CHAPTER 25: THE URINARY SYSTEM

The function of the urinary system is the maintenance of homeostasis through the removal of waste products from the metabolism of nutrients in body cells, including carbon dioxide and excess water and heat. The urinary system maintains homeostasis by controlling the composition and volume of blood. It does so by removing and restoring selected amounts of water and solutes. Urinary system is sometimes called the excretory system because waste removal is its primary function. Other body systems process/eliminate wastes, but that is not their primary job. The metabolic process in all body cells produces various by-products, including toxic nitrogenous wastes such as ammonia and urea from the catabolism of proteins. Also, many essential ions, such as sodium, chloride, sulfate, phosphate and hydrogen tend to accumulate in excess of the body’s needs.

ORGANS OF THE URINARY SYSTEM

The urinary system consists of a pair of kidneys, two ureters, one bladder and one urethra. The functional unit of the kidney is the nephron, which consists of a (1) glomerular (Bowman’s) capsule, (2) proximal convoluted tubule (PCT), (3) loop of Henle, (4) distal convoluted tubule (DCT) and collecting duct. There are between 500,000 - 1,000,000 nephrons in each kidney.

(1) Kidneys

Paired reddish, kidney bean-shaped organs found above the waist between the parietal peritoneum and the posterior wall of the abdomen (retroperitoneal). The kidneys are located between 12th thoracic and 3rd lumbar vertebrae. Right kidney is slightly lower than the left due to the large area occupied by the liver. Average adult kidney measures 10-12 cm (4-5") long, 5-7.5 cm (2-3") wide and 2.5 cm (1") thick. Hilus is an indentation near the center of the concave border of the kidney. It is the exit point of the ureter and entry/exit point of nerves, blood vessels and lymph vessels. The hilus is the entry point to a cavity in the kidney termed the renal sinus. The renal pelvis is a flat, funnel-shaped tube that is continuous with the ureter. Three layers of tissue surround each kidney: (1) renal capsule, (2) adipose capsule and (3) renal fascia. Two layers of internal structure, the cortex and the medulla, form the parenchyma of the kidney.

The cortex is a smooth textured area extending from the renal capsule to the bases of the renal pyramids of the medulla. Extensions of the cortex create the renal columns, which dip into the medulla between the pyramids. The glomerular (Bowman’s) capsules of the nephrons are located here. The renal medulla has a striated appearance due to presence of 8-18 renal (medullary) pyramids. The straight tubules and blood vessels associated with the pyramids provide the striped appearance. The broader bases of the pyramids face the cortical region of the kidney and their apices, called renal papillae, are directed towards the center of the kidney. Collecting ducts and loops of Henle are located in the medulla. The inner edge of the medulla joins a large cavity called the renal pelvis, which connects to the ureter. The pelvis is divided into two or three major calyces and they subdivide to form the minor calyces, which enclose the papillae of the pyramids and collect urine.

(2) Ureters

Ureters are extensions of the pelvis of each kidney that enter the bladder at the superior lateral angle fit its base. They are retroperitoneal. Ureters have no valves. Rather they respond to bladder pressure since they pass underneath the bladder. Pressure building up in the bladder prevents backflow during urination. Principal function of the ureters is to transport urine from the renal pelvis to the bladder, but hydrostatic pressure and gravity also contribute to urine movement. Peristaltic waves pass from the kidney to the bladder at a rate varying from 1 to 5/minute depending on the
amount of urine formation. The walls of the ureters have three layers of tissue: (1) mucosa, (2) muscularis and (3) a fibrous coat.

(3) Urinary bladder

A hollow muscular organ situated in the pelvic cavity posterior to the symphysis pubis. The bladder is anterior to the rectum in the male and to the vagina in the female. It is a freely movable structure held in position by the folds of the peritoneum. Shape of the bladder depends on amount of urine contained within its structure at that particular moment. When empty, the bladder looks like a deflated balloon. When full it becomes spherical. The trigone is a small triangular area at the base of the bladder that is formed by the urethral opening and the openings of the ureters. When empty the bladder wall folds to form rugae, but when the bladder fills the rugae smooth out and disappear. The position of bladder changes as it fills. It rises in the abdominal cavity as it fills. Four coats make up the wall of the bladder: (1) mucosa, (2) submucosa, (3) muscularis (detrusor coat) and (4) serous coat.

(4) Urethra

A small, thin-walled muscular tube extending from the urinary bladder to the body exterior. In the male it serves a dual function providing for the passage of both urine as well as semen. In females it serves only a urinary function. In females its location is posterior to the symphysis pubis, embedded in the vaginal wall. The length in the female is approximately 3.8 cm (1-1/2 inches) and in the male it is about 20 cm (8 inches). The urethra is the terminal portion of the urinary system. The internal urethral sphincter is a portion of the detrusor muscle (a circular muscle) of the bladder that surrounds the bladder neck at the junction of the urethra.

