Chapter 9

Excretion and the Interaction of Systems

Goals for This Chapter

1. Describe the function of the kidney in excreting wastes and expelling them into the environment
2. Identify the main structures and functions of the human excretory system
3. Explain the function of the nephron
4. Describe how the kidneys maintain homeostasis with respect to water and ions
5. Relate the design of dialysis technologies to the design of the kidney

Excretion of Wastes

- Excretion is the process of separating wastes from the body fluids and eliminating them
- The respiratory system (lungs) and the skin (sweat) are both involved in excretion
- Your liver metabolizes (breaks down) toxic blood compounds and prepares them for excretion by the kidneys
- However, the elimination of solid food residue (feces) by the large intestine (colon) is not considered to be excretion

Urinary System Intro CC

TedX - Intro

The Role of the Liver

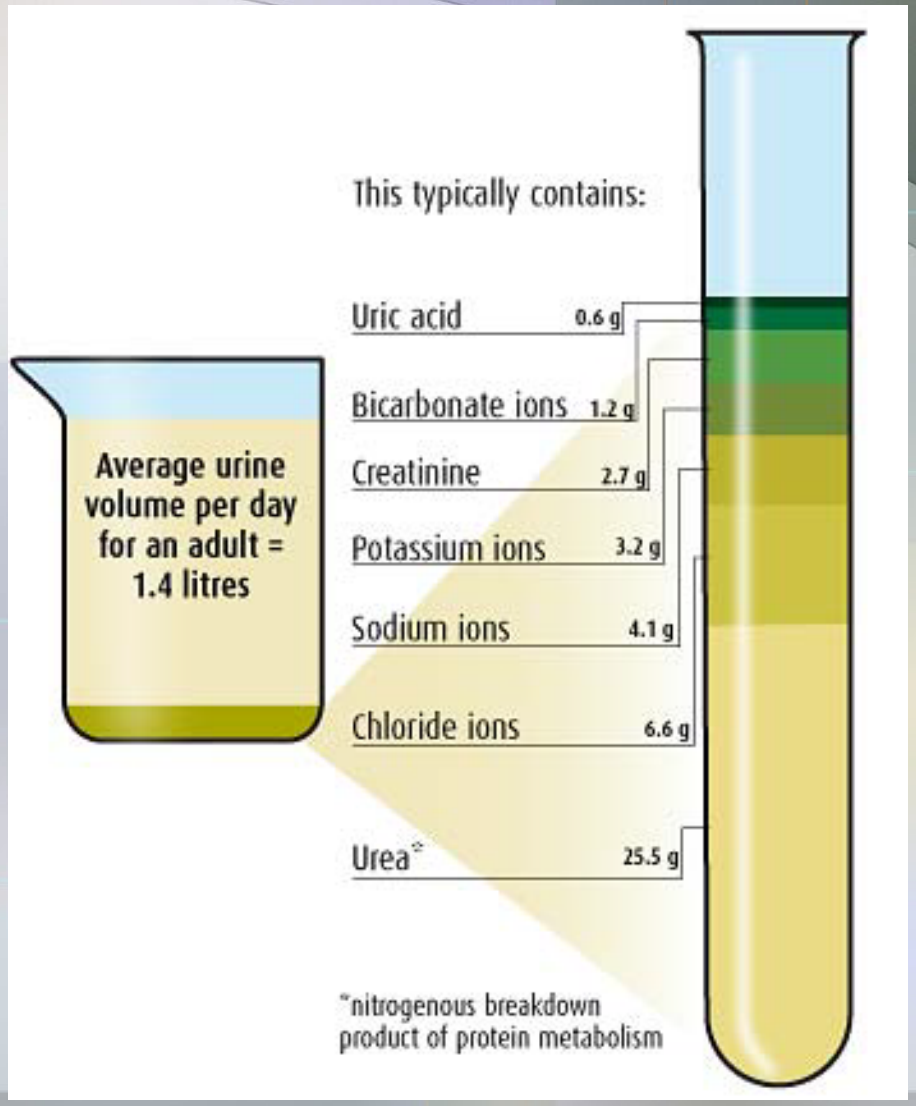
- Our liver cells break down complex compounds into simpler ones
- Many of the simple compounds can be toxic – therefore must be excreted
- Protein contains nitrogen. The amino group (NH_2) must be excreted from the body.
  - The liver begins this process by converting NH_2 to ammonia (NH_3). This is referred to as **deamination**.
  - The liver then combines this ammonia (water soluble toxic gas) with carbon dioxide to form urea (much less toxic)
  - Uric acid is another waste product produced in the liver from the breakdown of nucleic acids, like DNA, for example.

