NORMAL ANATOMY OF THE KIDNEYS

The kidneys serve a number of important functions required to maintain normal human physiologic function. They are the primary organs for maintaining fluid and electrolyte balance, and they play a large role in maintaining acid-base balance. They produce renin, which plays a vital role in controlling blood pressure, and erythropoietin, affecting red blood cell production. They affect calcium metabolism, in particular calcium absorption, by converting a precursor of vitamin D to the most active form 1,25-dihydroxyvitamin D ***(Madias and Adrogue, 2003)***.

Gross and Microscopic Anatomy

Grossly, the kidneys are paired reddish brown organs (**fig. 1**). Typically each kidney weighs 150 g in the male and 135 g in the female. The kidneys generally measure 10 to 12 cm vertically, 5 to 7 cm transversely, and 3 cm in the anteroposterior dimension. Because of compression by the liver, the right kidney tends to be somewhat shorter and wider. In children, the kidneys are relatively larger and possess more prominent fetal lobations. These lobations are present at birth and generally disappear by the first year of life, although occasionally they persist into adulthood ***(Drake et al., 2005).***

As one proceeds centrally from the peripherally located reddish brown parenchyma of the kidney, the renal sinus is encountered. Here the vascular structures and collecting system coalesce before exiting the kidney medially. These structures are surrounded by yellow sinus fat. At its medial border, the renal sinus narrows toform the renal hilum. It is through the hilum that the renal artery, renal vein, and renal pelvis exit the kidney and proceed to their respective destinations.

Both grossly and microscopically there are two distinct components within the renal parenchyma: the medulla and the cortex. The medulla is composed of multiple, distinct, conically shaped areas noticeably darker in color than the cortex (fig. 1). These same structures are also frequently called renal pyramids. The apex of the pyramid is the renal papilla, and each papilla is cupped by an individual minor calyx .The renal cortex is lighter in color than the medulla and not only covers the renal pyramids peripherally but also extends between the pyramids themselves. The extensions of cortex between the renal pyramids are given a special name: the columns of Bertin ***(Drake et al., 2005)***.

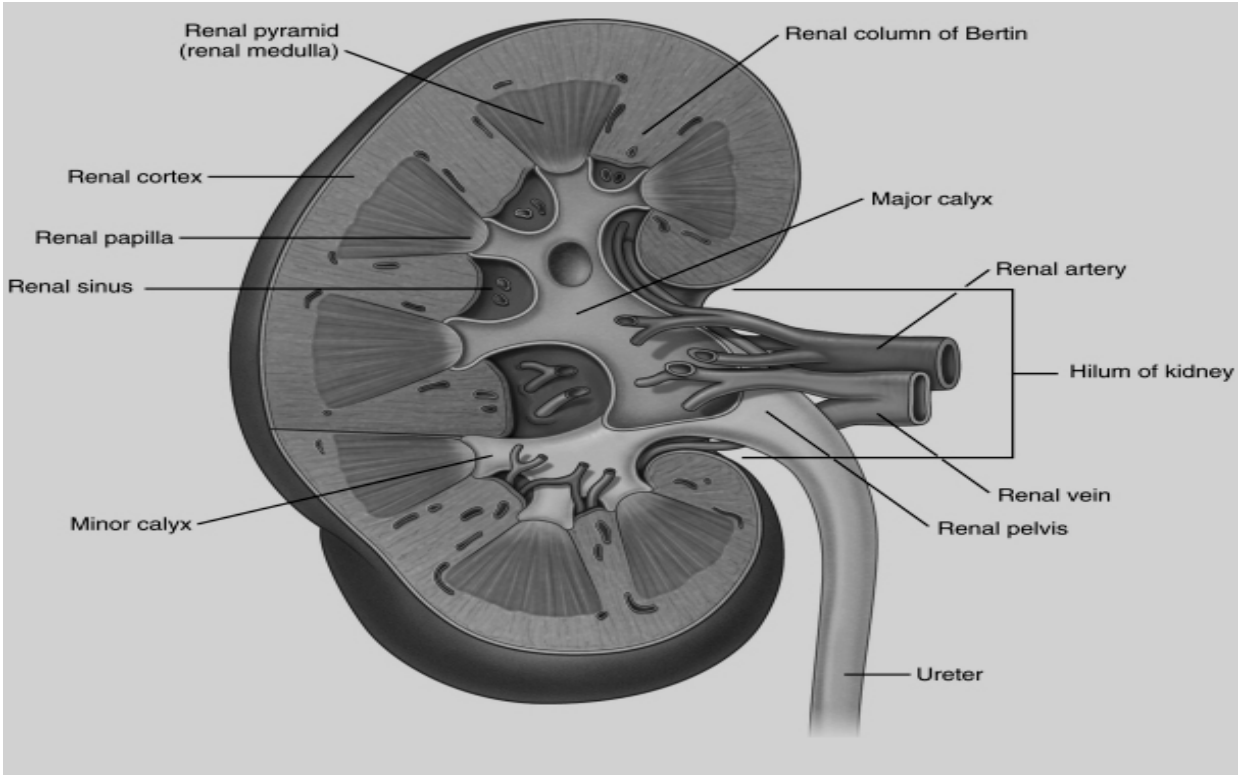

Fig. 1: Internal structure of the kidney. **(Quoted From Drake et al., 2005).**

Relations and Investing Fascia

The position of the kidney within the retroperitoneum varies greatly by side, degree of inspiration, body position, and presence of anatomic anomalies. The right kidney sits 1 to 2 cm lower than the left in most individuals owing to displacement by the liver. Generally, the right kidney resides in the space between the top of the first lumbar vertebra to the bottom of the third lumbarvertebra. The left kidney occupies a more superior space from the body of the 12th thoracic vertebral body to the third lumbar vertebra***(Williams et al., 2007).***

Both kidneys have similar muscular surroundings. Posteriorly, the diaphragm covers the upper third of each kidney, with the 12th rib crossing at the lower extent of the diaphragm. Medially the lower two thirds of the kidney lie against the psoas muscle, and laterally the quadratus lumborum and aponeurosis of the transversus abdominis muscle are encountered**(fig. 2)**. The effect of the muscular relations on the kidneys is severalfold. First, the lower pole of the kidney lies laterally and anteriorly relative to the upper pole. Second, the medial aspect of each kidney is rotated anteriorly at an angle of approximately 30 degrees. An understanding of this renal orientation is again of particular interest for percutaneous renal procedures in which kidney orientation influences access site selection***(Sampaio, 2000)***.

