherapy**

A single session of PCNL can be successful in patients with a major stone burden and a central (i.e. pelvic) stone load in an enlarged (i.e. dilated) collecting system (borderline and partial staghorn calculi, Furthermore, slightly opaque or shock-wave resistant calculi (i.e. cystine) are candidates for PCNL alone. (Renner et al 1999)

**Indications combined ESWL and PCNL**

The combination of ESWL and PCNL, principally initiated with a percutaneous approach, is applied in all patients with a major stone burden (i.e. partial and complete staghorn stones) with a central and peripheral stone load. The rationale for the combined therapy is to reduce the morbidity of PCNL, which is carried out in most cases via one lower pole tract, and to use the ESWL selectively for disintegrating those
calculi (parts of the staghorn stone) that cannot be reached with the nephroscope. (Renner et al 1999)

**Indications for open surgery**

Surgery is a potential treatment option for any staghorn stone, for several reasons. The stone can be removed by a single procedure and produce comparable stone-free rates. Therefore, some authors still advocate open surgical removal for complete staghorn stones. However, there is the problem of the loss of renal function after such extensive surgical interventions like anatrophic intersegmental pyelolithotomy, which reportedly occurs in 30-50% of patients. Overall, the residual stone rate after open renal surgery is 15%, with a 30% stone recurrence rate over 6 years and a 40% risk of UTI (Paik et al 2000).

The indications for open surgery to those patients with a massive stone burden that cannot be reached endoscopically or by a considerable number of ESWL treatments, or if additional reconstructive surgery (i.e. calyco-ureterostomy, pyelo-plasty) is required. Nonfunctioning kidneys can be removed laparoscopically (Wang et al 1997).

**Therapeutic approach**

Independent of the procedure, every patient with a staghorn stone requires antibiotic prophylaxis (i.e. gyrase inhibitors) at least 2 days before the intervention. In our series, 38% of the patients presented with UTIs before treatment, 51% of which were from Proteus mirabilis (Wang et al 1997).

ESWL monotherapy: The techniques of ESWL have been described in detail previously. If the stone is large (>2 cm) we
recommend the insertion of a JJ stent before ESWL, to avoid obstruction of the ureter by steinstrasse; the stent does not inhibit the passage of fragments along the ureter. Staghorn stones should be treated initially in the pelvic part to enable the passage of fragments; thereafter, the upper and middle calyces are treated, leaving the lower pole untreated to avoid fragments falling into the lower calyces, from where further passage may be prolonged (Lam et al 1992).

Depending on the energy setting of the machine, the number of shocks per session should be <4000; the interval between each treatment should be at least 2 days.

PCNL monotherapy: This is performed as a one-stage procedure, with the patient under general anaesthesia, using a retrograde balloon occlusion catheter placed at the PUJ. Access is usually through the lower pole posterior calyx with removal of the lower calyceal and pelvic stone burden. If the stone burden is large, we always place an Amplatz sheath down the percutaneous tract. This allows the removal of larger stone fragments and reduces the risk of pelvicalyceal influx. Only in selected cases (e.g. stones less suitable for ESWL, like cystine) do the puncture of an additional calyx to achieve complete stone clearance in a single PCNL session. Another option to access stone burden in upper and middle calyces may be the use of a flexible cystoscope together with a holmium or dye laser introduced via the Amplatz sheath (Lam et al 1992)
Combination:

In the combined approach starting with a PCNL via the lower pole posterior calyx. The kidney is punctured under combined ultrasonographic and fluoroscopic control; sometimes several tracts (maximum three) can be made if there is a massive stone burden (i.e. in the upper dilated calyx). Open surgery: Whereas in our earlier experience the technique of clamping and cooling was used (Wang et al 1997), we have recently preferred the technique of radial nephrotomies with intraoperative colour duplex ultrasonography. Other options include extended pyelolithotomy, anatrophic nephrolithotomy or posterior lower nephrolithotomy. Currently we do not place the same emphasis on achieving complete stone clearance, because minor residual stones can be treated effectively with ESWL.
Supracostal PCNL

Introduction:

Stone free clearance and improved patient outcome during percutaneous nephrolithotomy are largely dependent on the appropriate selection of the access to the kidney while standard PCNL is often performed through a subcostal lower calyceal approach, upper calyceal access through supracostal approach can be ideal for many clinical situations, Traditionally, concerns for increased potential postoperative complications particularly intrathoracic, have limited utilization of supracostal access however with good understanding of the anatomy surrounding the upper pole of the kidney and attention to a few technical consideration during the procedure, upper calyceal access through a supracostal approach can be performed safely and efficiently. (Gupta et al 2002).