The Importance of Kidneys

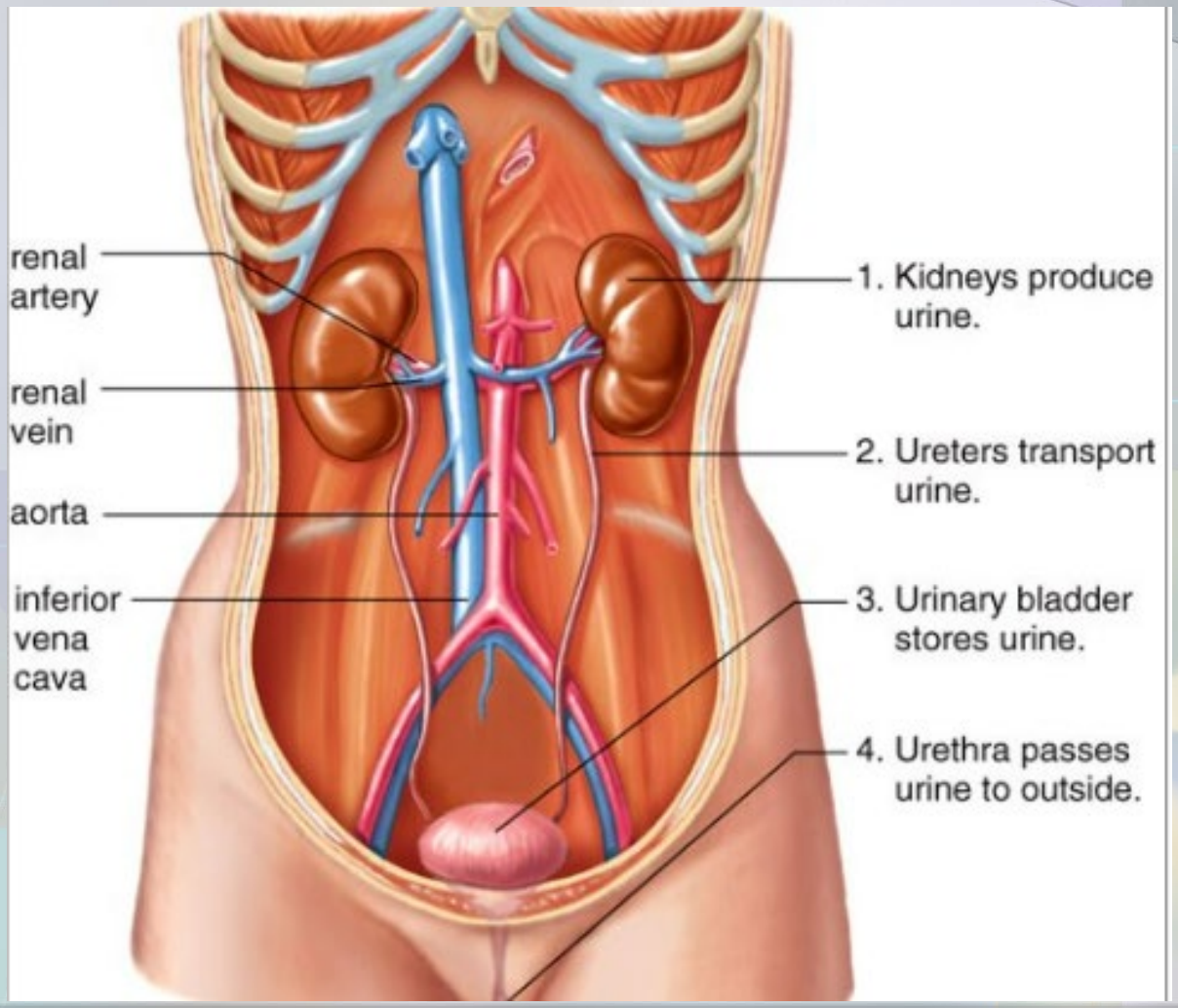
- The kidneys filter out the urea and uric acid from the blood to form urine (stored in the urinary bladder)
- The kidneys play a crucial role in filtering / removing waste
- Kidneys also balance blood pH and maintain water / salt balance.
  - more on this later!!

Composition of Urine

Waste drains out of the kidneys in the form of urine. Urine is about 95% water and 5% urea (from protein breakdown).
Fresh urine has no bacteria in it. It is quite sterile (probably cleaner than your hands).



The Urinary System



The Urinary System - Overview

- Renal arteries branch from the aorta and enter the kidneys
- Waste is filtered from the blood in the kidneys and sent to the bladder via ureters
- The urinary sphincter at the base of the bladder releases urine into the urethra, where it leaves the body

Urinary Organs

- Ureters
  - Conduct urine from kidney to bladder
  - Conveys urine by peristalsis
- Urinary bladder
  - Stores urine
  - Expandable
    - Middle layer of circular muscle – can constrict or dilate
  - 2 sphincters in bladder neck
    - Internal sphincter – smooth muscle
      - » Involuntary control
    - External sphincter – skeletal muscle
      - » Voluntary control

