2 Anatomy for PNL

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Percutaneous nephrolithotomy (PNL) involves percutaneous puncture into the target calyx, establishment of access, intraluminal lithotripsy, and insertion of nephrostomy tube and/or JJ stent. As an invasive procedure, a thorough understanding of the target organ anatomy is definitely necessary, to increase the success rate of the operation and also decrease complications. Typically, since stones are scattered over the renal collecting system, and the kidney is hidden in the retroperitoneum, a successful PNL should make a precise puncture into the target calyx, avoid perirenal viscera and interlobar artery injury, and get into different calyxes to remove the stones [1]. Since all these procedures are not carried out in open operation manner, several potential injuries are hard to avoid. Thus, the anatomy of kidney, perirenal viscera, renal collecting system, and renal vessels is significant in the guidance of PNL.

2.1 Kidney

2.1.1 General Anatomy

Kidneys are a pair of vital, broad bean-shaped organs. The lateral edge of the kidney is bulged, with a flat back and a convex front. The central depression area is called hilum, where the vessels, nerves, lymphatics, and ureter extend out. The kidney is 10–12 cm in length, 4–6 cm in width, and 3–4 cm in thickness, weighing 100–120 g. The size of the kidney varies, and the ratio of the size of the kidney to the body weight in newborns is about three times than that in adults.

The right kidney is little lower than the left kidney because of the location of liver. The upper edge of the right kidney is on the level of the 12th rib thoracic vertebra, and the lower edge is on the level of the third lumbar vertebra, while the upper edge of the left kidney is on the level of the 11th rib thoracic vertebra, and the lower edge is on the level of the second lumbar vertebra. The right kidney hilum is on the level of the second lumbar vertebra, while the left kidney hilum is on the level of the first lumbar vertebra. The location of kidneys also varies; the kidney in lean people is relatively lower, while it is higher in obese people.

Both the kidneys lie on the posterior abdominal wall, against the psoas major muscles, the longitudinal axis striding across the psoas major muscles. Moreover, since the psoas major muscles have a shape of a cone, the kidneys are also dorsal and inclined on the longitudinal axis. Therefore, the upper poles are more medial and more posterior than the lower poles. The lateral borders of both the kidneys are posterior positioned. Hence, the puncture from the upper pole is more prone to be close to the spine, while the

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puncture from the lower pole is more prone to be away from the spine and deeper than the puncture from the upper pole.

2.1.2 Perirenal Covering

The surface of kidney is enclosed in a continuous covering of fibrous tissue called 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. 2.1). The perirenal fat is enclosed by the renal fascia (so-called fibrous renal fascia of Gerota or, in this book, Gerota's fascia). The renal fascia is enclosed anteriorly and posteriorly by another layer of adipose tissue, which varies in thickness, called pararenal fat.

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. The anterior and posterior layers of the renal Gerota's fascia subdivide the retroperitoneal space in three potential compartments (Fig. 2.1): (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; and (3) the anterior pararenal space, which extends across the mid-line from one side of the abdomen to the other. This space contains the ascending and descending colon, the duodenal loop, and the pancreas.

During normal PNL procedures, the nephroscope is inserted into the renal collecting system which inspects the renal collecting system, but when the percutaneous tract is lost or the percutaneous access fails to enter the renal collecting system, the perirenal viscera organs are noted. The loose perirenal fat looks like cobweb or cloud cluster. Sometimes, the pink renal capsule is also found. Since kidney moves up and down with breathing, once the percutaneous tract is lost, it is difficult to find the original access into the renal collecting system. Retrograde injection of the methylene blue is helpful to trace the previous tract, which does not work every time. If the tract cannot be found in a short period of time, the irrigation would bring much more difficulty in the later puncture, since the irrigation would push the kidney far away to a deeper position. Thus, another puncture is required when the tract is lost and cannot be found in a short time.

