Kidney, Adrenal, Ureter

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1. Introduction

A thorough understanding of genitourinary anatomy is necessary for all practicing urologists. In this section, the relevant embryology, surgical anatomy and histology of the upper urinary tract will be reviewed. The physiology of the urinary tract will be reviewed in a separate section.

2. Kidney

The kidneys are paired reddish-brown organs that lie within the retroperitoneum. Each adult male kidney weighs approximately 125 to 170g; the kidney is 10 to 15g smaller in females.[1] They measure approximately 10 to 12 cm vertically, 5 to 7.5 cm transversely, and 2.5-3 cm in thickness. The right kidney is situated lower in the retroperitoneum because of the liver. 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. A focal parenchymal bulge, otherwise known as a dromedary hump, is a common feature seen. This is a normal variation without pathologic significance, presumably related to downward pressure from the spleen or liver.

2.1 Renal Embryology

The embryologic development of the kidney can be described as three distinct entities: pronephros, mesonephros and metanephros.[2] The pronephros and mesonephros regress in utero. However, the metanephros develops into the kidney.[3] All three develop from the intermediate mesoderm. There are several molecular mechanisms involved in renal and ureteral development.

2.1.1 Pronephros

The pronephros develops during the first 4 weeks of gestation.[4] It develops as five to seven paired cervical segments and completely degenerates by the end of the fifth week.[3]

2.1.2 Mesonephros

The duct of the pronephros is thought to persist as the mesonephric duct. The mesonephric duct extends caudally to drain into the urogenital sinus and serves as the principle excretory organ during early embryonic life between 4 and 8 weeks. [2] Mesonephric tubules develop and by the fourth month, the human mesonephros has almost completely disappeared. A few elements persist and become part of the reproductive tract: the efferent ductules of the testis in men and nonfunctional mesosalpingeal structures in women, the epoöphoron and paroöphoron. [3]

2.1.3 Metanephros

The metanephros is the final phase of development of the nephric system. It forms in the sacral region as the ureteric bud originates from the posteromedial aspect of the mesonephric duct where it enters the cloaca. [4] The metanephric mesenchyme condenses from the intermediate mesoderm during the early part of the fifth week and is induced by ureteral bud to form the metanephric kidney. There is extensive “cross talk” between the bud and mesenchyme. [5] Ultimately, nephrogenesis is usually completed by 32 to 34 weeks of gestation. The glomerulus, proximal tubule, loop of Henle, and distal tubule are thought to derive from the metanephric mesenchyme. [6] Successive divisions of the ureteral bud ultimately result in formation of the collecting system encompassing the collecting ducts, calyces, renal pelvis and ureter.