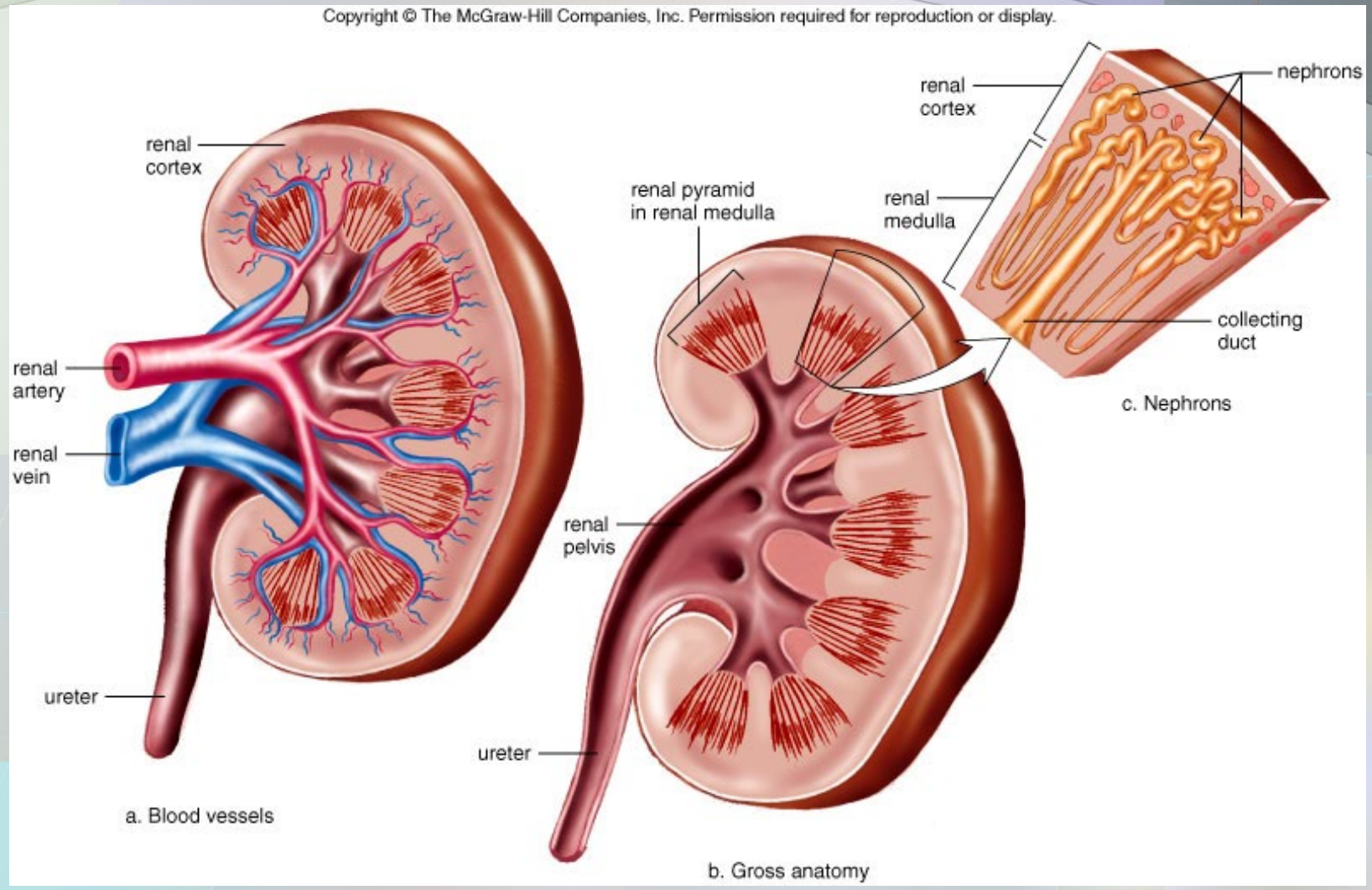
Urinary Organs

- Urethra
  - Conducts urine out of body
  - Very short in females
    - Increases likelihood of urinary tract infection
  - Longer in males
    - Prostate associated with urethra
    - Common pathway for reproductive and urinary tracts

The Kidney

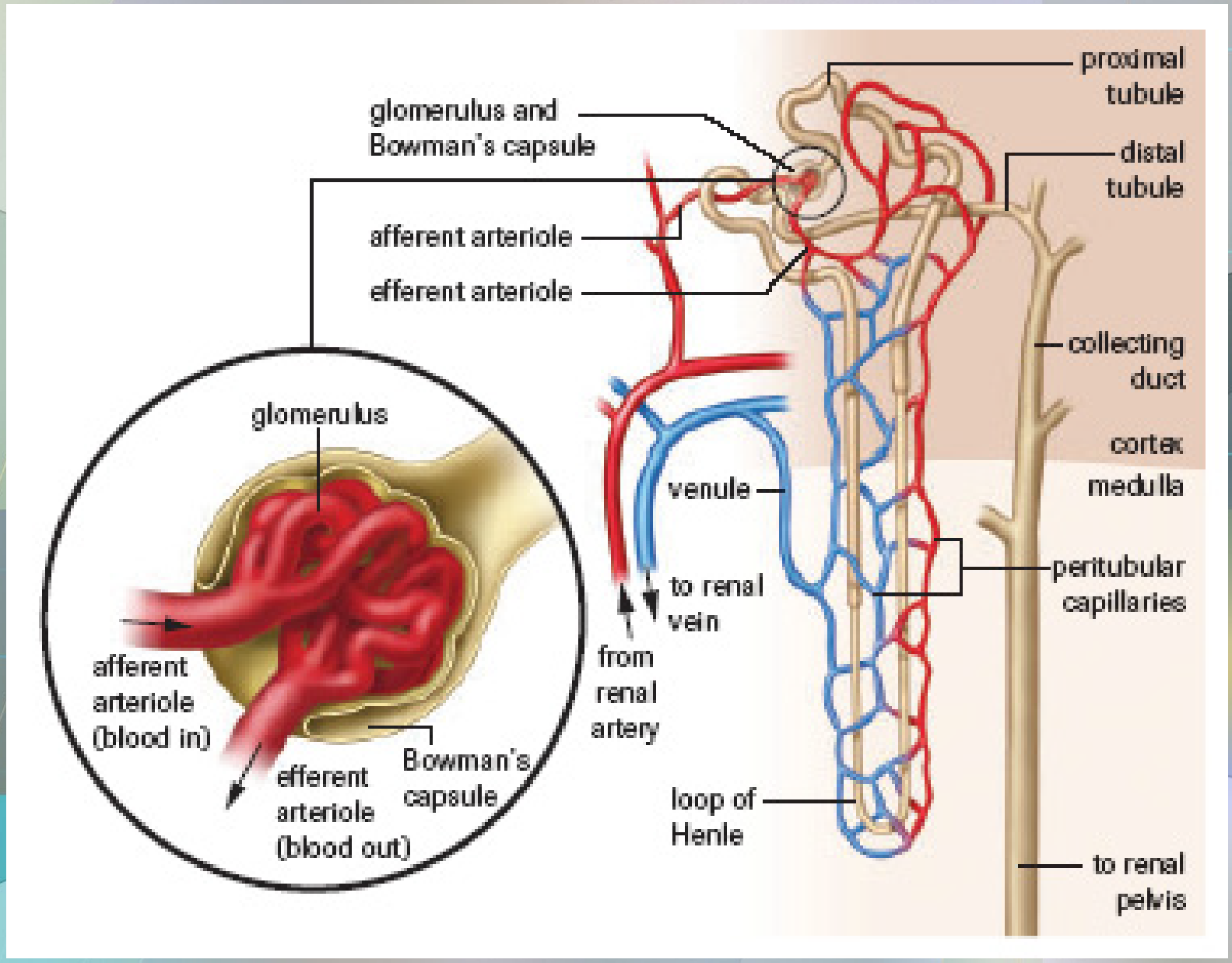
- The kidney has three different layers
- An outer layer, the **cortex**, encircles the kidney
- The inner layer, the **medulla**, is found beneath the cortex
- The **renal pelvis** is a hollow chamber which joins the kidney with the ureter