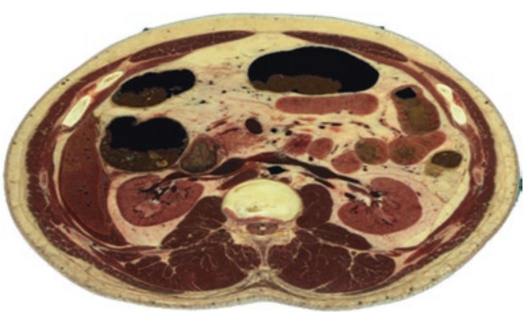

Fig. 2.1 Perirenal covering and potential compartments

2.1.3 Relationship Between Kidney and the Diaphragm, Pleural Cavity, and Ribs [2]

Both the kidneys lie below the diaphragm, which is almost symmetrical on both the sides. On the lower side, the liver and spleen lie on the right and left side, respectively. While on the upper area, pleura and ribs cover the upper pole and mostly middle pole of the kidney, respectively. Due to the position of the liver, the right kidney is lower than the left kidney. The posterior surface of the right kidney is crossed by the 12th rib, and the left kidney is crossed by the 11th and 12th ribs.

The posterior surface of the diaphragm is attached to the extremities of the 11th and 12th ribs, and the posterior aspect of the diaphragm arches as a dome above the superior pole of both the kidneys on each side. Therefore, most of the intercostal punctures into the upper pole traverse the diaphragm, but almost without any symptoms, while referring pain in shoulder in few cases. Regardless of the degree of respiration, middle or full expiration, the puncture between the 10th and 11th ribs has a risk of injury to the lung, but there is no report of lung injury during PNL. Intercostal puncture between the tenth and 11th ribs, even sometimes, subcostal puncture, would pass the pleural cavity. Because of the negative pressure in the pleural cavity during the inspiratory phase, gas or irrigation would be sucked into the pleural cavity during PNL, especially when torque the nephroscope and sheath, hydropneumothorax would be noted. However, most of the time, the tract passage through the pleural cavity will not bring hydropneumothorax, because the diaphragm would stop the leakage. Anyway, supracostal puncture should be done cautiously, especially when puncture from the tenth intercostal space.

In the course of PNL, we must pay attention to body surface positioning, which is helpful in the selection of percutaneous puncture points. Some patients may have received rib excision or truncation during previous open operation. Misjudgment of rib position might lead to the supracostal puncture site being above the tenth intercostal space, and cause pleural injury, in serious cases, hemothorax or pneumothorax.

Intercostal vessels often travel along the lower edge of the ribs. In order to avoid injury to intercostal vessels, any intercostal puncture should be performed below half of the intercostal space. While using sharp knife for incision on skin and subcutaneous tissue, attention should be paid to the direction of incision; it should go along the axis of intercostal space, so as to avoid longitudinal incision which would cause intercostal artery injury.

2.1.4 Relationship Between Kidney and the Liver and Spleen [2]

Below the diaphragm and above the kidney hilum, the liver and spleen lie on the right and left sides, respectively (Fig. 2.2). The liver and spleen lie exactly posterolaterally on each side. When hepatosplenomegaly is noted or sometimes when liver and spleen have deviation toward the midaxis, the lateral margin of the kidney would be covered by the liver or spleen. Preoperative CT scan is required to identify the relationship between kidney and perirenal organs. Intraoperative real-time ultrasonography guidance could guide the puncture and help avoid liver or spleen injury during PNL. Percutaneous puncture should be close to the inner side, rather than the outboard.

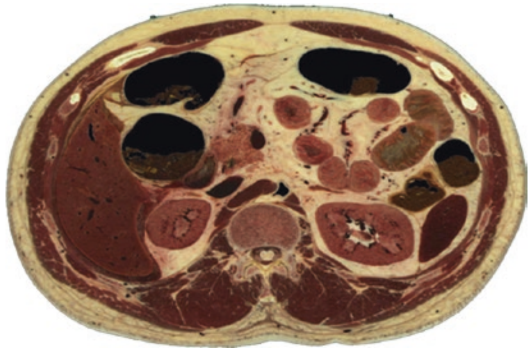

Fig. 2.2 Relationship between kidney and the liver and spleen

Very few liver and spleen injuries has been reported so far, but this complication is always worrisome, especially the spleen injury in PNL always causes severe bleeding, which leads to splenectomy. Liver injury in PNL is relatively not as urgently as spleen injury, because bleeding from liver vein would stop when nephrostomy tube is inserted, except when a large hepatic vein is injured.