Indications and patient selection:

Indications for upper pole Supracostal access:
- Staghorne calculi.
- Large stone burden
- Large upper pole stones
- Need for direct puncture to untopelvic junction (UPJ)
- Large impacted proximal ureteral stones UPJ obstruction requiring antegrade endopeylothotomy.

Complex ananatomy:
- Upper pole calyeal diverticulum
- Complex lower pole calculi
- Horseshoe kidney
- Superiorly located kidneys (Yadav et al 2008)
During upper calyceal approaches, supracostal Access is performed along the long axis of the kidney this allow for direct entry is the upper calyx and optimal visualization of the renal pelvis, uretropelvic junction (UPJ) and upper ureter . The performance of Rigid Nephpscopy in the direction of the long axis of the kidney minimize the torque requirement on the kidney and results in decreased bleeding and improved clearance rates (Pedro et al 2009).

In certain circumstances, a laterally situated intercostals tract can be placed between the tips of the 11th and 12th ribs or an infracostal approach may be used to access the upper pole while the risk of pleural injury may be less with these techniques as compared to the more superior supracostal puncture the benfitis in visualization outside the upper pole is limtted with rigid instruments and may require increased reliance on flexible endoscopy (Pedro et al 2009).

Supracostal upper calyceal access can be advantageous in several clinical situations , upper pole access can be optimal for large upper pole stones or for complete stagehorn renal calculi direct access to the upj and proximal ureter may be beneficial for treatment of large or impacted proximal ureteral calculi, particularly with concomitant renal pelvic stones, or need for antegrade endopyelotomy during upj obstruction management. Similarly, Stones in more complicated renal systems such as upper pole cayceal diverticulum or complex lower pole configurations may be more amenable to an upper calyx approach. In situations with superior kidneys located above the ribs Middle or even lower calcyeal access may require a supracostal approach. (Yadav et al 2008)
Conversely in few patients upper calyx puncture may be possible via a subcostal route depending on the renal anatomy for example due to just in complete ascent, horse shoe kidneys are best accessed in the upper pole (Yadav et al 2008) Howeve this can usually be performed from a subcostal approach.

**Anatomic considerations:**

The anatomy of the upper pole of the kidney in relation to the surrounding structures is necessary to minimize complications during supracostal access to the upper calyx.(Gupta et al 2002)

The intercostal nerves and vessels are located along the inferior portion of each respective rib, puncture sites are directed to the middle portion of the intercostal space to avoid injury to the intercostals artery and development of a haemothorax in most situations, lateral posterior calyces are targeted during percutaneous access to avoid the major branches of the renal artery posterior calyces generally transverse broadel's bloodless line, the avascular plane between the anterior and posterior divisions of the renal artery. (Yadav et al 2008)

Posteriors calyces offer the shortest access path to the collecting system (Yadav et al 2008)

Needle punctures should be directed along the axis of the renal calyx through the center of the renal papilla to avoid infundibular or renal pelvic puncture. Injury to interlobar arteries has been noted in up to 67.6% of kidneys following upper pole infundibular puncture and to retro
pelvic vessels in 33% following direct renal pelvic puncture (Munver et al., 2001).

The concern for intrathoracic injury following upper calyceal access is secondary to the close relationship of the upper kidney to the lungs and pleura. The upper portions of both kidneys are located anterior to the posterior portion of the 11th and 12th ribs. A review of 90 normal supine intravenous urograms during full expiration noted that 85% of upper renal calyces are located above the 12th rib (Miller et al., 2007).