Gross Anatomy of the Kidney



Anatomy of the Kidney

- Nephron
  - Functional unit of kidney – filters blood
  - Approximately one million nephrons in each kidney
  - Each composed of a system of tubules
  - Each has its own blood supply
    - From renal artery, **afferent arteriole** leads into **glomerulus**
      - » Glomerulus – specialized capillaries
      - » Blood leaves glomerulus by **efferent arteriole**
    - Efferent arteriole takes blood to peritubular capillaries
      - » Surround rest of the nephron
      - » Blood then goes to renal vein


proximal tubule
glomerulus and Bowman's capsule
distal tubule
afferent arteriole
efferent arteriole
collecting duct
glomerulus
cortex
medulla
venule
peritubular capillaries
to renal vein
from renal artery
afferent arteriole (blood in)
Bowman's capsule
efferent arteriole (blood out)
loop of Henle
to renal pelvis

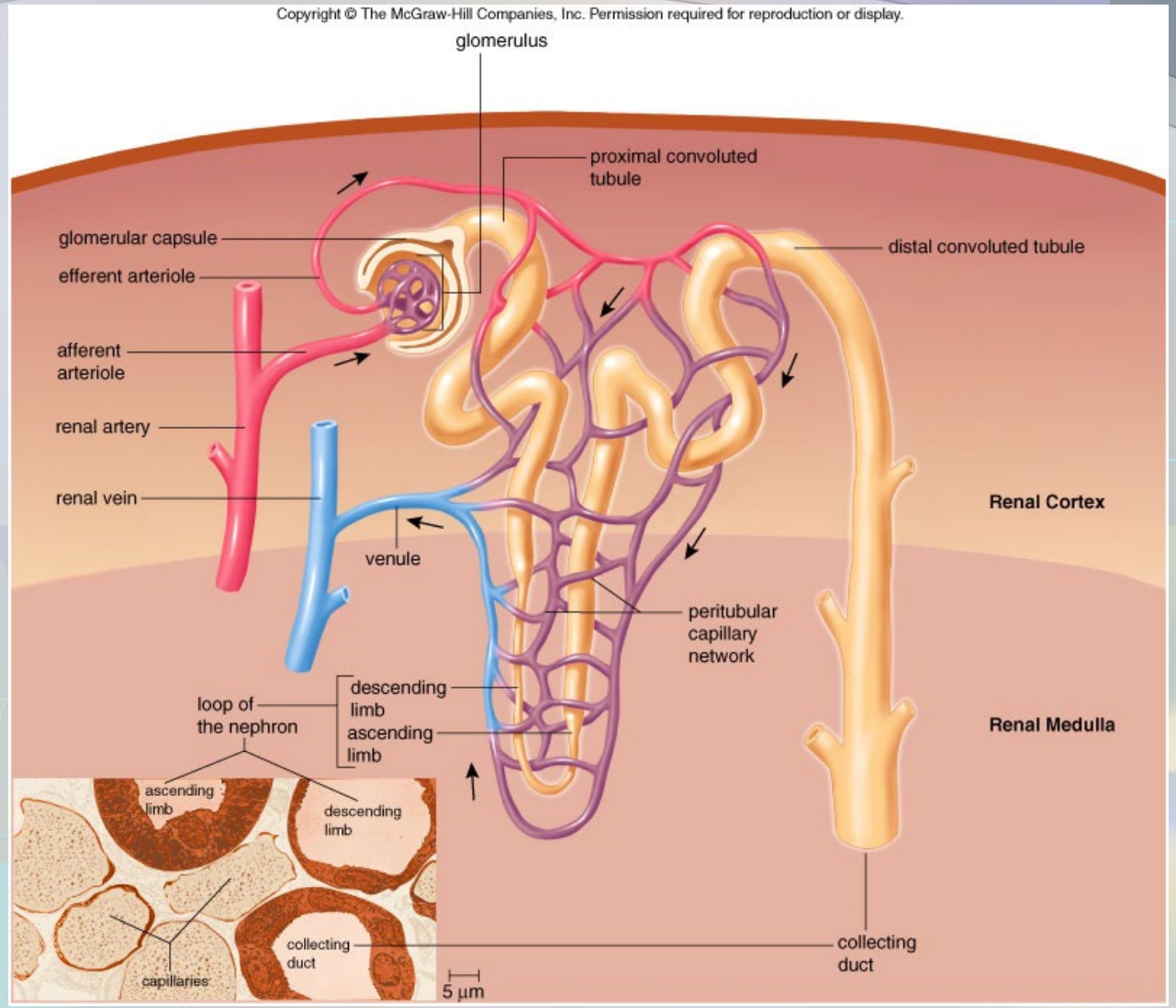
The Nephron

- **Nephron** parts