2.1.5 Relationship Between Kidney and the Colons [3]

The ascending colon dips down from the ileocecal 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.

It is important to consider the position of the retroperitoneal ascending and descending colons. It has been occasionally noted in routine abdominal CT scan that the retroperitoneal colon lies in a posterolateral or even a postrenal position. In these cases, there is a great risk of colon injury during PNL. The retrorenal colon is much more frequently noted in elder female, thin patients, at the left side, lower pole of kidney, and also a puncture into ante-

Fig. 2.3 Retrorenal colon

rior calyx (Fig. 2.3). Much more attention should be paid to these cases when puncture is made under fluoroscopy guidance. In some urologists' personal experience with colon injury during PNL, it has been stated that there is no special resistance when the needle puncture into colon, but the dilation into colon is different, since the colon serosa has high toughness and the colon would move away, thus obvious resistance would be noted.

2.2 Renal Collecting System

2.2.1 Pelviocalyceal System

The renal parenchyma basically consists of two kinds of tissues: the cortical and the medullar tissues. On a longitudinal section, from the lateral to the medial, there is successively the capsule, cortical tissue, medullar tissue, and renal calyx and renal pelvis.

The cortical tissue consists of glomerulus, which contains proximal and distal convoluted tubules. The renal pyramids comprise the loops of Henle and collecting ducts. These ducts join the papillary ducts, open at the papillary surface, where always the center of the fornix, and then drain into minor calyx and into renal pelvis at last. The renal papilla is at the apex of a pyramid-shaped medullar tissue. The layer of the cortical tissue between adjacent pyramids is named renal columns, where the interlobular artery passes through.

A minor calyx is defined as the calix that drains the papilla directly. The number of minor calyces varies, ranging from 5 to 14. The minor calyces may drain straightly into an infundibulum or join to form major calyces, which subsequently drains into an infundibulum. Finally, the infundibula drain into the renal pelvis [4].

The anatomy shape of renal collecting system varies extremely, even the left kidney and right kidney in one person is not symmetrical. Thus, there is no fixed pattern for the puncture in PNL procedures. When performing PNL, attention must be paid to the anatomical diversity of the renal collecting system, because the structure of the renal collecting system would directly affect the operating. Generally, the slender calyx seriously affects the operation using endoscopy, while the wide and shallow calyx is relatively easy to look over. However, the general consensus of renal collecting system should be well known.

In Smith's textbook of Endourology, Sampio analyzed three-dimensional polyester resin corrosion endocasts of the pelviocalyceal system [5]. According to the endocasts, the pelviocalyceal system is divided into two major groups A and B . Group A (62.2%) comprises pelviocalyceal systems that present two major calyceal groups (superior and inferior) as a primary division of the renal pelvis and a midzone calyceal drainage dependent on these two major groups. Group B (37.8%) comprises pelviocalyceal systems that present the kidney midzone (hilar) calyceal drainage independent of both the superior and the inferior calyceal groups.

Since the kidney looks like a bean, the middle pole is much more thick and solid than the upper and the lower poles. Regarding the calyceal drainage at different poles of the kidney, 98.6% of the upper poles are drained by a calyx; for the lower pole, 57.9% are drained by two calyces in pairs and 42.1% are drained by a single calyx; the middle pole is mostly composed of multiple pairs of anterior and posterior calyces. From this point of view, the calyces in the middle pole are much more complex, the parallel calyces, the anterior and posterior calyces, which would cause difficulty for puncture manipulation. Thus, the well understanding of the pelvio-calyceal systems was crucial to guide the puncture and manipulation during the PNL procedure.

