

The Urinary System

The kidneys are the major organs of excretion. Metabolic wastes, toxins and excess ions are removed in the urine. The urinary system also includes the ureters, the urinary bladder and the urethra.

Gross Anatomy

The kidneys lie between the dorsal body wall and the parietal peritoneum. They receive some protection from the lower part of the rib cage. The right kidney is crowded by the liver and lies slightly lower than the left. The indented area of the medial surface is called the renal hilus and is where the ureters, renal veins and arteries, lymphatics, and nerves join the kidney. There are three supportive layers of the kidney:

- the renal capsule, a transparent membrane adhering to the outside of the kidney and is continuous with the covering of the ureter.
- the adipose capsule that cushions the kidney
- the renal fascia, the outermost layer of dense fibrous connective tissue that anchors the kidney to surrounding tissue

Internally, the kidney is divided into three regions (superficial to deep):

- the renal cortex
- the renal medulla which contains the renal pyramids (8 to 18 per kidney) made up of urine-collecting tubules. Between the pyramids are the renal columns which are inward extensions of cortical tissue.
- The renal pelvis, a funnel-shaped tube continuous with the ureter leaving the hilus. Internally, the pelvis branches to form two or three major calyces each of which subdivide to form several minor calyces. Each minor calyx drains the papilla of a pyramid.

Urine flows from the renal pyramids out of the papillae to the minor calyces, to the major calyces, to the renal pelvis, out of the kidneys through the ureters to the urinary bladder, and through the urethra to the outside of the body at the urinary meatus. The walls of the calyces, pelvis and ureter contain smooth muscle which propels the urine by peristalsis.

Subbranches of the renal artery called the arcuate arteries form an arch over the renal pyramids. From these radiate the interlobular arteries that supply the renal cortex. Approximately 1/5 of the blood pumped by the heart flows through the kidneys each minute.

Nephrons

Nephrons are the structural and functional units of the kidneys. Over one million nephrons are in each kidney. The nephron consists of a glomerulus, a knot of capillaries containing arterial blood. The capillaries are both fed and drained by arterioles, the afferent and efferent arteriole respectively. Fitting overtop of this ball of capillaries is the Bowman's capsule. Together, the glomerulus and the Bowman's capsule are referred to as the renal corpuscle. The external layer of the Bowman's capsule consists of simple squamous epithelium. The inside endothelial layer consists of branching epithelial cells called podocytes that cling to the basement membrane of the glomerulus. This makes a very porous layer allowing the filtrate to pass into the renal tubule. The renal tubule has three parts: the proximal convoluted tubule, the loop of Henle (descending, then ascending), and the distal convoluted tubule. The efferent artery forms a fine network of vessels called the peritubular capillaries around the renal tubule before emptying into an interlobular vein.

Urine Formation

There are three processes involved in the formation of urine:

1. Golmerular filtration. This is a passive, nonselective process in which hydrostatic pressure forces fluids and dissolved substances across the endothelium capsular membrane (or filtration membrane) surrounding the glomerulus. This is possible because the membrane is vastly more permeable to water and solutes and because the pressure in the capillaries is about three times the pressure of normal capillaries. Although small molecules pass freely through the membrane, large molecules such as protein, and blood cells are retained in the capillaries. The rate of glomerular filtration is kept relatively constant by a number of regulating mechanisms including sympathetic nervous system control of arterial smooth muscle and the renin-angiotensin mechanism. This latter mechanism involves the juxtaglomerular cells, large smooth muscle cells located in the afferent

arteriole. When stimulated, by a drop in blood pressure for example, these cells release an enzyme called rennin. Renin acts on a plasma protein called angiotensinogen which is made by the liver and the nephron itself. Angiotensinogen is converted to angiotensin I which in turn is converted to angiotensin II by the angiotensin converting enzyme (ACE) found in the capillary endothelium of various body tissues (especially the lungs). Angiotensin II is a very potent vasoconstrictor causing an increase in arterial blood pressure. ACE inhibitors are common drugs used for controlling blood pressure.

2. Tubular Reabsorption. The glomerular filtration rate is about 125 ml/min or 180 L/day but only 1% of this becomes urine. By far, most of what was removed by glomerular filtration is selectively reabsorbed into the peritubular capillaries beginning in the proximal convoluted tubule. Reabsorption may be passively or actively transported out of the tubular cell and some reabsorption is under hormonal control. Most ions and virtually all organic nutrients such as glucose and amino acids are completely reabsorbed. Many substances are retained in the tubules particularly nitrogenous wastes from protein and nucleic acid metabolism such as urea (about 50%), all creatinine and uric acid. By the time the distal convoluted tubule is reached, only 25% of the water is retained in the tubule.
3. Tubular Secretion. Kidney tubules secrete a number of ions, particularly H^+ , K^+ , and NH_4^+ , and other substances such as creatinine, urea and uric acid (and some drugs), into the filtrate. This eliminates some urea and uric acid that has been reabsorbed passively, and also regulates the blood pH (blood pH = 7.35 – 7.45). If the pH drops too low, more HCO_3^- is reabsorbed. The pH of urine itself is normally slightly acidic but varies from 4.5 to 8. Acidic urine discourages bacterial growth.

Diuretics are chemicals that enhance urinary output.

The ureters, about 10 – 12 inches long, convey the urine from the kidneys to the bladder by smooth muscle peristalsis (and gravity). They enter the bladder through the posteroinferior wall. The two ureter openings together with the urethral opening form an area of the bladder called the trigone. The bladder is lined on the inside with mucosa and on the outside by a fibrous layer. Between them is a thick muscular layer called the detrusor muscle consisting of smooth muscle fibers arranged in different planes. The urethra conveys the urine to the outside of the body. In the female it is about 3 – 4cm long. The external urethral meatus lies in the vestibule of the vagina between the vaginal opening and the clitoris. The male urethra is about 20cm and is divided into three sections: the prostatic urethra (2.5cm) runs within the prostate gland, the membranous urethra (2cm) runs from the prostate to the penis, and the penile urethra (15cm) passes through the penis to the external urethral meatus at its tip.

Micturition (=urination) is controlled by two muscular sphincters – the internal sphincter (involuntary) found at the point where the urethra leaves the bladder, and the external sphincter (voluntary), which surrounds the membranous urethra in the male and about midway along the urethra in the female. When about 200ml of urine have accumulated in the bladder, stretch receptors in the bladder wall are stimulated and impulses are sent to the pons where micturition reflexes are initiated contracting the detrusor muscle and (if convenient) urine is expelled. Involuntary expulsion of urine is referred to as incontinence.