  - **Bowman's capsule** (aka Glomerular capsule)
    - Cuplike structure located in kidney cortex
    - Fluids to be processed into urine enter Bowman's capsule from the blood (major site of filtration)
  - **Proximal convoluted tubule** – PCT
    - located in kidney cortex
    - permeable to water, sodium, urea, and other solutes
    - Contains cells with microvilli
      - » Increased surface area for absorption

The Nephron

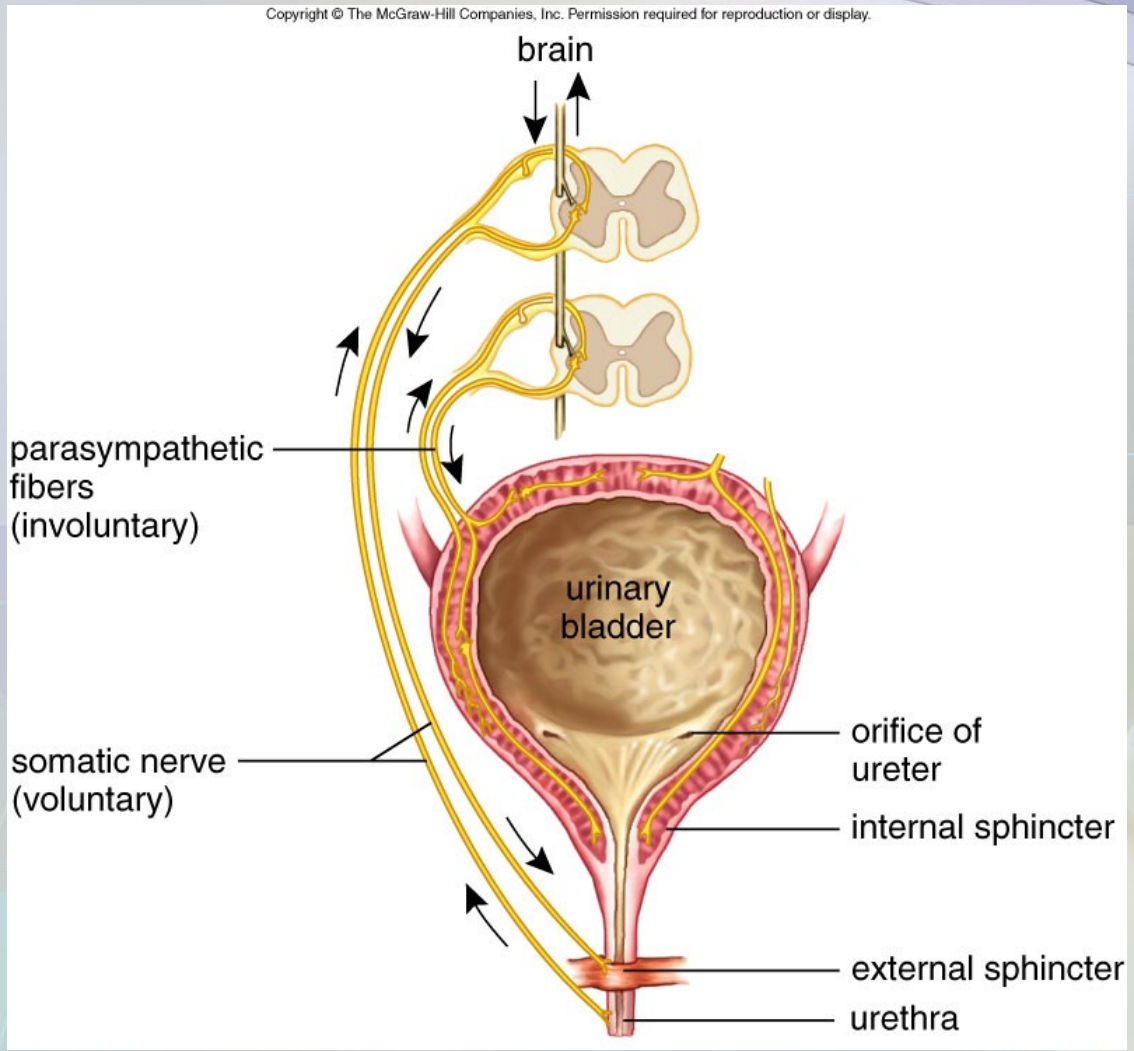
- **Loop of Henle**
  - U-shaped tube located in the renal medulla
    - **Descending limb** – permeable to water; NOT sodium
    - **Ascending limb** – lots of mitochondria (provide energy for active transport of wastes); permeable to urea & sodium, but NOT water
- **Distal convoluted tubule** – DCT
  - Located in kidney cortex
  - No microvilli – not permeable to water
    - reabsorb sodium and chloride ions
  - DCT's of several nephrons enter one collecting duct
- **Collecting ducts** empty into renal pelvis