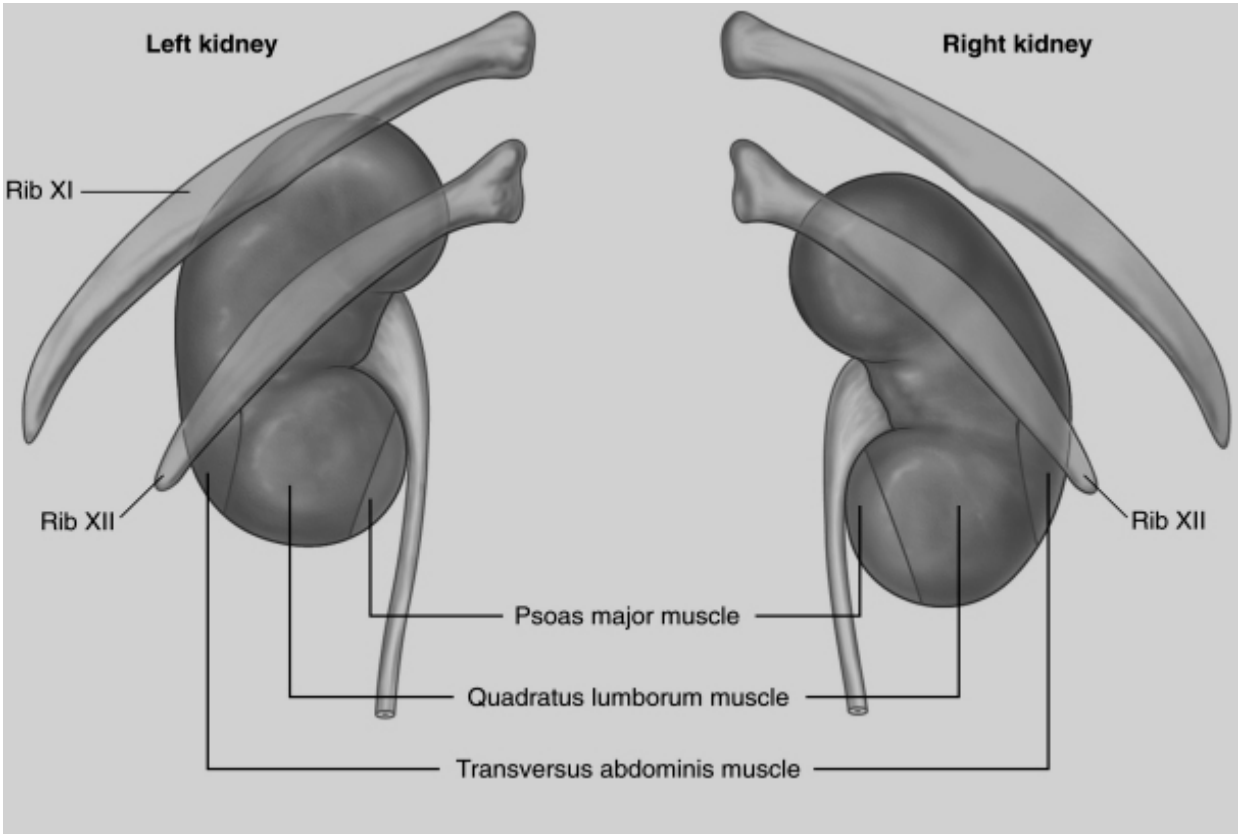

Fig. 2: Structures related to the posterior surface of the kidney. ***(*Quoted*From Drake et al., 2005).***

Anteriorly, the right kidney is bordered by a number of structures **(fig. 3)**. Cranially, the upper pole lies against the liver and is separated from it by the peritoneum except for the liver's posterior bare spot. The hepatorenal ligament further attaches the right kidney to the liver. Also at the upper pole, the right adrenal gland is encountered. On the medial aspect, the descending duodenum is

intimately related to the medial aspect of the kidney and hilar structures. Finally, on the anterior aspect of the lower pole lies the hepatic flexure of the colon. The left kidney is bordered superiorly by the tail of the pancreas with the splenic vessels adjacent to the hilum and upper pole of the left kidney. Also cranial to the upper pole is the left adrenal gland and further superolaterally, the spleen. The splenorenal ligament attaches the left kidney to the spleen. Superior to the pancreatic tail, the posterior gastric wall can overlie the kidney. Caudally, the kidney is covered by the splenic flexure of the colon ***(Sampaio, 2000)***.