2.2 Anatomy

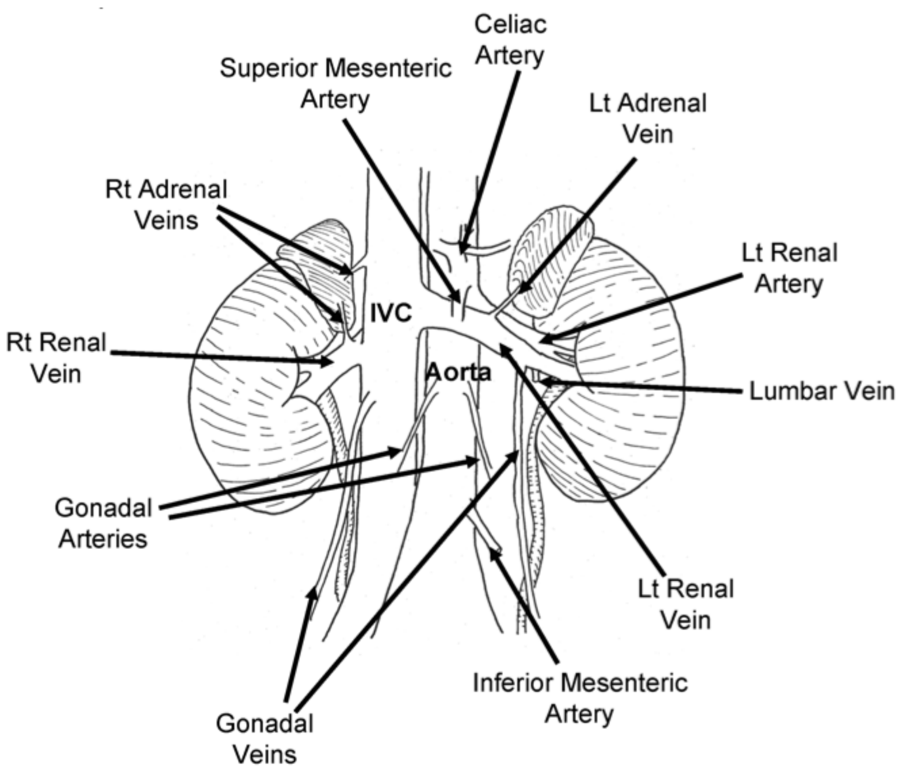

Figure 1: Renal Vascular Anatomy

The position of the kidney within the retroperitoneum varies greatly by side, degree of inspiration, body position, and presence of anatomic anomalies. [1,7]

The kidneys are supported by the perirenal fat, renal vascular pedicle, abdominal muscle tone and abdominal viscera.[8] These factors allow variations in the degree of renal mobility. The average descent on inspiration or on assuming the upright position is 4–5 cm. Lack of mobility suggests abnormal fixation, but extreme mobility is not necessarily pathologic.[9]

The orientation of the kidney is greatly affected by the structures around it. The upper poles are situated more medial and posterior than the lower poles. The medial aspect of the kidney is more anterior than the lateral aspect.

The kidney and its perirenal fat are encased within the perirenal fascia, otherwise known as Gerota's fascia. Gerota's fascia envelops the kidney on all aspects except inferiorly, where it remains an open potential space. Medially it extends across the midline to fuse with the fascia from the contralateral side

The renal pedicle typically consists of one artery and vein that enter the kidney at the renal hilum (**Figure 1**).[10] They branch from the aorta and inferior vena cava just below the superior mesenteric artery at the level of the second lumbar vertebra. From anterior to posterior, the renal hilar structures are the renal vein, artery, and collecting system/ureter.