Nephron Anatomy



[Kidney Review]

Urination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brain
parasympathetic fibers (involuntary)
urinary bladder
somatic nerve (voluntary)
orifice of ureter
internal sphincter
external sphincter
urethra

Bladder Volume

- At a urine volume of 200 mL, the bladder stretches and sends a message to the brain indicating that it needs to be emptied
- At 400 mL, a more urgent message is produced
- At a volume of 600 mL, the voluntary control of the bladder is lost, and it empties itself

Formation of Urine

- Formation of urine involves three functions:

1. Filtration
2. Reabsorption
3. Secretion

1. Filtration

- Blood moves into the glomerulus, which acts as a high-pressure filter
- Dissolved solutes pass through the walls of the glomerulus into Bowman's capsule, creating a filtrate similar to blood plasma
- Plasma proteins, platelets and erythrocytes do not pass into Bowman's capsule because they are too large to pass through the membrane

Solute	Glomerulus	Bowman's Capsule
water	yes	yes
sodium chloride	yes	yes
glucose	yes	yes
amino acids	yes	yes
hydrogen ions	yes	yes
urea	yes	yes
plasma proteins	yes	no
erythrocytes	yes	no
platelets	yes	no

2. Reabsorption

- About 120 mL of fluid per minute is filtered into the nephron – about 70% is reabsorbed back into the blood via the proximal convoluted tubule
- Reabsorption is required otherwise you would need to continually consume fluids to maintain homeostasis
- This is accomplished by active and passive transport

Reabsorption From Nephrons

TABLE 16.1 REABSORPTION FROM NEPHRONS

Substance	Amount Filtered (per day)	Amount Excreted (per day)	Reabsorption (%)
Water, L	180	1.8	99.0
Sodium, g	630	3.2	99.5
Glucose, g	180	0.0	100.0
Urea, g	54	30.0	44.0

L = liters, g = grams

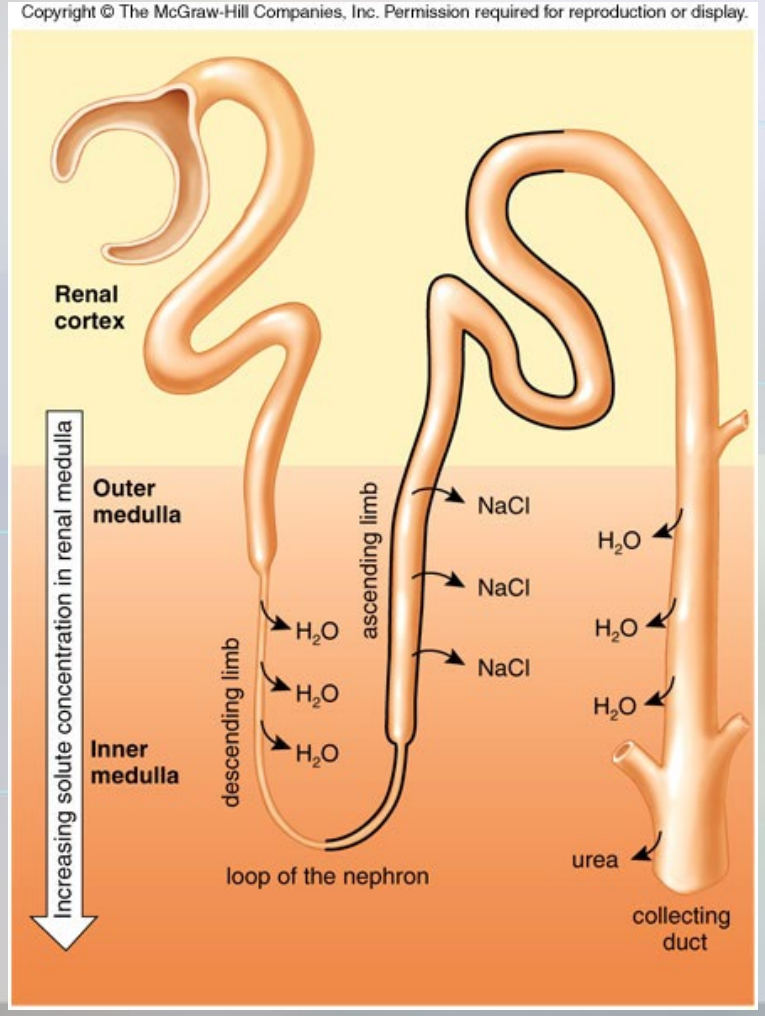
Man vs. Wild

2. Reabsorption

- A hormone called aldosterone (released from adrenal glands) stimulates Na^+ ions to be reabsorbed into the blood – via active transport – mostly in PCT (67%), ascending loop of Henle (25%), and a little in DCT (8%)
- For active transport, these cells have a large number of mitochondria to produce ATP (energy) to help reabsorb Na^+
  - Negative ions, like Cl^- and HCO_3^-, which are attracted to Na^+, then follow into the bloodstream via passive transport
  - The concentrated solutes in the blood create an osmotic pressure (concentration gradient) that pushes water back into the blood
- Glucose and amino acids are also reabsorbed into the blood by attaching themselves to carrier molecules
- This also increases osmotic pressure into the blood (more solutes in blood → water moves to blood)