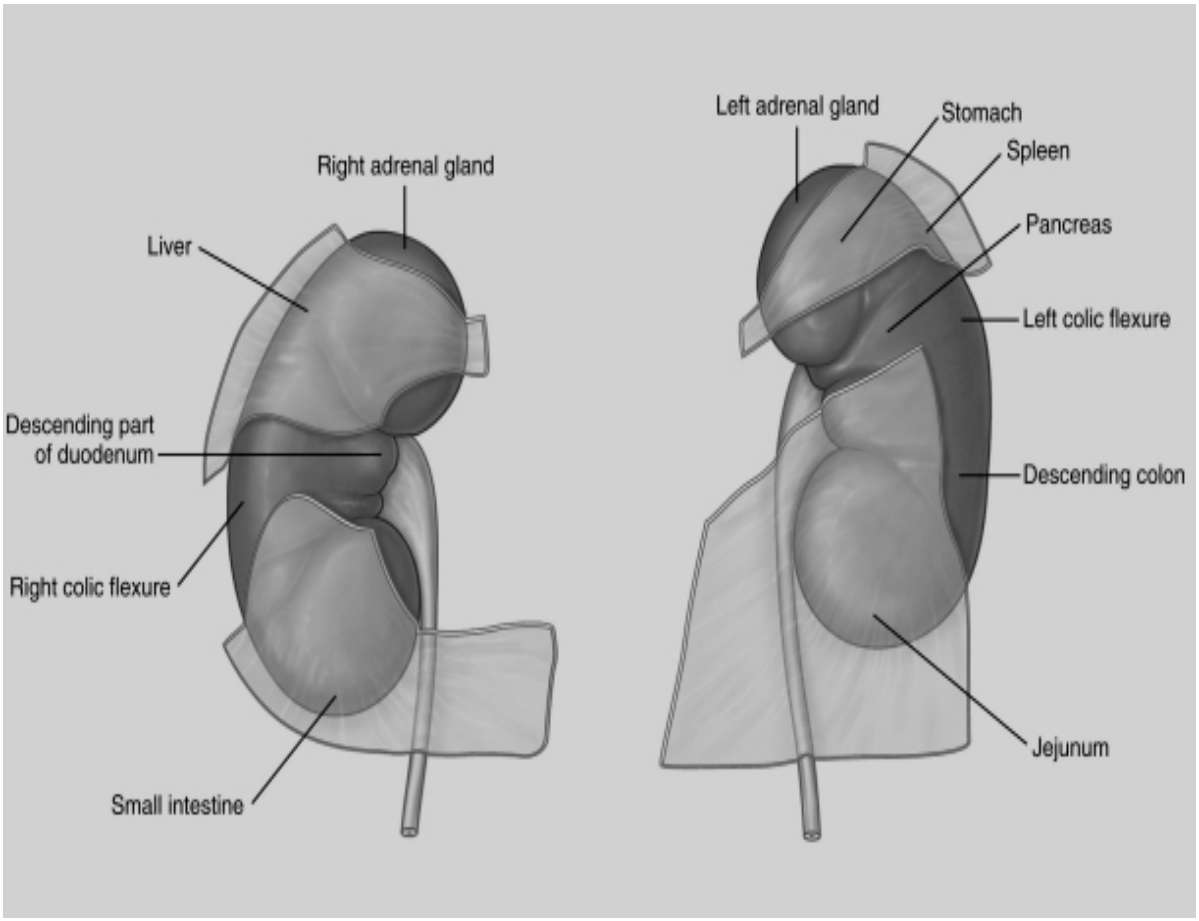

Fig. 3: Structures related to the anterior surfaces of each kidney. ***(*****Quoted*****From Drake et al., 2005).***

"Gerota's Fascia", an important fascia, is interposed between the kidney and its surrounding structures **(fig. 4)**.This fascial layer encompasses the perirenal fat and kidney and encloses the kidney on three sides: superiorly, medially, and laterally. Superiorly and laterally Gerota's fascia is closed, but medially it extends across the midline to fuse with the contralateral side. Inferiorly, Gerota's fascia is not closed and remains an open potential space. Gerota's fascia serves

as an anatomic barrier to the spread of malignancy as well as a means of containing perinephric fluid collections. Thus, perinephric fluid collections can track inferiorly into the pelvis without violating Gerota's fascia***(Drake et al., 2005).***

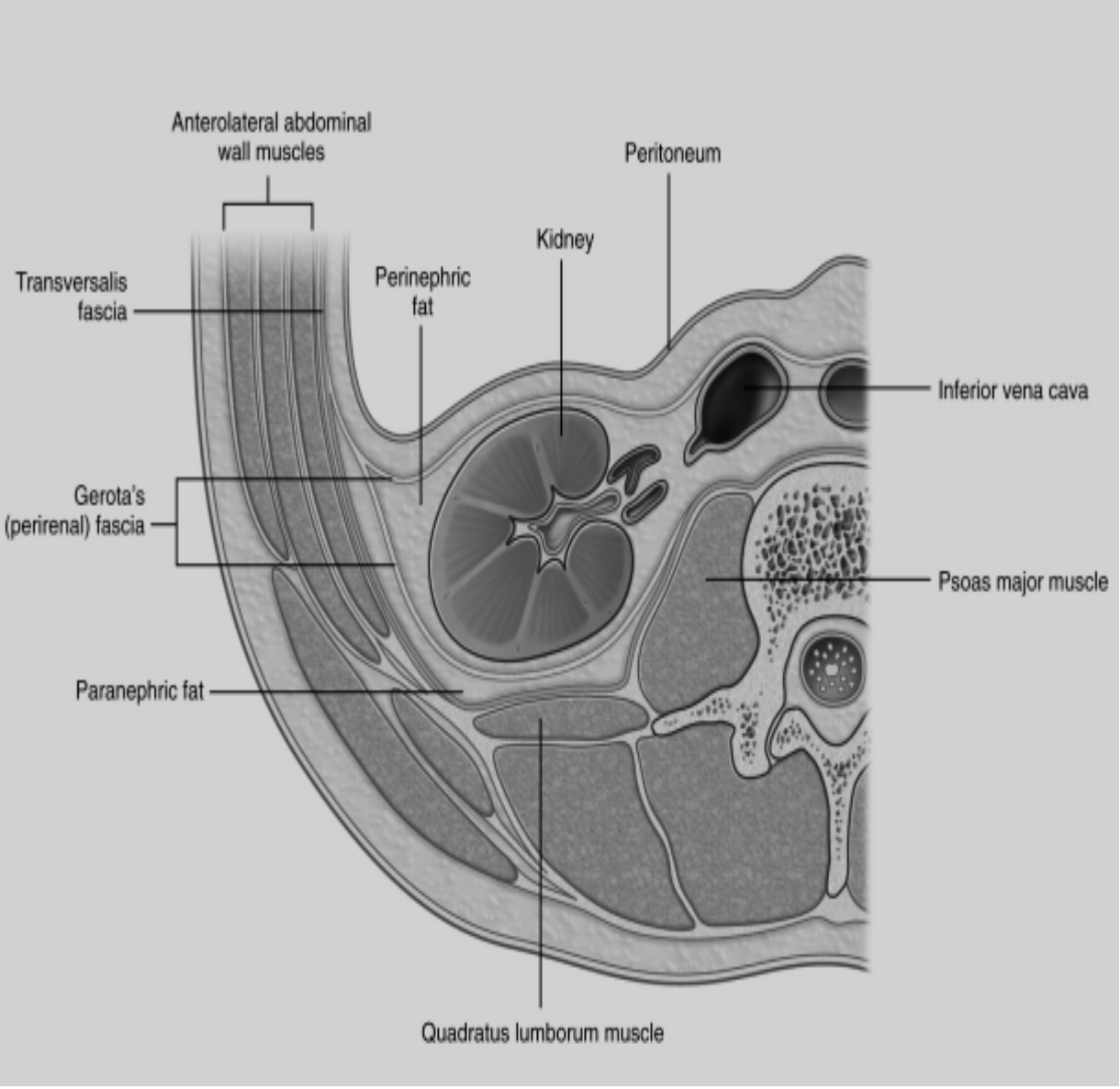

Fig. 4: Organization of the fat and fascia surrounding the kidney.***(*****Quoted*****From Drake et al., 2005).***