2.2.2 Urography and Significance

A thorough understanding of the spatial anatomy of the pelvis and calyx is of great importance for PNL. However, it is difficult for the urologists to imagine the actual three-dimensional structure, since the excretory urography (IVU) or retrograde urography can only demonstrate the two-dimensional planar image. The anatomical background could help urologists to conceive a three-dimensional image of the renal collecting system, even though when observing a two-dimensional image (Fig. 2.4). Three-dimensional CT reconstruction is a powerful and significant tool to reconstruct the three-dimensional image of the renal collecting system and stones but had the limitation of high cost and radiation. In Smith's textbook of Endourology, Sampio analyzed three-dimensional polyester resin corrosion endocasts of the pelviocalyceal system. By comparing the urography and three-dimensional cast of the renal collecting system, we can have a preliminary impression of the three-dimensional structure of the renal collecting system.

Since the calyces stretch with different angle, length, and width, the projection on two-dimensional plain film varies. The renal stones and contrast in renal collecting system demonstrate different structures. Some calyces are arranged in parallel with others. Some calyces have the projection of a sealed ring with a transparent area in the middle. Some calyces overlap almost completely, and since the calyces are irregular, there would be some local area that shows dense shadow [6].

In several cases, perpendicular minor calyces go directly into the renal pelvis or into a major calyx (Fig. 2.5). The minor calyces almost perpendicular to the surface of the collecting system, thus in the projection, has been demonstrated as a black circle, which overlaps with the background. The residual stones in these perpendicular minor calyces are always posterior; hence, the anterior calyces are much easier to detect in PNL. Most of time, the puncture goes from the posterior calyx, thus for the residual stones in the perpendicular minor calyces, another puncture directly to the target calyx is required. It has to be noticed that most of these calyces lie near the infundibulum or renal pelvis, and the puncture and tract dilation are at high risk of vascular injury, thus a very precise puncture would not cause severe bleeding in these cases.

For these overlapping calyces, overlapped either almost together or into a circle (Fig. 2.6), a thorough understanding of the hierarchical relationship of posterior and anterior calyces is crucial. Unfortunately, the plain film could only demonstrate a two-dimensional planar image. The preoperative CT scan can provide an accurate

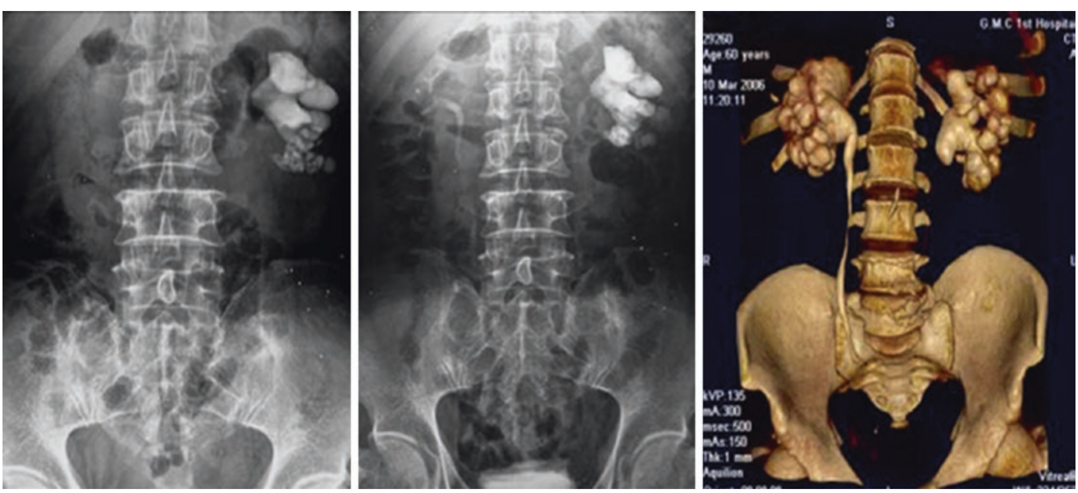

Fig. 2.4 The KUB, IVU, and 3D CT reconstruction of renal collecting system and stones