2.2.1 Arterial Anatomy

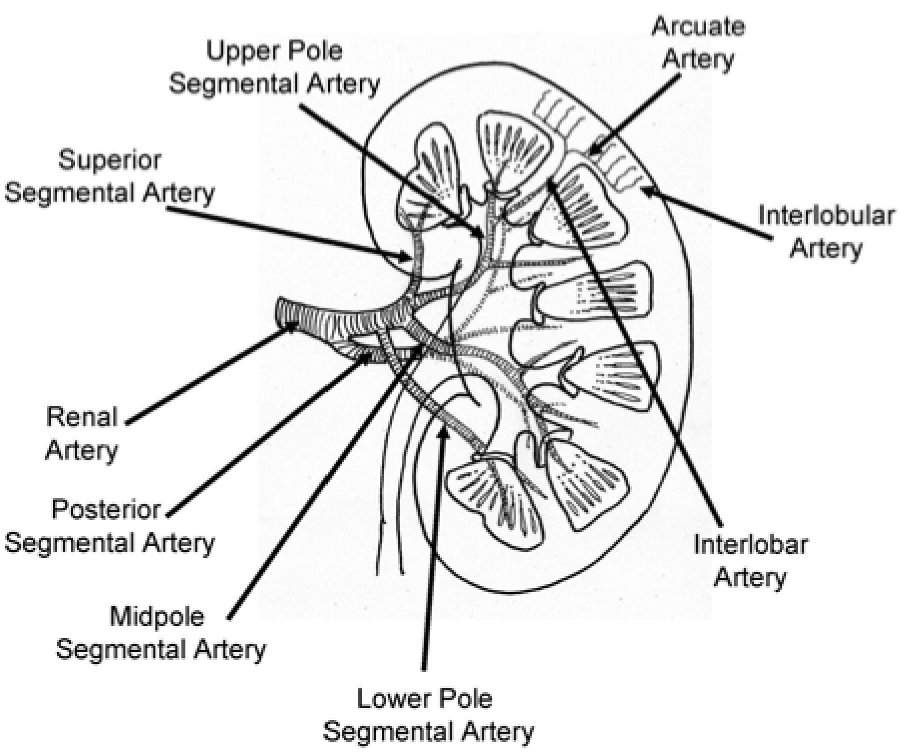

Figure 2: Intrarenal Arterial Anatomy

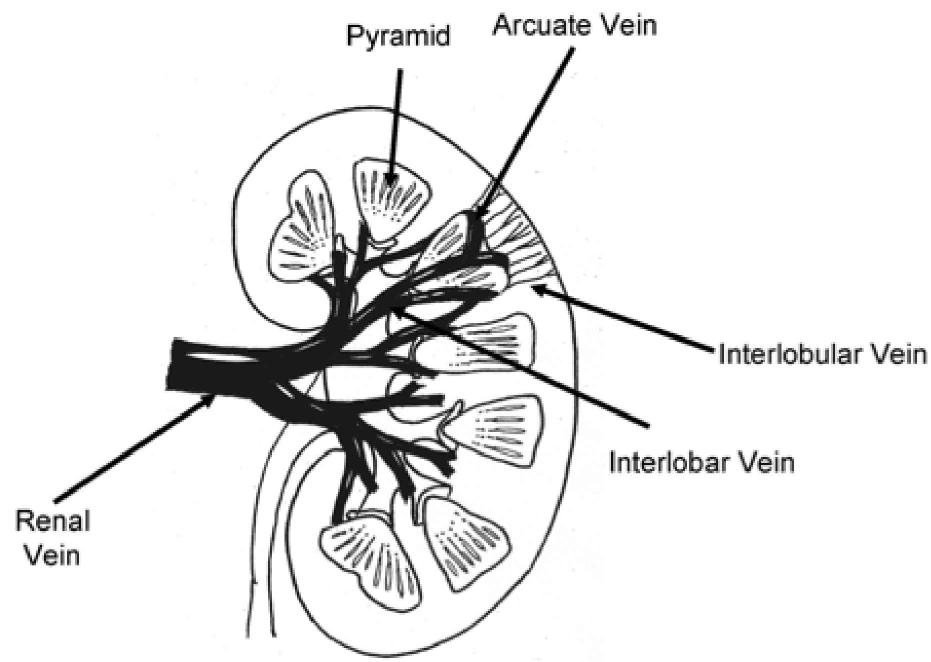

Figure 3: Intrarenal Venous Anatomy

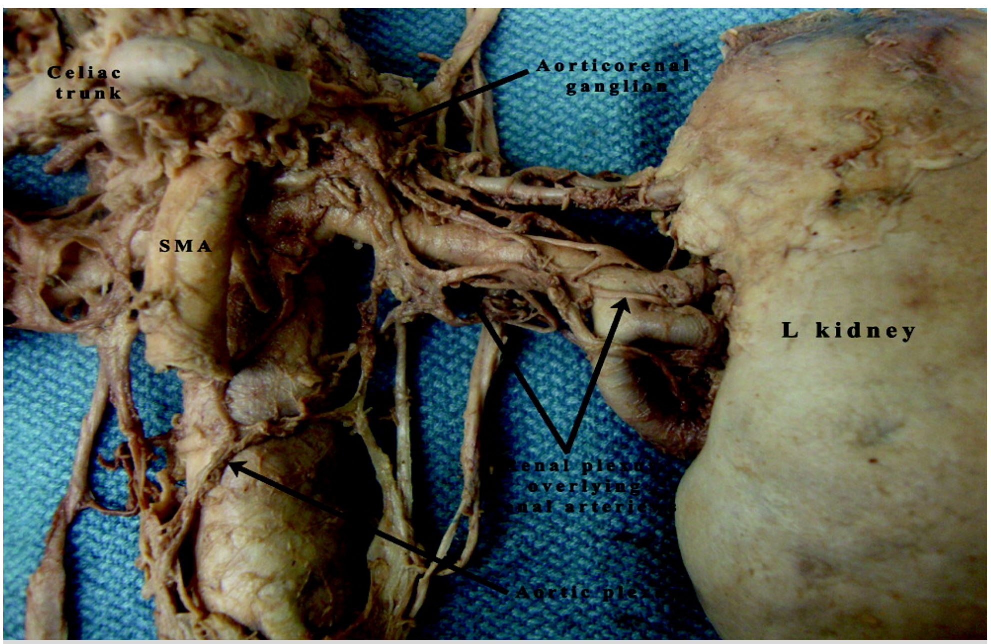

Figure 4: Renal Innervation

The renal artery splits into segmental branches. Typically, the first branch is the posterior segmental artery, which passes posterior to the collecting system. Three to four anterior segmental branches pass anteriorly to supply the anterior kidney: the apical, upper, middle and lower segmental arteries.[10] This resembles a hand (main renal artery) grasping a glass (renal pelvis).[11] After passing through the renal sinus, segmental arteries further branch into lobar arteries followed by interlobar arteries. Interlobar arteries travel within cortical columns of Bertin, branching at the base of the renal pyramids to form arcuate arteries which further branch into interlobular arteries (**Figure 2**).[10] Interlobular arteries divide to form afferent arterioles to the glomeruli. The renal artery and all of its branches are end arteries, with occlusion resulting in infarction of the involved segment.

2.2.2 Venous Anatomy

Renal venous drainage mirrors the arterial blood supply with one caveat (**Figure 3**).[10] While occlusion of an arterial branch results in infarction, occlusion of a segmental vein is not problematic because of extensive collateral circulation.

Postglomerular capillaries are drained by interlobular veins, which also communicate freely via a subcapsular venous plexus of stellate veins with veins in the perinephric fat. Interlobular veins drain into arcuate veins followed by interlobar, lobar and segmental branches. The segmental branches coalesce into three to five venous trunks that eventually combine to form the renal vein.[1,7]

The renal vein lies anterior to the renal artery but its position can vary 1 to 2 cm cranial or caudal to the artery. The right renal vein is 2 to 4 cm in length and enters the 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. The left adrenal vein, a lumbar vein, and left gonadal vein typically drain into the left renal vein.