In prone position, further cephalad movement of the kidney occurs in 80% of patients. Despite controlled maximal expiration, this cephalad movement results in an estimated likelihood of lung injury following supracostal access of 29% on the right side and 14% on the left side. The posterior diaphragm arises from the distal ends of 11th and 12th ribs, the tips of L1 Transverse process and the anterior aspect of the upper lumbar vertebral body. During full inspiration, the postero inferior margin of the lung expands to fill the posterior costophrenic recess during expirations, the lung retracts and the pleura ascends cranially and laterally on the ribs (Gupta et al., 2002).

The lower limit of the posterior parietal pleura crosses the 12th rib obliquely near the lateral border of the erector spinae muscles in the mid scapular line. The visceral pleura has a similar relationship at the 10th rib, the initial needle puncture for a supra 12th rib access is advocated at a maximal expiration and lateral to the erector spinae muscles in the 11th and 12th interspace to avoid lung and pleural injury. Supra 11th rib access can be performed in a similar fashion between 11th and 12th rib interspaces (Pedro et al., 2009).
Surgical technique

Our percutaneous approach for upper calyceal access is similar to that used for the lower pole. At the onset of the procedure, the patient is placed in the dorsal lithotomy position, using rigid cystoscopy, we place a 5F open–ended ureteral catheter to allow opacification of the renal collecting system. After subsequent placement of a Foley catheter, the patient is placed in the prone swimmer’s position. A chest roll is placed horizontally to facilitate ventilation, with the neck maintained in a neutral position. An additional roll is used to slightly elevate the side of interest in order to align the posterior calyces in a more vertical position. The Ipsilateral upper extremity is placed at 90o flexion, while the contralateral arm is positioned parallel to the patient. Particular attention is given to properly pad all pressure points and secure the patient to the table using the biplanar fluoroscopy. (Yadav et al 2008)

the “bulls eye or triangulation” technique for percutaneous access. The bulls eye technique is described before and here supracostal approach using the triangulation technique will detailed.

Triangulation technique:

For upper calyceal access, generally a puncture site within the 11th and 12th intercostals space, just lateral to the erector spinae muscles. A supra – 11th rib puncture is avoided when possible. Following identification of the targeted upper pole calyx under fluoroscopy, the triangulation technique is started with an 18G diamond-tipped access needle puncture in the inferior border of the 11th rib at the skin, the needle is angled acutely. (Yadav et al 2008)
So that it enters at the center of the intercostals nerve and vessels of the 11th rib. Biplanar fluoroscopy is performed using the C-arm in two positions, anteroposterior and oblique the anteroposterior view is along the plane parallel to the line of puncture. (Yadav et al 2008)

When the C-arm is in the anteroposterior position adjustments to the needle position. The oblique view is obtained by rotating the C-arm through 30o, when the C-arm is position are made in the cranial – caudal (up-down) orientation with care not be drift into the mediolateral position ventilation is suspended in full expiration as the access needle is advanced towards the desired calyx the C-arm is maintained in the oblique position in order to gauge the depth of puncture. After initial advancement, the C-arm is rotated back to the AP view to confirm the mediolateral orientation before continuing needle movement in the oblique view. Simultaneous retrograde instillation of contrast via the open-ended catheter allows for collecting system opacification and identification. (Yadav et al 2008)

After entry into the renal calyx, aspiration of fluid is performed to confirm the needle position in the collecting system. 0.038 inch hydrophilic nitinol core glidewire is advanced through the access needle and manipulated down the ureter if possible. If entry to the ureter is prohibited, the wire is coiled in the renal pelvis or in the calyx that is accessible and furthest away from the calyx of puncture. An 8F fascial dilator and subsequently a 5F cobra-tipped angiographic catheter are sequentially passed over the glide wire. In order to facilitate wire positioning in the ureter. The glide wire is next exchanged for an amplatz super-stiff wire, a second standard guide wire is placed as a safety wire.
into the ureter and secured to the drape following placement of an 8/10F coaxial dilator over the super-stiff wire. (Yadav et al 2008)

A nephromax balloon is advanced over the super-stiff wire until the radio-opaque marker is noted just inside the collecting system. (Yadav et al 2008)

Following balloon infilation to 14-20 atm, the 30F Amplatz sheath is advanced one the balloon into the collecting system and standard stone treatment is performed.