Renal Vasculature

The renal pedicle classically consists of a single artery and a single vein that enter the kidney via the renal hilum**(fig. 1)**. These structures branch from the aorta and inferior vena cava just below the superior mesenteric artery at the level of the second lumbar vertebra. The vein is anterior to the artery. The renal pelvis and ureter are located further posterior to these vascular structures.

Renal Artery :

Specifically, the right renal artery leaves the aorta and progresses with a caudal slope posterior to the IVC toward the right kidney. The left renal artery courses almost directly laterally to the left kidney. Both renal arteries move posteriorly as they enter the kidney. Also, both arteries have branches to the respective adrenal gland, renal pelvis, and ureter.

Upon approaching the kidney, the renal artery splits into four or more branches, with five being the most common. These are the renal segmental arteries**(fig. 5)**. Each segmental artery supplies a distinct portion of the kidney with no collateral circulation between them **(fig. 6)**. Thus, occlusion or injury to a segmental branch will cause segmental renal infarction. Generally, the first and most constant branch is the posterior segmental branch, which separates from the renal artery before it enters the renal hilum. There are typically four anterior branches, which from superior to inferior are apical, upper, middle, and lower ***(Dworkin and Brenner, 2004).***

Once in the renal sinus, the segmental arteries branch into lobar arteries, which further subdivide in the renal parenchyma to form interlobar arteries **(fig. 7)**. These interlobar arteries progress peripherally within the cortical columns of Bertin. At the base (peripheral edge) of the renal pyramids, the interlobar arteries branch into arcuate arteries. The arcuate arteries parallel the edge of the corticomedullary junction. Interlobular arteries branch off the arcuate arteries and move radially, where they eventually divide to form the afferent arteries to the glomeruli***(Evans et al., 2004).***

The 2 million glomeruli within each kidney represent the core of the renal filtration process. Each glomerulus is fed by an afferent arteriole. As blood flows through the glomerular capillaries, the urinary filtrate leaves the arterial system and iscollected in the glomerular (Bowman's) capsule. Blood flow leaves the glomerular capillary via the efferent arteriole and continues to one of two locations: secondary capillary networks around the urinary tubules in the cortex or descending into the renal medulla as the vasa recta***(Pallone et al., 2003).***

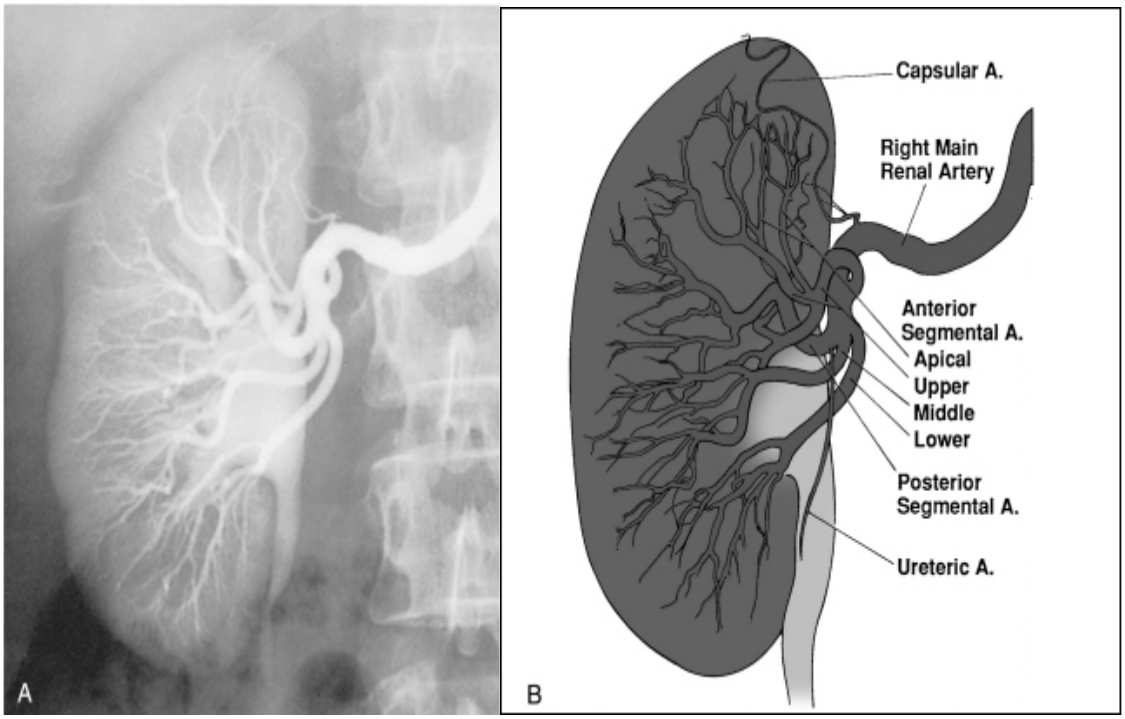

Fig. 5: A and B, Segmental branches of the right renal artery demonstrated by renal angiogram***(Williams et al., 2007).***