2.2.3 Lymphatic Anatomy

Renal lymphatic channels follow the course of blood vessels within the renal parenchyma before coalescing into several large lymphatic trunks in the renal sinus. Lymphatics from the renal capsule, perinephric tissues, renal pelvis and upper ureter join these as they exit the renal hilum. On the left, primary lymphatic drainage is into the left lateral para-aortic lymph nodes. Occasionally, the left kidney lymphatics drain to the retrocrural nodes or directly into the thoracic duct above the diaphragm. On the right, drainage is into the right interaortocaval and right paracaval lymph nodes. The right renal lymphatics can also drain into the retrocrural nodes. [1,7]

2.2.4 Innervation

The kidneys receive pre-ganglionic sympathetic input from the eighth thoracic through first lumbar segments. These nerves travel to the celiac and aorticorenal ganglia. From here, postganglionic fibers travel to the kidney via the autonomic plexus that surrounds the renal artery. [7,10] Parasympathetic innervation originates from the vagus nerve and travels with the postganglionic sympathetic nerves via the autonomic plexus surrounding the renal artery (**Figure 4**).[12] The autonomic innervation of the kidney serves a vasomotor purpose with sympathetic activation leading to vasoconstriction and parasympathetic activity resulting in vasodilatation. One important consideration is that the kidney may function well without neurologic control as evidenced by the success of renal transplantation.

2.2.5 Fascial Investments/Anatomic Relations/Anatomic Variations

An intimate understanding of the kidney and its surrounding structures is necessary for both open and minimally invasive surgical techniques.[1] Posteriorly, the diaphragm covers the upper third of each kidney and 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.