URINARY PHYSIOLOGY

The functional unit of the kidney is the nephron. The term renal corpuscle (renal capsule) refers to the glomerular capsule, plus its capillary (glomerular) tuft. The tubules and blood vessels associated with the nephrons form structures called renal pyramids, which are located in the medullary layer of the kidney. The collecting tubules pass through the renal pyramids and open into minor calyces at the renal papillae as the papillary ducts. Minor calyces empty into major calyces, which in turn empty into the renal pelvis.

Each nephron is associated with a glomerular capillary bed that produces filtrate and a peritubular bed that reclaims most of the filtrate. Afferent arterioles from the interlobular arteries feed into the nephron's glomerular tuft. They have a larger diameter than the efferent arterioles so there is a pressure system similar to that of the lymph nodes. There are two types of nephrons: (1) cortical and (2) juxtamedullary.

The capsular portion of a nephron starts as a double-walled cup called the glomerular (Bowman's) capsule, which lies in the cortex of the kidney. Outer wall of capsule is called the parietal layer and consists of simple squamous epithelium. Space called capsular space separates this layer from the inner layer. The inner layer is called the visceral layer and consists of epithelial cells called podocytes. The inner layer surrounds a capillary network called the glomerulus. The visceral layer of the capsule and the endothelium of the glomerulus form an endothelial-capsular membrane. The endothelial-capsular membrane filters water and solutes in the blood. Large molecules (such as proteins and the formed elements of blood) do not normally pass through the endothelial-capsular membrane. The water and solutes that are filtered out of the blood pass into the capsular space between the visceral and parietal layers of the glomerular capsule and then into the renal tubule. The tubular portion of a nephron consists of: (1) the PCT, (2) the loop of Henle, (3) the DCT and (4) the collecting ducts.
The arteries that supply the kidneys are (in order) the: (1) renal arteries, (2) segmental arteries, (3) lobar arteries, (4) interlobar arteries, (5) arcuate arteries, (6) interlobular arteries, (7) afferent arterioles and (8) efferent arterioles. Veins are subdivided like the arteries, but more or less in reverse. The renal vein joins the inferior vena cava in the abdominal cavity.

The juxtaglomerular apparatus (JGA) consists of the (1) the macula densa (MD) cells, which are associated with the DCT and the (2) the juxtaglomerular (JG) cells, which are part of the wall of the afferent arteriole. The macula densa (MD) associated with the distal convoluted tubule contains chemoreceptors and osmoreceptors that respond to solute concentration of the filtrate in the DCT. Juxtaglomerular cells are large smooth muscle cells with prominent secretory granules containing renin. This system helps regulate renal blood pressure. When arterial blood pressure falls, juxtaglomerular cells release renin into the blood. Release of renin triggers a series of enzymatic reactions that produce angiotensin I, which is converted to angiotensin II by angiotensin-converting enzymes (ACE) in the lungs and plasma. Angiotensin II is a potent vasoconstrictor and also stimulates the thirst center located in the hypothalamus. Renin also stimulates the adrenal cortex to produce aldosterone, which enhances renal reabsorption of Na⁺ and encourages the posterior pituitary to release ADH, thereby increasing water retention. Increasing water retention means that ADH helps increase blood volume and blood pressure. Aldosterone, Angiotensin II and ADH all work to increase blood pressure and volume. ANP (atrial natriuretic peptide) provides homeostatic regulation of this system by lowering blood pressure. It works by regulating sodium levels.

Physiology of the nephron consists of: (1) glomerular filtration, (2) tubular reabsorption and (3) tubular secretion.

- (1) Glomerular filtration involves a relationship between endothelial pore size and the size of the available solutes. Endothelial pores restrict size of materials that can pass through the membrane into the capsule. The basement membrane permits passage of smaller molecules and restricts flow of larger ones. The filtration slits are located between the pedicels of the podocytes and are only 6–9 nm wide. The efferent arteriole is much smaller in diameter than the afferent, so resistance to outflow is created. Consequently, the blood pressure is higher in the glomerular capillaries than in other capillaries (60 mm Hg, compared to 30 mm Hg elsewhere). Hydrostatic pressure (blood pressure, in this case) in the glomerulus tends to move fluid out of the glomeruli. Capsular hydrostatic pressure opposes filtrate movement and some filtrate is pushed back into the capillary. This occurs because when the filtrate is forced out of the glomerular capillaries into the space between the walls of the glomerular capsule it meets with two forms of resistance: (1) the walls of the capsule and (2) the fluid that has already filled the renal tubule. As a result, some filtrate is pushed back into the capillary.