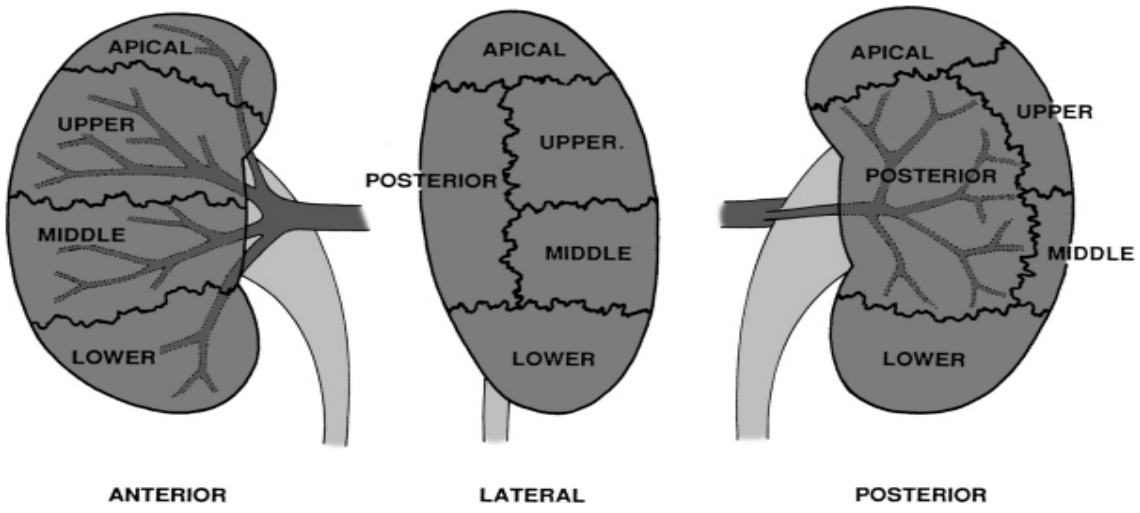

Fig. 6: Typical segmental circulation of the right kidney, shown diagrammatically***(Williams et al., 2007).***.

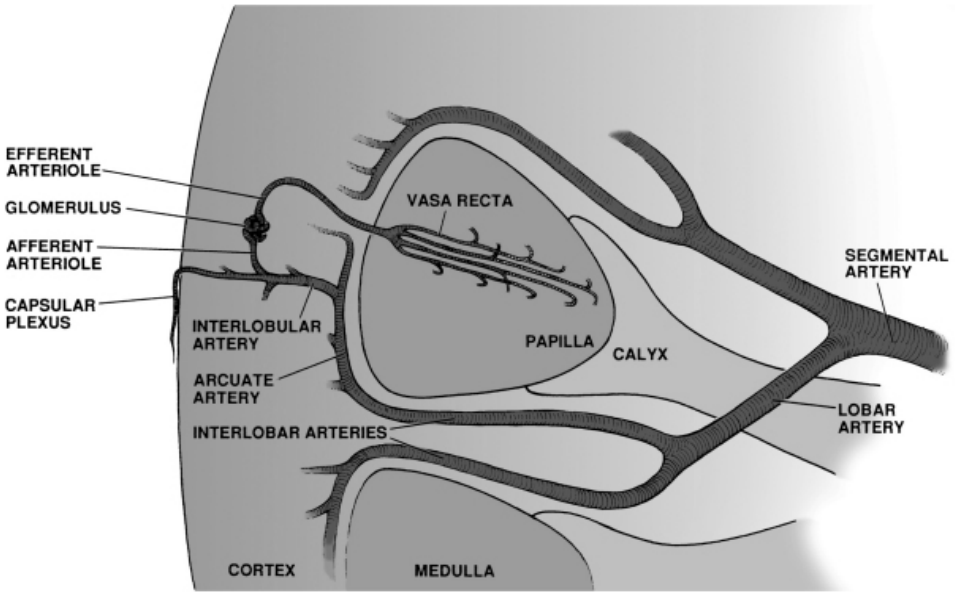

Fig.7: Intrarenal arterial anatomy***(From Drake et al., 2005).***

Renal Veins

The renal venous drainage correlates closely with the arterial supply. The interlobular veins drain the post glomerular capillaries. These veins also communicate freely via a subcapsular venous plexus of stellate veins with veins in the perinephric fat. After the interlobular veins, the venous drainage progresses through the arcuate, interlobar, lobar, and segmental branches, with the course of each of these branches paralleling the respective artery. After the segmental branches, the venous drainage coalesces into three to five venous trunks that eventually combine to form the renal vein **(fig. 8)** . Unlike the arterial supply, the venous drainage communicates freely through venous collars around the infundibula, providing for extensive collateral circulation in the venous drainage of the kidney ***(Dworkin and Brenner, 2004).***

The renal vein is located directly anterior to the renal artery, although this position can vary up to 2 cm cranially or caudally relative to the artery. The right renal vein is generally 2 to 4 cm in length and enters the right lateral to posterolateral edge of the IVC. The left renal vein is typically 6 to 10 cm in length and enters the left lateral aspect of the IVC after passing posterior to the superior

mesenteric artery and anterior to the aorta **(fig. 9)**. The left renal vein receives the left adrenal vein superiorly, lumbar vein posteriorly, and left gonadal vein inferiorly **(fig . 9).** The right renal vein typically does not receive any branches.