Anteriorly, the right kidney is surrounded by a number of structures. Cranially, the upper pole lies against the liver and is separated from the liver 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. 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. This attachment can lead to splenic capsular tears if excessive downward pressure is applied to the left kidney. 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. [7]

2.2.6 Anatomic Variations

Anatomic variations in the renal vasculature are common, occurring in 25% to 40% of kidneys. Supernumary renal arteries are the most common variant, occurring more often on the left. These arteries can enter the hilum or renal parenchyma directly. Lower pole arteries on the right can cross anterior to the IVC, while lower pole arteries on either side can cross anterior to the collecting system, resulting in ureteropelvic junction obstruction. Supernumary veins occur but are less common. It is also possible for the left renal vein to pass posterior to the aorta or divide to and send one limb anteriorly with the other passing posterior to form a collar type circumaortic formation.[7]

2.3 Histology

Grossly and microscopically, the kidney is divided into the cortex and medulla while the functioning unit of the kidney is the nephron. The medulla is divided into 8 to 18 striated, distinct, conically shaped areas often referred to as renal pyramids. [1] These are separated by sections of renal cortex called *columns of Bertin.* Each renal pyramid terminates centrally in a papilla.

Microscopically, the renal collecting system originates in the renal cortex at the glomerulus as filtrate enters Bowman's capsule. Together the glomerular capillary network and Bowman's capsule form the renal corpuscle. The filtrate is initially collected in Bowman's capsule and then moves to the proximal convoluted tubule.[7,10] The proximal tubule continues deeper into the cortical tissue where it becomes the loop of Henle. Within the renal medulla, the loop of Henle reverses course and moves back toward the periphery of the kidney, becoming the distal convoluted tubule. This tubule eventually returns to a position adjacent to the originating glomerulus and proximal convoluted tubule. The distal convoluted tubule turns once again towards the interior of the kidney, becoming 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. This is the first gross structure of the renal collecting system. Usually there are 7 to 9 papillae per kidney, but this number is variable, ranging from 4 to 18. [7] Each papilla is cupped by a minor calyx. Groups of minor calyces join to form a major calyx. The major calyces combine to form the renal pelvis.

3. Adrenal

The adrenal glands are paired retroperitoneal organs that are 3-5 cm in greatest transverse dimension, 1 cm thick and weigh approximately 5 g.[7,13] The weight of the adrenal can range from 2 to 6 grams with no variation in genders. [14]

3.1 Embryology

The adrenal glands are formed from two embryologically distinct parts: the cortex and medulla.[15] The cortex and medulla remain independent in primitive vertebrates. However, they are fused in mammals.

The cortex is derived from mesoderm from an area between the base of the mesentery medially and the mesonephros and undifferentiated gonad laterally; ectopic cortical tissue has been discovered below the kidneys, sometimes associated with the testes or ovaries. The cortex is composed of three layers, remembered easily using the moniker GFR. From external to internal the layers are the zona glomerulosa, zona fasciculata, and zona reticularis. Each layer serves a unique purpose with the glomerulosa producing mineralocorticoids (e.g., aldosterone), the fasciculata producing glucocorticoids (e.g., cortisol), and the reticularis synthesizing sex steroids (androgens). [7,14]

The medulla is derived from ectoderm and develops from migrating cells of the neural crest. It is an important site of chromaffin cells that are innervated by presynaptic sympathetic fibers from the sympathetic chains, with the secretion of neuroactive catecholamines by the adrenal medulla falling under sympathetic control.

3.2 Anatomy

The adrenal glands lie within Gerota's fascia and appear yellow-orange. The outer cortex has a finely granular surface and firm consistency distinguishing it from the surrounding adipose tissue.[15] The inner medulla is dark red and somewhat friable. It is usually not visible unless the cortex has been violated.

3.2.1 Arterial Anatomy

The adrenal glands receive their arterial blood supply from three sources. Superiorly, the adrenal gland usually derives blood flow from branches of the inferior phrenic artery, and rarely by the aorta, celiac axis, or intercostal arteries.[14] The middle adrenal artery usually arises from the lateral aspect of the aorta. Inferiorly, there can be a branch from the ipsilateral renal artery.