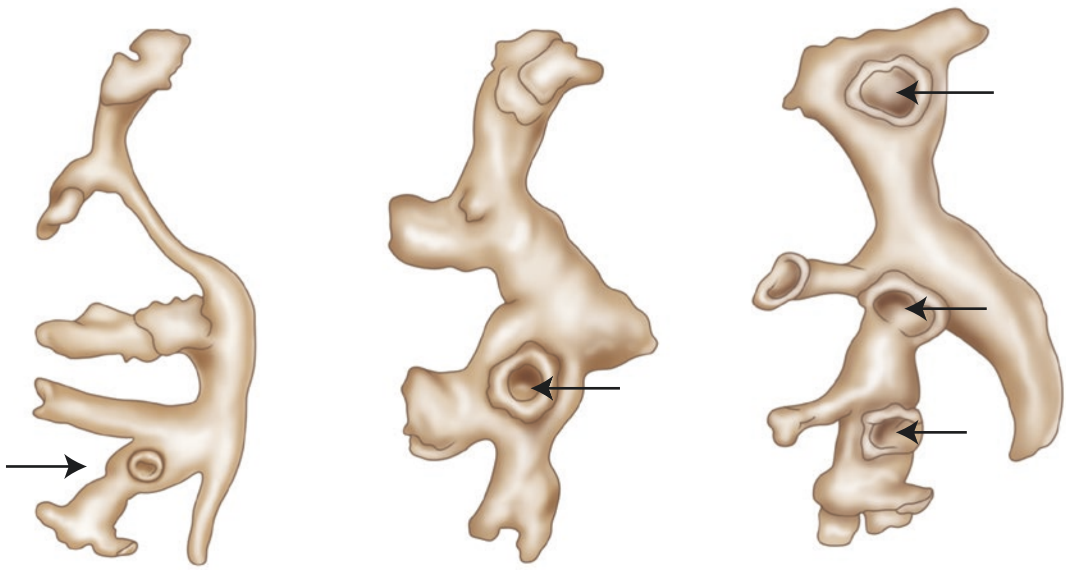

Fig. 2.5 Perpendicular minor calyces draining directly into the renal pelvis or into a major calyx

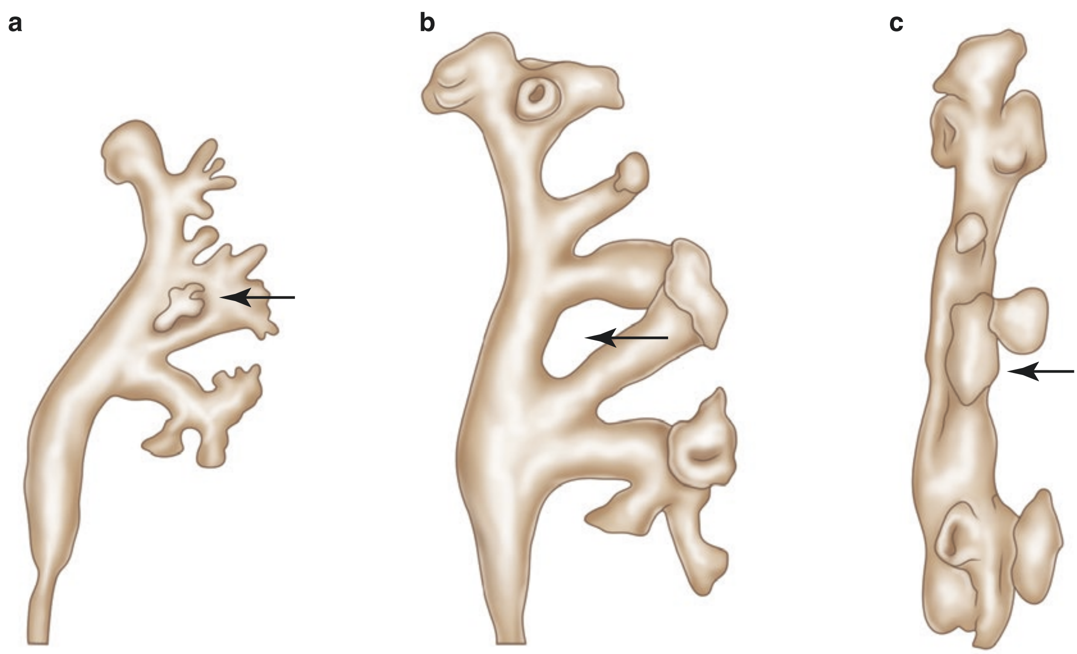

Fig. 2.6 For these overlapping calyces, overlapped either almost together or into a circle, as shown in these figures (**a**, **b**, **c**) from different visual angles