Reabsorption of Water

[Amoeba Sisters Review]

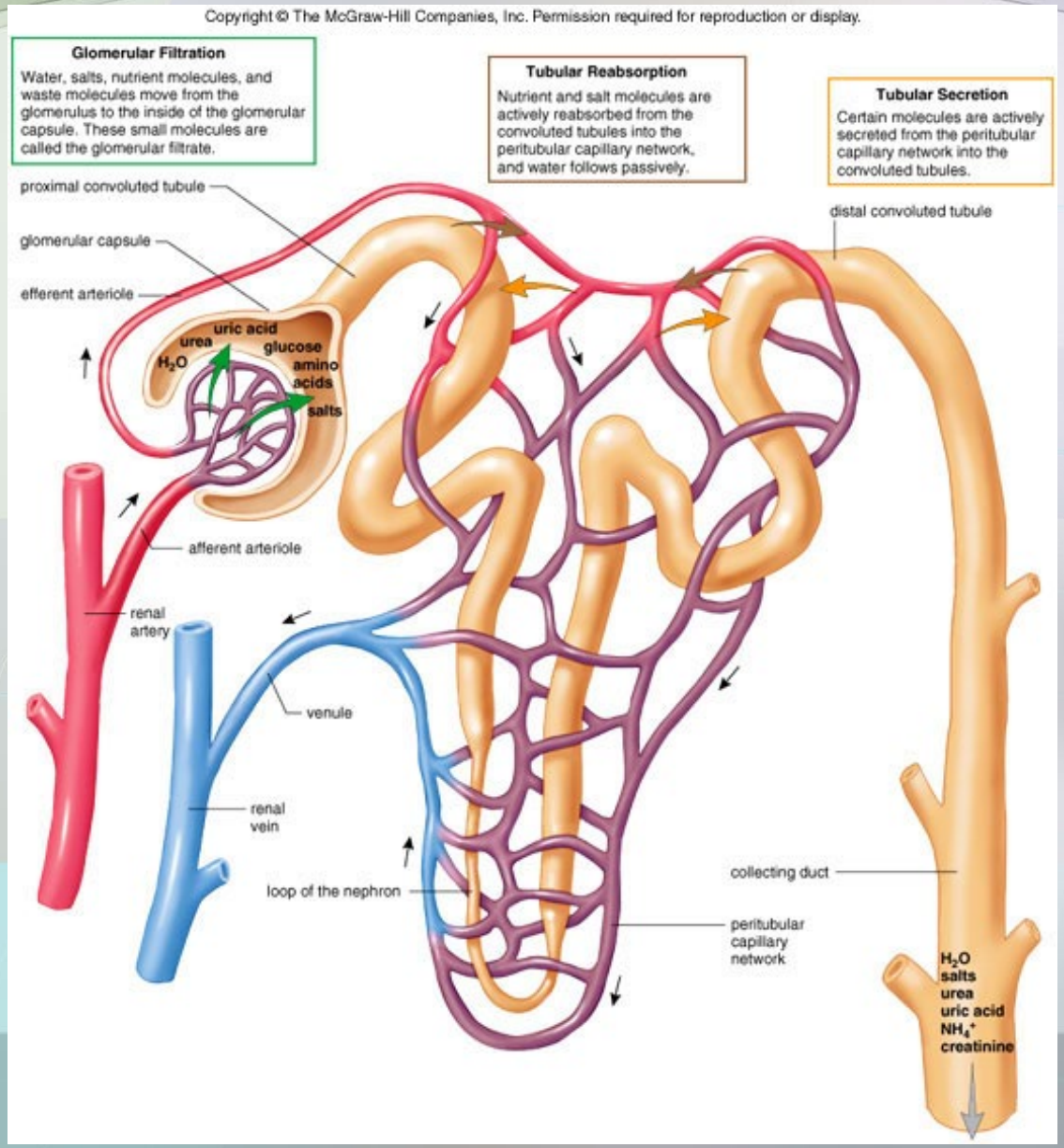


[CC Urinary System P1]

3. Secretion

- Secretion is the movement of wastes from the blood into the nephron
- Nitrogen wastes (urea), histamine, excess hydrogen ions, and mineral levels are balanced through secretion
- Secretion involves active transport, but molecules are moved from the blood into the nephron
- Occurs in PCT and DCT primarily (lined with mitochondria for energy)
- After reabsorption, there is some waste (among other materials to be excreted) still in blood.
- Need to get these back into the nephron – secretion
- Urine therefore contains filtered substances that have not been reabsorbed and those that have been actively secreted