3.2.2 Venous Anatomy

The venous drainage from the adrenal is important from both the anatomic and physiologic viewpoint. The venous drainage varies with the right adrenal vein being somewhat short and directly emptying into the posterolateral portion of the inferior vena cava. The left adrenal vein usually terminates into the left renal vein but it may also empty into the left inferior phrenic vein. There can be numerous accessory adrenal veins on each side. [15]

3.2.3 Lymphatic Anatomy

The lymphatic drainage of the adrenal glands accompanies its blood supply and follows three pathways. On the right, the pathways lead to the right lateral aortic nodes anterior to the right crus of the diaphragm, right lateral aortic nodes proximal to the junction of the left renal vein and vena cava, and the thoracic duct or posterior mediastinal nodes.

On the left, the first two pathways end in the left lateral aortic nodes proximal to the celiac trunk and left renal vein, while the third is through the diaphragm, similar to the right. Avisse et al. described the lymphatic drainage of the adrenal glands as an image of physiologic and embryologic duality. Lymphatic vessels drain the cortex, not the medulla, explaining why corticosteroids can be found in the thoracic duct. [15]

3.2.4 Innervation

Innervation of the adrenal gland is important for release of catecholamines from the chromaffin cells of the medulla. [14] The sympathetic visceral nervous system provides innervation to the adrenal gland. Preganglionic sympathetic nerve fibers from the lower thoracic and lumbar spinal cord travel via the sympathetic chain to reach the adrenal cortex. Visceral afferent fibers that arise from the celiac ganglia traverse the cortex to reach the medulla.

3.2.5 Fascial Investments/Anatomic Relations/Anatomic Variations

Both adrenal glands lie within the retroperitoneum and are distinct embryologically from the kidney. The posterior surface of both glands is in contact with the diaphragm.

The right adrenal gland is pyramid shaped, embedded in the perirenal fat and superior to the kidney within Gerota's fascia. There is a fibrous transverse lamella, formed by connections between the ventral and dorsal layers of the renal fascia that separate it from the kidney. The right adrenal gland is located more superiorly in the retroperitoneum than the left. [7,14] A portion of the gland is posterolateral to the inferior vena cava. The anterior surface lies in close proximity to the inferior-posterior surface of the liver. [13] The duodenum is anteromedial to the right adrenal gland.

The left adrenal gland is crescent shaped and lays in a position more supero-medial to the left kidney. The pancreas and splenic vein are located just anterior to it.

3.3 Histology

The adrenal gland is divided into two components histologically: the cortex and medulla. The cortex is made up of three layers, each with different functions described previously. The medulla is composed of chromaffin cells. Chromaffin cells are postganglionic sympathetic neurons that have lost their axons and dendrites. [14]

4. Ureter

The ureters are bilateral structures that transport urine from the kidney to the bladder. Understanding ureteral anatomy and its anatomic relationships to other structures is necessary to avoid and properly manage intra-operative ureteral complications.

4.1 Embryology

It is difficult to consider the embryology of the ureter without considering that of the kidney. The ureter begins as a ureteral bud from the mesonephric duct as it bends to join the cloaca. Through reciprocal inductive interactions with the surrounding metanephric mesenchyme, the ureteral bud undergoes a dichotomous branching morphogenesis. [2,16]

4.2 Anatomy

The ureters are generally 22 to 30 cm in length in adults with a diameter of 1.5 to 6 mm and vary according to the height of the individual.[1,9] They typically measure 6.5 to 7 cm in neonates.

4.2.1 Arterial Anatomy

The ureter receives its arterial blood supply form several vessels along its course towards the bladder. [1] The upper portion of the ureter is supplied by vessels from the medial direction while arterial branches that supply the pelvic ureter come from the lateral direction. The upper ureter derives its blood supply from arterial branches from the renal artery, gonadal artery, abdominal aorta and common iliac artery. The pelvic ureter is supplied by branches from the internal iliac artery, including the vesical, uterine, middle rectal and vaginal arteries.