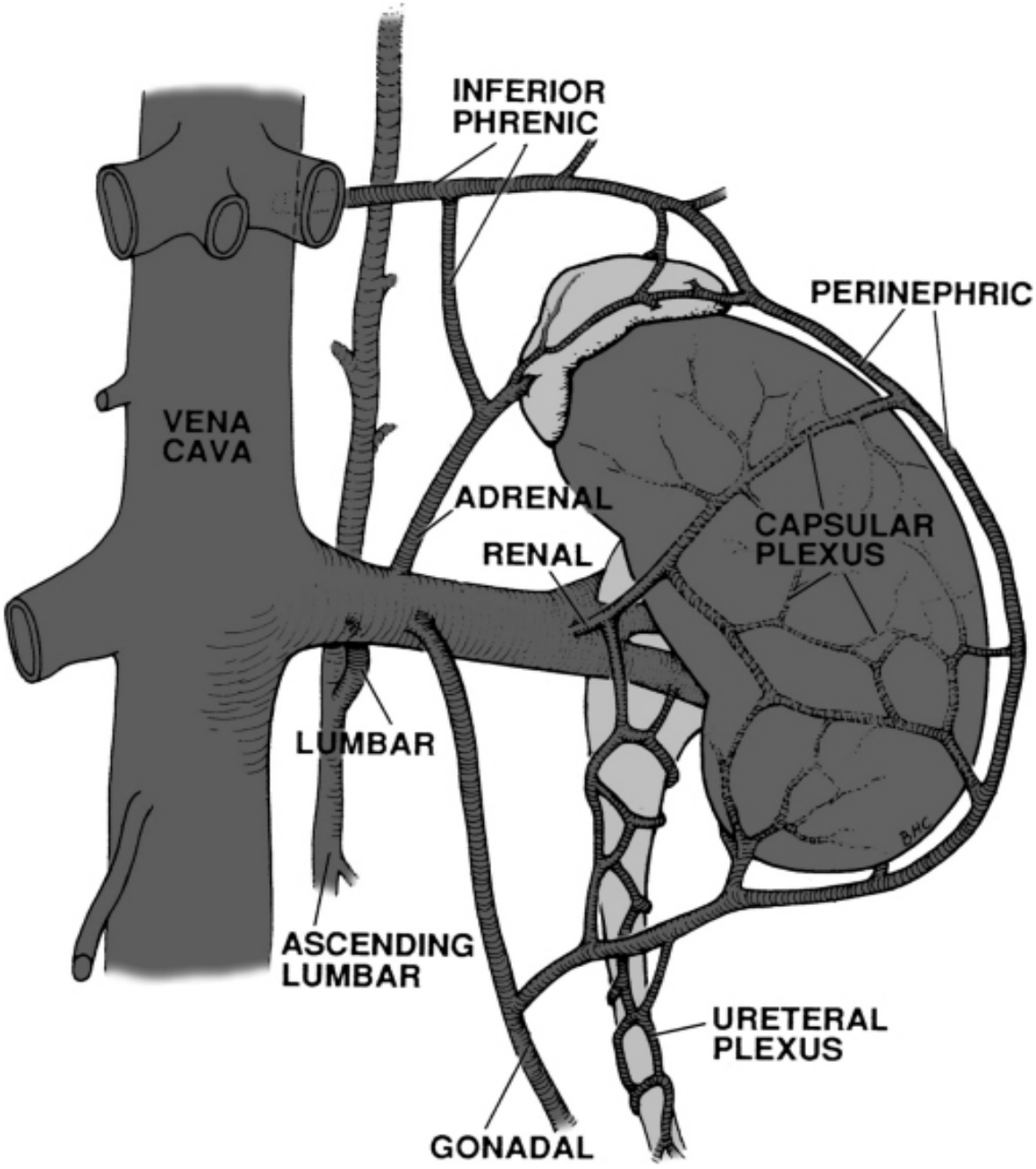

Fig. 8: Venous drainage of the left kidney showing potentially extensive venous collateral circulation ***(Williams et al., 2007).***

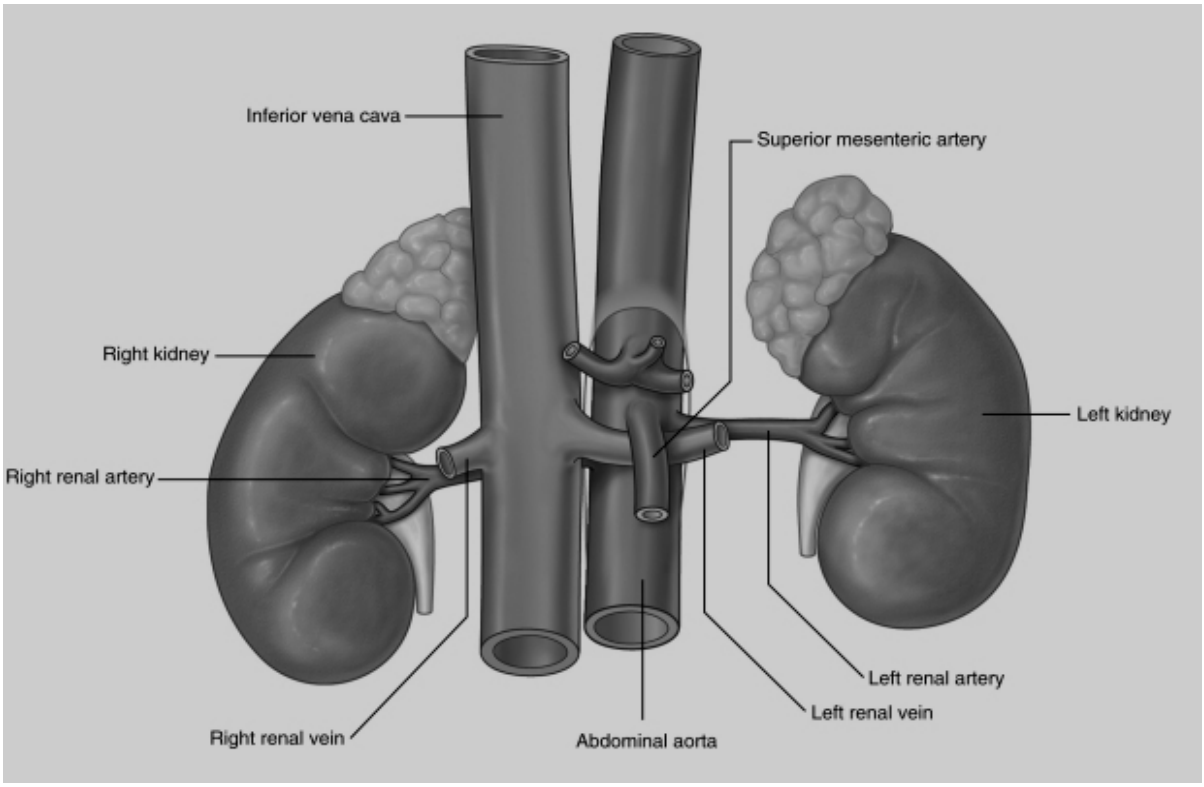

Fig. 9: Renal vasculature. Note path of left renal vein posterior to the superior mesenteric artery***(From Drake et al., 2005)***.

