Chapter 18 The Urinary System Renal Function

Chapter Outline

• Functions of the Urinary System
• Anatomy of the Urinary System
• Basic Renal Exchange Processes
• Regional Specialization of the Renal Tubules
• Excretion

18.1. Functions of the Urinary System

• Primary Functions
  o Regulate plasma ionic composition, plasma volume plasma osmolarity and plasma pH
  o Remove metabolic waste products and foreign substances from plasma

• Secondary Functions of the Kidneys
  o Secrete erythropoietin and renin
  o Activate vitamin D3 to calcitriol
  o Gluconeogenesis

18.2 Anatomy of the Urinary System

a. ___form urine.

b. ___ transport urine from kidneys to bladder.

c. ___ store urine.

d. ___ excrete urine from bladder to outside of body.

Anatomy of the Kidney (Figure 18.1)

Microscopic Anatomy of the Kidney (Figure 18.2)

• Nephron is the functional unit. It is composed of renal tubules. It functions in filtration of blood and form urine

• Both cortical/juxtamedullary nephrons produce   _______.
  o The cortical nephron (Figure 18.4a) is the most numerous, 80–85% with short loop of Henle
  o The juxtamedullary nephron (Figure 18.4b) contains long loop of Henle extends into medulla. It is responsible for establishment of the ________ _______ ________

Blood Supply to Kidneys (Figure 18.6a)

• Kidneys receive 20% of cardiac output at rest

• Renal artery→ segmented arteries → interlobar arteries → arcuate arteries → interlobular arteries→ afferent arterioles → capillary beds→ interlobular veins → arcuate veins → interlobar veins → segmented veins → renal vein

Nephron Blood Supply (Figure 18.6b)

• Two capillary beds: peritubular capillaries and vasa recta
Juxtaglomerular Apparatus (Figure 18.5)
- Two components: Macula densa and granular cells (juxtaglomerular cells)
- Function: ________________________________

18.3 Basic Renal Exchange Processes (Figure 18.7)
- Glomerular ________ is the bulk movement of protein-free plasma from glomerulus to Bowman’s capsule
- __________ is the selective transport of molecules from tubules to peritubular capillaries.
- __________ is the selective transport of molecules from peritubular capillaries to tubules
- __________ is the elimination of urine from tubules out of body

Three Exchanges Processes
- Glomerular filtration
- Reabsorption
- Secretion

Glomerular Filtration
- Location: ________ _______, which contains a glomerulus and a Bowman’s capsule.
- Filtration of small molecules is nonselective
- The filtrate in Bowman’s capsule is a mixture that mirrors the concentration of various solutes in the blood plasma
- Filtration membrane is composed of capillary _____________. basement membrane and __________ cell (podocyte). Large proteins cannot travel across the filtration membrane (basement membrane)
- Driving Forces for Glomerular Filtration
  o Starling forces favoring filtration
    ▪ Glomerular capillary hydrostatic pressure \( (P_{GC}) =60 \text{ mm Hg} \). It is high due to resistance of efferent arteriole
    ▪ Bowman’s capsule oncotic pressure \( (\pi_{BC}) =0 \text{ mm Hg} \). It is low due to lack of protein in filtrate
  o Starling forces against filtration
    ▪ Bowman’s capsule hydrostatic pressure \( (P_{BC}) =15 \text{ mm Hg} \). It is relatively high (compared to systemic capillaries) due to large volume of filtrate in closed space
    ▪ Glomerular oncotic pressure \( (\pi_{GC}) =29 \text{ mm Hg} \). It is higher than in systemic capillaries due to plasma proteins in smaller volume of plasma
  o Driving force of glomerulus filtration =Glomerular Filtration Pressure (______) (Figure 18.9a)= \( (P_{GC} + \pi_{BC}) - (P_{BC} + \pi_{GC}) = 16 \text{ mmHg} \).
- Glomerulus filtration rate (______) = the volume of filtrate produced by both kidneys/min (Figure 18.9)
  o Averages 115 ml/min in women; 125 ml/min in men
  o GFR =125 mL/min = 180 liters/day (45 gallons in men)
- Renal plasma flow = 625 mL/minute
- Filtration __________ is the fraction of the renal plasma being filtered. Filtration fraction=\( \frac{\text{GFR}}{\text{renal plasma flow rate}} \)
Filtered ______-is the quantity filtered of a solute per unit time= GFR x P_x

- **Filtered Load of Glucose (Figure 18.20)** = (125 mL/min) x (1 mg/mL) = 125 mg/min

**GFR highly regulated by intrinsic and extrinsic mechanisms**

- **GFP experience little changes between MAP 80-180 mmHg**
  - ↑ MAP beyond 180 mmHg, ↑GFP and GFR
  - ↓MAP< 80 mmHg, ↓ GFR

**Intrinsic Regulation of GFR: MAP: 80-180 mm Hg**

- **Myogenic regulation** is similar to the myogenic regulation of blood flow covered in Chapter 14. Smooth muscle of afferent arteriole is sensitive to pressure change (Figure 18.11 a). When the smooth muscle of the afferent arteriole stretches due to the increased MAP, vasoconstriction occurs.