Arterial vessels coalesce to form an extensive anastomosing plexus within the peri-ureteral adventitia. As long at the adventitia is not stripped, the ureter can be mobilized from surrounding retroperitoneal tissues without compromising its blood supply. The portion of the ureter at most risk of harm is the mid ureter between the lower pole of the kidney and the brim of the pelvis as it is thought to be the most poorly vascularized. [17]

4.2.2 Venous Anatomy

The venous drainage of the ureter mirrors its arterial blood supply.[9]

4.2.3 Lymphatic Anatomy

The lymphatic drainage of the ureter mirrors its blood supply. The renal pelvis and upper ureteral lymphatic vessels have a similar drainage to the ipsilateral renal lymphatics. In the abdomen, the right ureteral lymphatics drain to the right paracaval and inter-aortocaval nodes while the left drain to the para-aortic nodes. In the pelvis, ureteral lymphatics drain to internal, external, and common iliac nodes. [1]

4.2.4 Innervation

The role the ureteral innervation plays in peristalsis and the transport of urine is unclear. Normal ureteral peristalsis does not require autonomic input. Excised portions of the ureter continue to contract without nervous control and denervation of the lower portion of the ureter does not result in reflux.[1] Peristalsis is thought to originate and propagate from intrinsic smooth muscle pacemaker sites located in the minor calyces of the renal collecting system. The ureter receives preganglionic sympathetic input from the 10th thoracic through 2nd lumbar spinal segments. Postganglionic fibers arise from several ganglia in the aorticorenal, superior, and inferior hypogastric autonomic plexuses. Parasympathetic input is received from the 2nd through 4th sacral spinal segments.

Renal pain fibers are stimulated by tension or distension of the renal capsule, renal collecting system, or ureter.. Mucosal irritation of the upper tract may also stimulate nociceptors. Signals travel with the sympathetic nerves and may result in a visceral-type pain referred to the sympathetic distribution of the kidney and ureter, thus resulting in visceral-type referred pain in the flank, groin, or scrotal (labial) regions.[1]

4.2.5 Fascial Investments/Anatomic Relations/Anatomic Variations

The ureter begins at the ureteropelvic junction posterior to the renal artery and begins its descent. It continues along the anterior edge of the Psoas muscle where it is crossed by the gonadal vessel on each side. It then further descends into the pelvis, passing over the iliac vessels usually marking the bifurcation of common iliac into the internal and external iliac vessels.[1]

The ureteral caliber is not uniform throughout its descent. Three distinct areas of narrowing described are the ureteropelvic junction, crossing of the iliac vessels, and the ureterovesical junction.

Ureteral segmentation has been described in two ways. One system divides the ureter into abdominal and pelvic portions, with the iliac vessels serving as a border. Typically the ureter is described in three segments. The segment extending from the renal pelvis to upper border of the sacrum is considered the upper segment. The segment between the upper and lower borders the sacrum comprises the middle ureter. The lower segment extends from the lower border of the sacrum to the bladder.[7]

The right ureter is closely related to the ascending colon, cecum, colonic mesentery, and appendix. The left ureter lies close to the descending colon, sigmoid colon and their accompanying mesenteries.[9] These structures lie anterior to the ureter on either side. Processes involving any of these structures can result in obstruction of damage to the ureter

In females, the uterine arteries are closely related to the juxtavesical portion of the ureters, passing anterior to the ureters. The ureter is passes close to the uterine cervix. This places the ureters at risk of involvement by an inflammatory process, gynecologic mass benign or injury during hysterectomy.

The vasa deferentia leave the internal inguinal rings and sweep over the lateral pelvic walls anterior to the ureters before joining the seminal vesicles medially to penetrate the base of the prostate and form the ejaculatory ducts.

4.3 Histology

See Reference 18

The ureter is composed of multiple layers that work in unison to propagate the flow of urine distally to the bladder. The inner most layer is composed of transitional epithelium. This is surrounded by the lamina propria. Together the transitional epithelium and lamina propria comprise the mucosal lining. There is then an inner longitudinal layer of muscle followed by a circular layer. These work in unison to create the peristaltic wave that transports urine down the ureter and into the bladder. Some have described an addition longitudinal layer of muscle. The outermost layer is the adventitia which surrounds the plexus of blood vessels and lymphatics that travel along the ureter.[1,17]

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