Renal Lymphatics

The renal lymphatics largely follow blood vessels through the columns of Bertin and then form several large lymphatic trunks within the renal sinus. As these lymphatics exit the hilum, branches from the renal capsule, perinephric tissues, renal pelvis, and upper ureter drain into these lymphatics. Thenthey empty into lymph nodes associated with the renal vein near the renal hilum. From here, the lymphatic drainage between the two kidneys varies. On the left, primary lymphatic drainage is into the left lateral para-aortic lymph nodes including nodes anterior and posterior to the aorta between the inferior mesenteric artery and the diaphragm. On the right, drainage is into the right interaortalcaval and right paracaval lymph nodes, including nodes located anterior and posterior to the vena cava, from the common iliac vessels to the diaphragm***(Dworkin and Brenner, 2004).***

Renal Collecting System

The renal collecting system originates in the renal cortex. Together the glomerular capillary network and Bowman's capsule form the renal corpuscle (**fig. 10)**. The glomerular capillary network is covered by specialized epithelial cells

called podocytes that, along with the capillary epithelium, form a selective barrier across which the urinary filtrate must pass. The filtrate is initially collected in Bowman's capsule and then moves to the proximal convoluted tubule. The proximal tubule continues deeper into the cortical tissue where it becomes the loop of Henle. The loop of Henle extends variable distances into the renal medulla.

Within the renal medulla, the loop of Henle reverses course and moves back toward the periphery of the kidney. As it ascends out of the medulla the loop thickens and becomes the distal convoluted tubule. This tubule eventually returns to a position adjacent to the originating glomerulus and proximal convoluted tubule. Here the distal convoluted tubule turns once again for the interior of the kidney and becomes a collecting tubule. Collecting tubules from multiple nephrons combine into a collecting duct that extends inward through the renal medulla and eventually empties into the apex of the medullary pyramid, the renal papilla ***(Pallone et al., 2003).***

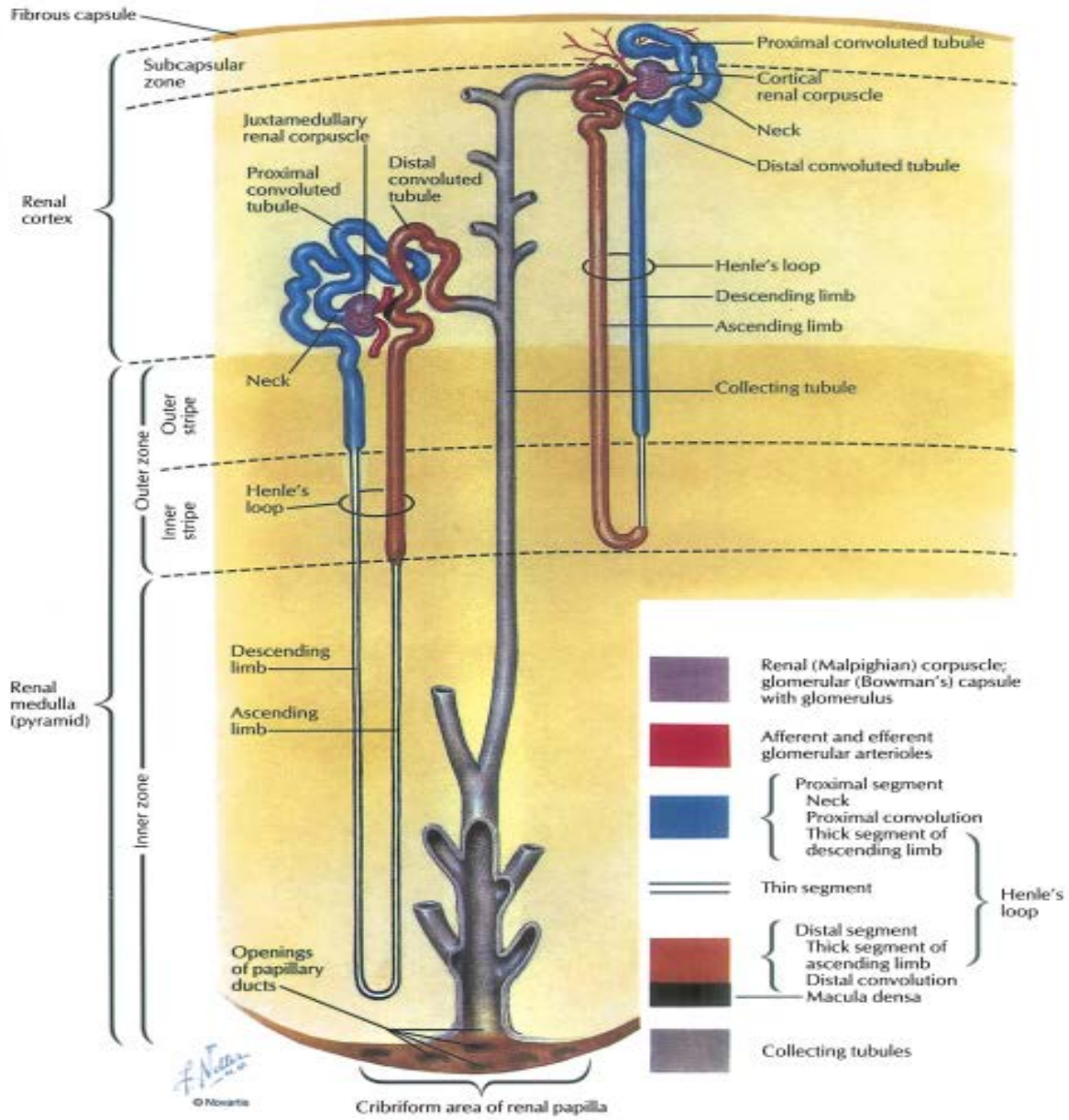

Fig. 10: Renal nephron and collecting tubule ***(From Drake et al., 2005)***.

Renal Papillae, Calyces, and Pelvis

The renal papillae are the tip of a medullary pyramid and constitute the first gross structure of the renal collecting system. Typically, there are 7 to 9 papillae per kidney, but this number is variable, ranging from 4 to 18. The papillae are aligned in two longitudinal rows situated approximately 90 degrees from one another **(fig. 11)**. Each of these papillae is cupped by a minor calyx .