Some patients, such as those with complete staghorn calculi, may require additional access into different calyx following initial percutaneous tract placement in the upper calyx. In this situation, the Amplatz sheath is left in the upper pole while working through the second access tract in order to prevent excessive extravasation from the upper pole calyx into the pleural cavity. (Yadav et al 2008)

The conclusion of the procedure, fluoroscopy is performed over the ipsilateral chest and lung fields to exclude the presence of hydrothorax. In the operating room, a pigtail catheter is inserted into the chest under fluoroscopic guidance in patients noted to have significant hydrothorax or pleural effusion. Patients who are symptomatic or for whom there is concern for a hydro-thorax in the postoperative period are followed with an upright chest x-ray in the recovery room and monitoring
of clinical respiratory vital signs. In the postoperative period, patients with symptomatic fluid collections are managed by tube thoracostomy. On the first postoperative day, a store-protocol CT scan which includes the lung bases, is performed in all patients to evaluate for residual stones. (Yadav et al 2008)

Alternative technique:

To avoid supracostal puncture, some authors have advocated a renal displacement technique, the intial placement of sheath or dilators is performed via an interpolar renal access in order to allow for torque of the kidney downward this can be held by an assistant while upper calyx puncture is performed via a subcostal rout (Pedro et al 2009)

Additionally, simultaneous fluoroscopy with retrograde flexible ureteroscopy via a ureteral access sheath has been described for endoscopically-guided percutaneous access (Khan et al 2006)
Operative complications

Over all complications rates following supracostal access during PCNL range from 10% to 26% (Gupta et al 2002) significant hemorrhage requiring blood transfusion, bacteremia and sepsis can occur following any PCNL procedure specific complications in relation to supracostal approaches are described in more detail below (Table 1)

Pulmonary complications:

Intrathoracie complication have been reported in approximately 1-15.3% of cases (Lang et al, 2009) supra – 11th access, In particular is associated with increased occurrence of pulmonary injuries in one series, six of 26 (23.1%) supra – 11th PCNLs Resulted in Intrathoracic complications as compared to one of 79 (1.4%) supra 12th Rib access (Lang et al 2009) Hydrothorax is the most common pleural injury noted secondary to collection of Irrigation fluid in the pleural space. The occurrence can be minimized with the judicious use and positioning of the amplatz sheath to avoid leakage in to the pleural space and maintenance of a low pressure system as well as adequate renal drainage postoperatively (Gupta et al 2002) adelyed hydrothorax may occur secondary to urine leakage through the PCNL Tract to the pleura, often secondary to the formation of Renopleural fistula prolonged fluid accumulation in the setting of a urinary tract infection can manifest as an empyema. A hemothorax may occur following injury to the intercostals vessels during initial needle puncture. The occurrence of an isolated pneumothorax is uncommon (Maheshwan et al 2009).

The diagnosis of pulmonary injuries can be made intraoperatively or postoperatively at the collusion of the PCNL, prone of fluoroscopy of
the ipsilateral lung fields should be performed in all cases involving supracostal access. A distinct fluid demarcation laterally along the chest wall from the lung or an obscured costophrenic angle warrants further evaluation or intervention of ventilation is difficult an upright chest x-ray or Computed tomography (CT) scan can be used to confirm the fluid density at the lung base in less defined cases with high suspicion during the postoperative setting while under anesthetic concerning of fluid collection may be aspirated during hyperventilation or treated with tube thoracostomy (Organ et al 2003). In the postoperative setting a period of observation may be warranted with small of fluid collections but aspiration or tube thoracostomy connected to underwater drainage should be utilized in symptomatic patients. An evaluation by a thoracic surgeon for potential thoracotomy or video-assisted thoracoscopic surgery may required for non improving or Infected pulmonary complications. (Organ et al 2003).

In patients with ureteral stents that show delayed presentation, the effusion may be secondary to stent related reflux and additionally treated with anticholinergics and maximal bladder decompression patients without ureteral stents may have delayed effusions. Secondary to transient obstruction from small calculi or blood clots. And require ureteral stent and foley catheter placement (Maheshwan et al 2009).

Other organ Injury:

Less common than pulmonary complication, injuries to adjacent organs. Including the liver, spleen, and intestines, can rarely occur during upper calyceal access, A retrorenal left colon occurring in 10% of patients in the prone position, may prohibit access to the 10th or 11th intercostals
space with increased risk associated with medial punctures \cite{Hopper1990}.