relationship of anterior and posterior calyx, but intraoperative CT guidance is unviable in PNL. Retrograde urography with contrast and air can also be performed to identify the posterior calyx. Even though the gradual deep–shallow relationship is helpful to identify the hierarchical relationship sometimes, a great deal of personal experience is required.

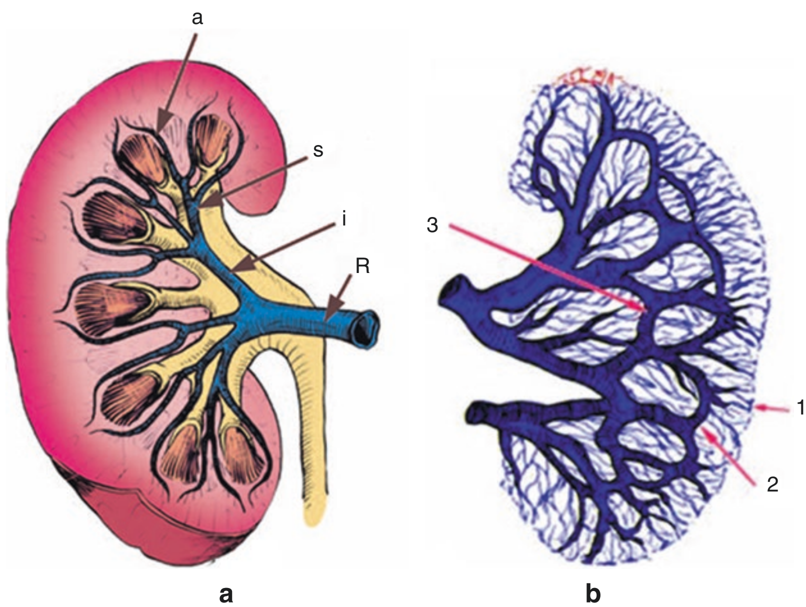

Fig. 2.7 A sketch from the anterior phase of the right kidney (**a**) showing four branches of the renal artery: *R* renal artery, *s* segmental artery, *I* interlobar (carotid) artery, and *a* arcuate artery. The right figure (**b**) shows three levels of arcuate veins

Since the percutaneous renal access to the renal collecting system through the posterior calyces could provide a better manipulation pattern in PNL with prone position, it is of great significance to identify which calyx is posterior calyx.

The angle of the posterior and anterior calyces with the horizontal plane is different. In most of time, anterior calyx stretches to a much more acute angle than posterior calyx. Thus, the projection of posterior calyx is prone to close to the renal pelvis, on the premise that the anterior and posterior calyces are in similar length. If the posterior calyx is much larger than the anterior calyx, the distal tip of projection of the posterior calyx is much more lateral rather than midway. However, the premise is not always working, and different angles and lengths destine that the hierarchical relationship of anterior and posterior calyx in projection is complex and hard to identify on plain film. Rotation of C-arm is helpful to identify the posterior calyx. When the bulb is rotated to 30°, the project direction is changed, the overlapped area is deviated, and then the posterior calyx would be displayed, since the top of posterior calyx would be highlighted in the 30° sagittal axis.

2.2.3 Intrarenal Vessels

Generally, the main renal artery divides into an anterior and a posterior branch after giving off the inferior suprarenal artery. The posterior branch (retropelvic artery) proceeds as the posterior segmental artery to supply the homonymous segment without further significant branching, whereas the anterior branch of the renal artery provides three or four segmental arteries [7].

The segmental arteries divide before entering the renal parenchyma into interlobar arteries (infundibular arteries), which progressed adjacent to the calyceal infundibula and the minor calyces, entering the renal columns between the renal pyramids (Fig. 2.7).