- **Tubuloglomerular feedback** occurs when macula densa cells secrete paracrine in response to an increase in flow of fluid past them. Smooth muscle of arteriole contract in response to this paracrine to prevent significant changes in GFR (Figure 18.11b)

- **Mesangial cell contraction** is similar to myogenic regulation by modify smooth muscle cells around glomerular capillaries. ↑ BP ↑GFR stretches mesangial cells. Mesangial cells contact to decrease the surface area for filtration therefore ↓GFR

**Extrinsic Control of GFR (Figure 18.12): MAP : < 80 mmHg or > 180 mm Hg.**

- Sympathetic nerve activity regulates the activity of smooth muscle in the afferent and efferent arterioles via baroreceptor reflex (review chapter 14). An decreased MAP causes an increased sympathetic nervous activity

### Reabsorption (Figure 18.13)

#### Table 18.1 Filtration and Reabsorption Rate. Which molecule is reabsorbed at 100%? ______

- **Selective transport; renal tubules to interstitial fluid**
- **Most occurs in proximal tubule; some in distal convoluted tubule and in distal convoluted tubule**
- **Barriers for reabsorption (Figure 18.13)**
  - Epithelial cells of renal tubules: apical membrane and basolateral membrane
  - Endothelial cells of capillary (minimal): very permeable, barrier to macromolecules only
- **Mechanisms of Reabsorption (Figure 18.14)**
  - Active solute reabsorption: Eg. Na+
  - Passive water reabsorption
  - Passive solute reabsorption via diffusion: Urea

**Transport Maximum (Tm)=Rate of transport when all carriers and pumps are saturated**

**Renal Threshold =Solute in plasma that causes solute in filtrate to saturate carriers and spillover into urine**

**Mechanism of Glucose Reabsorption (Figure 18.15)**

- Freely filtered at glomerulus
- Normally 100% actively reabsorbed in proximal tubule
- Carrier proteins for glucose reabsorption
  - Apical membrane: ____________with sodium by secondary active transport
Basolateral membrane: facilitated diffusion

Glucose Renal Curve (Figure 18.16)
- Transport maximum for glucose reabsorption = 375 mg/min
- Theoretical renal threshold = 300 mg/dL
- Actual renal threshold = 160–180 mg/dL
- Filtered load = 225 mg/min

Secretion
- Solute moves from peritubular capillaries into tubules
- Barriers same as for reabsorption
- Transport mechanisms same but opposite direction
- Secreted substances: potassium ions, hydrogen ions, choline, creatinine and penicillin

Table 18.2
- Most of small organic molecules such as amino acids and vitamins are reabsorbed at ____________;
- Ions are NOT reabsorbed at______________.
- Which tubule segment does not secrete anything? ________________
- Which ions are secreted? __, ___;
- H+ is only secreted at______.
- Water is not reabsorbed in______ __ ______.

18.4 Regional Specialization of Renal Tubules
- Specific regions perform special functions
- Nonregulated reabsorption in proximal tubule
- Regulated reabsorption and secretion in the distal tubule and collecting duct
- Water conservation in the Loop of Henle

Proximal Tubule Reabsorption (Figure 18.17 a)
- Proximal tubule is the ______ _________. 70% water and sodium, 100% glucose that is filtered, is reabsorbed here. Reabsorption is not regulated.
- Anatomic features that support mass absorption
  - Brush border with extensive microvilli provides for large surface area
  - There are a large number of mitochondria in transport cells
  - Leaky tight junctions allow paracellular transport

Distal Tubule and Collecting Duct (Figure 18.17b)
- Transport can be ________ across epithelium since tight junctions limit paracellular transport

Water Conservation due to Loop of Henle
- Loop of Henle establishes ______ ______in the medulla that is necessary to concentrate urine to conserve water.
18.5 Excretion

Excretion Rate

- Amount of substance excreted = amount filtered + amount secreted – amount reabsorbed

Basic Renal Processes (Figure 18.18)

Renal Handling of Solute

- If amount of solute excreted per minute is less than filtered load → solute was __________
- If amount of solute excreted per minute is greater than filtered load → solute was secreted

Clearance is the volume of plasma from which a substance has been removed by kidneys per unit time (Volume of plasma that contains the amount of a substance that has been excreted per unit time)

Clinical uses of Clearance = excretion rate/plasma concentration = \( \frac{U_x \times V}{P_x} \)
- \( U_x \): substrate concentration in urine
- \( V \): flow rate
- \( P_x \): substrate concentration in the plasma

Estimate of GFR: Use of Inulin (Figure 18.19)

- ________ is a polysaccharide commonly used by researcher to estimate GFR. It is injected to the blood stream. Inulin is freely filtered and neither reabsorbed nor secreted = GFR
- Amount of inulin excreted in urine = amount that was filtered = filtered load
- Excretion rate = Filtered load = GFR \( \times P_i \)

Estimate GFR: Use of Creatinine

- ________ is by-product of muscle metabolism. It is used clinically. It is freely filtered, not reabsorbed and small amount secreted. Therefore clearance is a little greater than GFR, 140 mL/min

Renal Blood Flow (Figure 18.20)

- ________ (para-aminohippuric acid): a molecule used clinically to measure renal blood flow
- Clearance = measure of renal plasma flow. Convert plasma flow to blood flow: Blood is 55% plasma

\( C_{PAH} = 625 \text{ml/min} \)

Determining Fate of Solute in Renal Tubules

- If \( C_x > \text{GFR} \), then substance was ________
- If \( C_x < \text{GFR} \), then substance was reabsorbed

Micturition (Figure 18.21)

- Micturition = urination
- Urine formed in renal tubules → renal pelvis → ureter → bladder → excreted

Micturition Reflex (Figure 18.22)

The micturition reflex is overridden by voluntary control. Descending pathways from the cerebral cortex can inhibit parasympathetic neurons and stimulate motor neurons that excite the external urethral sphincter and thus inhibit the micturition reflex.

Keep Your Kidneys Healthy

- National Kidney Disease Education Program
- Cleveland Clinic: Urine Color
- Mayo Clinic: Water Intake