Additionally a supra 11\textsuperscript{th} access could puncture the liver in 14\% and spleen in 33\% of patients, particularly during inspiration, in the hemodynamically stable patients, liver injuries can of ten be managed conservatively with tube drainage and serial monitoring \cite{ElNahas2008,Matlaga2006}.

Splenic injuries, are associated with increased bleeding and may require immediate exploration and splenectomy \cite{Shah2007}.

This underscores the importance of preoperative CT imaging to determine the relationship of adjacent structures, as well as evaluation under fluoroscopy in multiple planes intraoperatively prior to needle placement in order to minimize injury to other organs \cite{Organ2003}.

\section*{Post operative pain:}

Supracostal access during PCNL results in increased discomfort as compared to subcostal approach secondary to traversing of the diaphragm. During needle placement, medial puncture through the Paraspinal muscles is associated with increased pain and should be avoided if possible \cite{Shah2006}.
Several recommendation have been made to decrease pain following upper pole access. Intercostal nerve block has been advocated as a method to minimize supracostal tube discomfort (Kim et al 2005).

Instead of placing a supracostal tube, a lower pole nephrostomy tube may placed at the conclusion of the procedure via second not dilated subcostal puncture and allowing the supra costal puncture site to chose (Kim et al 2005).

Additionally, downsizing to a small-bore percutaneous catheter at the conclusion of the procedure is associated with reduced postoperative symptoms as compared to large percutaneous catheter (Kim et al 2005). Tubeless supracostal PCNL has been reported with decreased need for post operative analgesia (Gupta et al 2002), tubeless PCNL should be performed only in cases. In which complete stone extraction is a near certainty. Candidates for tubeless approaches should meet strict criteria, including no collecting system perforation or significant bleeding (Gupta et al 2002). Tubless procedures should also be avoided in patients with concerns for magnesium ammonium phosphate stones to minimize any potential spread of infection in the chest.
At the conclusion of the procedure, fluoroscopy is performed over the ipsilateral chest and lung fields to exclude the presence of hydrothorax. In the operating room, a pigtail catheter is inserted into the chest under fluoroscopic guidance in patients noted to have significant hydrothorax or pleural effusion. Patients who are symptomatic or for whom there is concern for a hydrothorax in the postoperative period are followed with an upright chest X-ray in the recovery room and monitoring of clinical respiratory vital signs. In the postoperative period, patients with symptomatic fluid collections are managed by tube thoracostomy. On the first postoperative day, a store-protocol CT scan which includes the lung bases is performed in all patients to evaluate for residual stones. (Gupta et al 2002)
Table (1): Supracostal, complications associated with renal access/ percutaneous nephrolithotomy (PCNL)

<table>
<thead>
<tr>
<th>Study</th>
<th>No</th>
<th>Supra 12th (%) supra – 11th (%)</th>
<th>Overall number complications (%)</th>
<th>Sepsis/bacteremia (%)</th>
<th>Thoracic %</th>
<th>Other organ injury % 0 (0)</th>
<th>Significant blood loss/ Required blood transfusion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golljan et al., 1998</td>
<td>115</td>
<td>115%</td>
<td>30 (26.1)</td>
<td>0 (0)</td>
<td>4 (3.5%)</td>
<td>0</td>
<td>20 (19.2%)</td>
</tr>
<tr>
<td>Munver et al. 2001</td>
<td>98</td>
<td>12 (73.5)</td>
<td>16 (16.3)</td>
<td>1 (1)</td>
<td>7 (7.1%)</td>
<td>0</td>
<td>4 (4.1%)</td>
</tr>
<tr>
<td>Kekre et al. 2001</td>
<td>102</td>
<td>102 (100%)</td>
<td>10 (9.8)</td>
<td>0 (0)</td>
<td>10 (9.8%)</td>
<td>0</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Gupta et al., 2002</td>
<td>62</td>
<td>62 (98.4)</td>
<td>14 (22.2)</td>
<td>7 (11)</td>
<td>7 (11%)</td>
<td>0</td>
<td>6 (9.5%)</td>
</tr>
<tr>
<td>Yadav et al., 2008</td>
<td>328</td>
<td>328 (98.8)</td>
<td>74 (22.2)</td>
<td>53 (16)</td>
<td>11 (3.3%)</td>
<td>0</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Lojana piwat and prasopsuk 2006</td>
<td>170</td>
<td>170 (%)</td>
<td>31 (18.2)</td>
<td>1 (0.6)</td>
<td>26 (15.3%)</td>
<td>0</td>
<td>4 (2.4%)</td>
</tr>
<tr>
<td>Shah et al. 2006</td>
<td>144</td>
<td>110 (76)</td>
<td>19 (13.2)</td>
<td>6 (4.1)</td>
<td>5 (3.5%)</td>
<td>0</td>
<td>7 (4.9%)</td>
</tr>
<tr>
<td>Sukumar et al., 2008</td>
<td>110</td>
<td>110 (100%)</td>
<td>13 (11.8)</td>
<td>2 (1.8)</td>
<td>10 (9.1)</td>
<td>0</td>
<td>2 (1.8%)</td>
</tr>
<tr>
<td>Lang et al., 2009</td>
<td>103</td>
<td>Not specified</td>
<td>11 (10.7)</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>0</td>
<td>7 (6.8%)</td>
</tr>
</tbody>
</table>
Outcomes:

Reported stone free rates following supracostal access PCNL are comparable to infracostal approaches and range between 68% and 90% (Lang et al. 2009) due to the lack of strict criteria defining stone free status with utilization of multiple imaging modalities may account for some of the variation in reported outcomes.

Additional percutaneous access was required up to one third of the time, this is not surprising given that complete stag horn calculi are one indication for upper pole access. Similarly, ancillary procedures, including second-look PCNL, ureteroscopy, and shock-wave lithotripsy, were performed in 3-46% of cases (Lang et al. 2009), (Table 2)

Table (2): Operative parameters following supracostal renal Assess/ (PCNL)

<table>
<thead>
<tr>
<th>Study</th>
<th>No</th>
<th>Additional access %</th>
<th>Overall stone free rate %</th>
<th>Ancillary procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golijanin et al., 1998</td>
<td>115</td>
<td>23 (50%)</td>
<td>78 (67.8%)</td>
<td>53 (46%)</td>
</tr>
<tr>
<td>Kekre et al., 2001</td>
<td>102</td>
<td>Not specified</td>
<td>81 (79.5%)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Gupta et al., (2002)</td>
<td>63</td>
<td>15 (23.8%)</td>
<td>57 (90%)</td>
<td>13 (20.6%)</td>
</tr>
<tr>
<td>Lojanapiwat and prasopsuk 2006</td>
<td>170</td>
<td>0 (0)</td>
<td>140 (82.4%)</td>
<td>6 (3.5%)</td>
</tr>
<tr>
<td>Shah et al., 2006</td>
<td>144</td>
<td>22 (15.3)</td>
<td>127 (88.2%)</td>
<td>5 (3.5%)</td>
</tr>
<tr>
<td>Sukumar et al., 2008</td>
<td>110</td>
<td>9 (8.2)</td>
<td>95 (86.4%)</td>
<td>15 (13.6%)</td>
</tr>
<tr>
<td>Lang et al., 2009</td>
<td>103</td>
<td>Not specified</td>
<td>91 (88%)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

Includes shock - wave lithotripsy, second-look PCNL, ureteroscopy.
Conclusion:

Supracostal percutaneous access to the upper pole the kidney during PCNL is a useful technique when optimal visualization is required for the upper calyx, upj, and proximal ureter. Supra – 12th rib puncture should be approached lateral to the erector spinae muscles towards the superior portion of the Rib during maximal expiration supracostal access above 11th Rib should be avoided when possible. (Lang et al 2009)

Intraoperative of fluoroscopy of the lung fields should be performed at the conclusion of the procedure and a strong suspicion for pulmonary injuries should be maintained in the postoperative period. Patients should be counseled appropriately regarding the potential risk and complications when upper calyceal access is anticipated, particularly with regards to intrathoracic complications, However with attention given to anatomic considerations, supracostal access to the upper pole can be obtained safety and efficiently to contribute to successful precutaneous renal surgery (Lang et al 2009).