The interlobar arteries progress near the base of the pyramids, originating (usually by dichotomous division) the arcuate arteries (Fig. 2.8). The arcuate arteries give off the interlobular arteries, which reach to the periphery giving off the afferent arterioles of the glomeruli.

Unlike the renal artery, the renal vein is not segmental, but it has abundant circulatory anastomosis [8]. Cortical venules, also known as stellate veins, drain into the interlobular veins that form a series of arches. There are usually three longitudinal

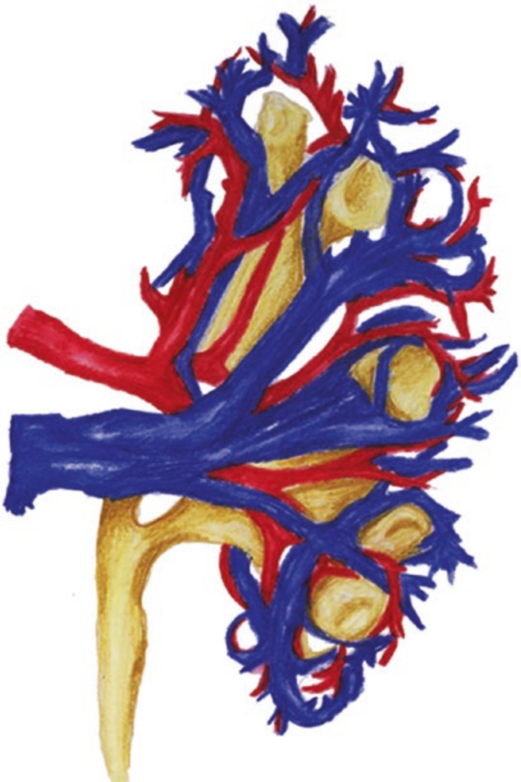

Fig. 2.8 Intrarenal vessels and the relationships between infundibulum and fornix

anastomotic arcuate systems in the renal parenchyma: 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) (Fig. 2.7).

2.2.4 Anatomical Relationship Between Intrarenal Vessels and Renal Collecting System [9]

As shown in the previous text, the intrarenal vessels are hidden in the renal cortex and medulla, which constitute the periphery of the renal collecting system. The puncture into the desired calyx must travels through the parenchyma and has the risk of injury to renal vessels. Bleeding is one of the most frequently noted complications following PNL, thus an ideal puncture should be well designed and accurately performed without severe vessel injury.

Thus, the major artery is located near the kidney hilum, and when we move forward to interlobular arteries and arcuate arteries, the artery gets smaller, and the peripheral artery injury would be spontaneously solidified.

Exactly, the interlobular arteries travel through renal column and then extend as arcuate arteries. Thus, when punctured from the apical center of calyx, where the renal papilla originates, named as fornix, only small arcuate arteries are injured.

In the previous study, investigators compared the punctures through a calyceal infundibulum and a calyceal fornix. It has been noted that puncture through an infundibulum (in any region of the kidney) resulted in much more artery and vein injury. Puncture through the upper pole infundibulum is the most dangerous because this region is surrounded almost completely by large vessels. Infundibular arteries and veins course parallel to the anterior and posterior aspects of the upper pole infundibulum [7, 10]. The posterior aspect of the lower pole infundibulum is widely presumed by urologists and interventional radiologists to be free of arteries. It is considered, therefore, to be a safe region through which to gain access to the collecting system and to place a nephrostomy tube.

Large venous anastomoses are similar to collars around the calyceal infundibula (the so-called calyceal necks). A venous lesion usually heals spontaneously, but consequent hemorrhage may be cumbersome during the procedure.

Direct puncture into renal pelvis is also at high risk of bleeding, since large branches of renal artery and main branches of renal veins are all nearby the renal pelvis. The injury of these large vessel branches is fatal. On the other hand, the nephrostomy tube inserted directly into the renal pelvis is much more prone to fall off, and there are much more extravasations during the PNL procedure.

In conclusion, the high rate of vascular injury destined that the puncture from infundibulum is not feasible, while the puncture from the fornix is the ideal pathway to decrease bleeding in PNL.

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