- (2) Tubular reabsorption is the movement of the filtrate through the epithelium of the renal tubules into the blood of the peritubular (or vasa recta) capillaries. The amount of filtrate that flows out of all the glomeruli every minute is called the glomerular filtration rate (GFR). In a normal adult, this is 180 liters (48 gallons) per day. Most is reabsorbed at a rate of 123-124 ml/min (178-179 liters/day). The movement of filtrate back into the blood of the peritubular capillaries is known as tubular reabsorption. Tubular reabsorption allows the body to retain most of its nutrients. Reabsorption is carried out by both passive and active transport mechanisms. Active transport of Na⁺ followed by passive transport of water molecules controls the process of tubular reabsorption. As Na⁺ is actively transported, water follows by osmosis. Active tubular reabsorption involves the movement of glucose, amino acids, lactate, vitamins and almost all ions (such as K⁺ and Na⁺) against an electrical and/or chemical gradient. Passive tubular reabsorption includes diffusion, facilitated diffusion and osmosis along an electrochemical gradient.
(3) Tubular secretion involves adding materials that were removed from the blood to the filtrate. Tubular secretion has two principal effects: (1) it rids the body of certain materials and (2) it controls the pH of the blood. A normal blood pH of 7.35-7.45 must be maintained. Since our diet varies, constant adjustments must be made. The renal tubules (primarily DCT) secrete acid-producing materials in the form of hydrogen and ammonium ions. Hydrogen ions stimulate the production of carbonic acid, using carbon dioxide diffused from peritubular capillaries. The hydrogen ion will bond with sodium to form a weak acid or salt of a weak acid that is eliminated in the urine. If blood pH is too acidic, it can be elevated by secretion of ammonium ions. Ammonia is a poisonous waste product from the deamination of amino acids. Ammonia is converted to urea by the liver. Urea and ammonia are part of the glomerular filtrate and are subsequently expelled from the body. When ammonia forms in the DC tubules and collecting tubules, it combines with hydrogen to form the ammonium ion. The cells secrete ammonia into the filtrate and it takes the place of a positive ion, usually sodium, in a salt and is eliminated.

Nephrons are regulated by (1) renal autoregulation and (2) neural controls. Renal autoregulation is accomplished by the juxtaglomerular apparatus and negative feedback mechanisms, which are triggered when the filtration rate is decreasing. Renal autoregulation kicks in when glomerular pressure falls. Extrinsic controls are from the sympathetic NS as well as from baroreceptors located in BV walls of the systemic circulation. Sympathetic activation results in the vasoconstriction of the afferent arterioles.

THE PRODUCT OF THE NEPHRON'S FUNCTION IS URINE

Volume per day approximately 1.5 L. Urine is 95% water. The yellow or amber-colored appearance of urine is caused by the presence of urochrome, which is a pigment by-product of the metabolism of bile. The color of urine can be affected by diet, such as the appearance of a reddish color when eating beets. The color can also be affected by water volume. The odor of urine may also vary. Ex: (1) asparagus adds methyl mercaptan that provides unique odor and (2) diabetics have fruity smelling urine. Stale urine has the smell of ammonia due to ammonium carbonate formation, which results from the bacterial metabolism of urea solutes. Normal urine is slightly acid (pH 5.0-7.8). It rarely becomes more acidic than 4.5 or more alkaline than 8.0. The variations in pH are related to diet. High protein diets increase acidity and vegetarian diets increase alkalinity. Specific gravity (ratio of weight of a volume of a substance to the weight of an equal volume of distilled water) of urine ranges from 1.008 to 1.030 depending upon the amount of dissolved solute present in the urine. Urine does not normally contain more than a trace of glucose, ketones, proteins, RBC's, WBC's, etc. Casts are tiny masses of material that have hardened and assumed the shape of tubule lumens. Casts are flushed from tubules by filtrate build up in back of them.

Micturition is urination. It occurs when approximately 200 ml of urine accumulates in the bladder, causing extension of the bladder walls. Micturition reflex centers are located in the sacral region of the spinal cord. When they receive impulses, parasympathetic fibers cause the detrusor muscles to contract and the sphincters to relax. As urine works its way into the urethra, afferent impulses are sent to the brain stem and cerebral cortex thereby creating the feeling of a need to void urine.
### DISORDERS/DISEASES

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<thead>
<tr>
<th>Disorder</th>
<th>Description</th>
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<tbody>
<tr>
<td>Anuria</td>
<td>Abnormally low urinary output per day (less than 50ml/day).</td>
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<tr>
<td>Cystitis</td>
<td>Bladder inflammation.</td>
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<tr>
<td>Diabetes insipidus</td>
<td>An injury (or tumor) in the hypothalamus or posterior pituitary results in the under production of ADH and therefore the overproduction of urine.</td>
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<tr>
<td>Hydronephrosis</td>
<td>Kinked ureter causes urine to back up into kidney. It can lead to necrosis.</td>
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<tr>
<td>Incontinence</td>
<td>Inability to control micturition.</td>
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<tr>
<td>Ptosis</td>
<td>Dropping of kidney due to loss of fatty tissue support. It is a big problem if/when ureter becomes kinked.</td>
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<tr>
<td>Pyelonephritis</td>
<td>Infection of renal pelvis and calyces. Can lead to infection of entire kidney.</td>
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<tr>
<td>Renal calculi</td>
<td>Kidney stones. Most are less than 5mm in diameter. Can have lithotripsy instead of invasive surgery for removal if not passed.</td>
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<tr>
<td>Urethritis</td>
<td>Inflammation of the urethra.</td>
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