At the upper and lower poles, compound calyces are often encountered. These compound calyces are the result of renal pyramids fusion. Each minor calyx

narrows to an infundibulum. As there is frequent variation in the number of calyces, the diameter and length of the infundibula varies greatly. Infundibuli combine to form two or three major calyceal branches. These are frequently termed the upper, middle, and lower pole calyces, and these calyces in turn combine to form the renal pelvis. The renal pelvis itself can vary greatly in size ranging from a small intrarenal pelvis to a large predominantly extrarenal pelvis. Eventually the pelvis narrows to form the ureteropelvic junction, marking the beginning of the ureter ***(Sampaio, 2000).***

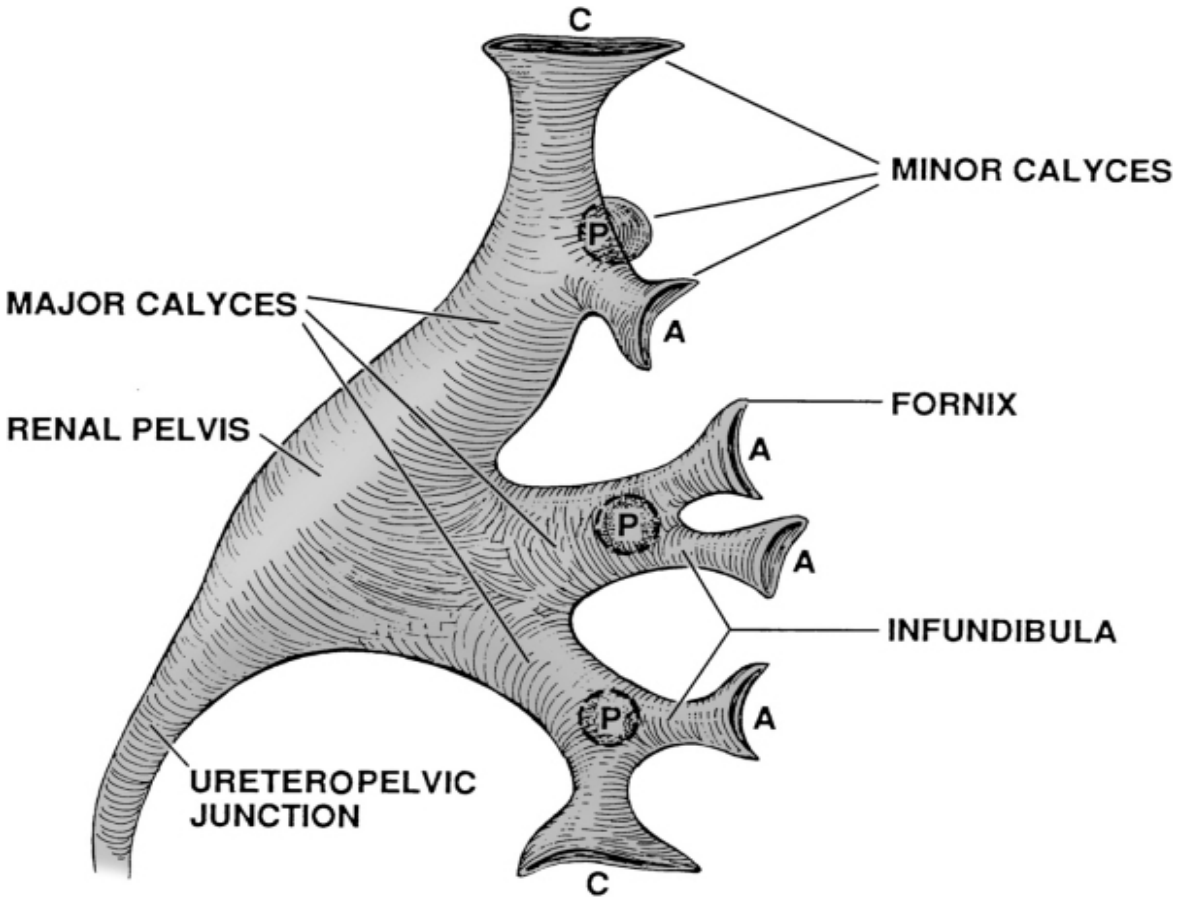

Fig. 11: The renal collecting system (left kidney). A, anterior minor calyces; C, compound calyces at the renal poles; P, posterior minor calyces***(Williams et al., 2007).***

Renal Innervation

Sympathetic preganglionic nerves originate from the eighth thoracic through first lumbar spinal segments and then travel to the celiac and aorticorenal ganglia. From here, postganglionic fibers travel to the kidney via the autonomic plexus surrounding the renal artery. Parasympathetic fibers originate from the vagus nerve and travel with the sympathetic fibers to the autonomic plexus along the renal artery. The primary function of the renal autonomic innervation is vasomotor, with the sympathetics inducing vasoconstriction and the parasympathetics causing vasodilation. Despite this innervation, it is important to realize that the kidney functions are well even without this neurologic control, as evidenced by the successful function of transplanted kidneys ***(Sampaio and Aragão, 1990).***

Normal appearance of the kidney by MRI and MRA :

MRI provides superb soft tissue contrast which is better than that of CT. On T1-weighted MRI(spin-echo or gradient-echo) sequences, most of the normal kidneys show distinct contrast between the cortex and the medulla as the renal cortex has a slightly higher signal than the medulla , while cortico-medullary contrast is decreased on T2- weighted images, as the renal cortex is slightly lower in signal than the medulla**(fig.12)*(Baert et al., 2008)*.**

Gadolinium (Gd) injection gives an accurate delineation of perfused and non-perfused areas of the graft, the cortex is first opacified and then medulla and pyramids, making it possible to distinguish between them***(Ryan et al, 2004)***.

On MRA, the renal arteries and veins can be visualized with or without contrast using flow Imaging sequences (**fig.13)*(Ryan et al, 2004)***. High-resolution 3D MR angiograms can be obtained for the entire arterial tree from the iliac axis to the third- or fourth-order branches ***(Baert et al., 2008)*.**