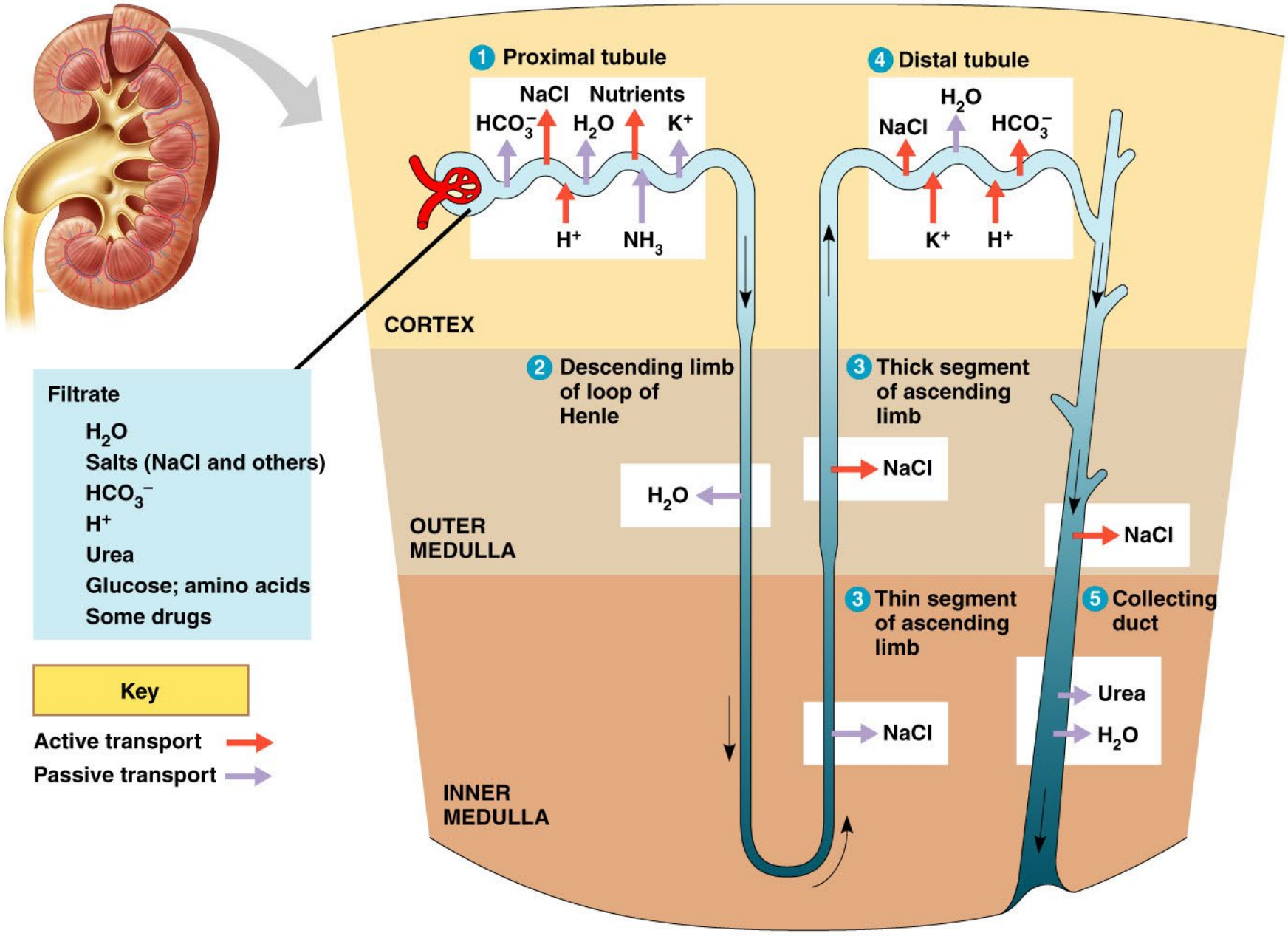
Processes in Urine Formation



[Urine Formation]

[Urinary System Recap]

[CC Excretory System]



Water Balance

- Increased water intake is adjusted for by increasing urine output
- The kidneys rely on the nervous and endocrine systems to help maintain a balance of water
- Involves two main hormones:
  - aldosterone: increases sodium reabsorption (indirectly increases water reabsorption)
  - ADH: increases water reabsorption (directly)

Regulating ADH

- ADH (antidiuretic hormone) – released from pituitary gland in brain – regulates the osmotic pressure in the kidneys to increase water absorption
- If ADH is released, more concentrated urine is produced
- ADH is released from the pituitary as the water from the pituitary cells leaves and they shrink (due to increased solute levels in the blood)
- The shrinking of pituitary cells also creates a sensation of thirst

ADH and the Nephron

- ADH makes the upper part of the distal tubule and collecting duct permeable to water
- This allows NaCl in the intercellular spaces to create an osmotic pressure that draws water from the tubule back into the blood
  - negative feedback loop!

Kidneys and Blood Pressure

- Kidneys regulate blood pressure by regulating blood volume
- Aldosterone acts on nephrons to increase Na^+ reabsorption
- If there is a decrease in blood pressure, aldosterone is produced, which increases Na^+ absorption and therefore brings more water into the blood, increasing its volume (and therefore, pressure)
  - negative feedback loop!

The Kidney-Heart Connection

- Kidneys can fail due to high blood pressure
- If the blood vessels in the kidneys are damaged due to high blood pressure, they lose their ability to filter wastes effectively
- Unfortunately, the symptoms of high blood pressure and kidney impairment to not appear until the damage has already been done

Regulating Kidney Output

- Diuretics – increase flow of urine
  - Alcohol
    - Shuts off ADH
    - Dehydration causes hangover
  - Caffeine
    - Increases glomerular filtration rate
    - Decreases reabsorption of sodium
  - Diuretic drugs
    - Many inhibit active transport of sodium at loop of Henle or DCT

Kidneys Regulating Blood pH

- The blood pH is maintained by acid-base buffer systems
- The most important acid-base buffer system is the following equation:

$$H^+ + HCO_3^- \Leftrightarrow H_2CO_3 \Leftrightarrow H_2O + CO_2$$

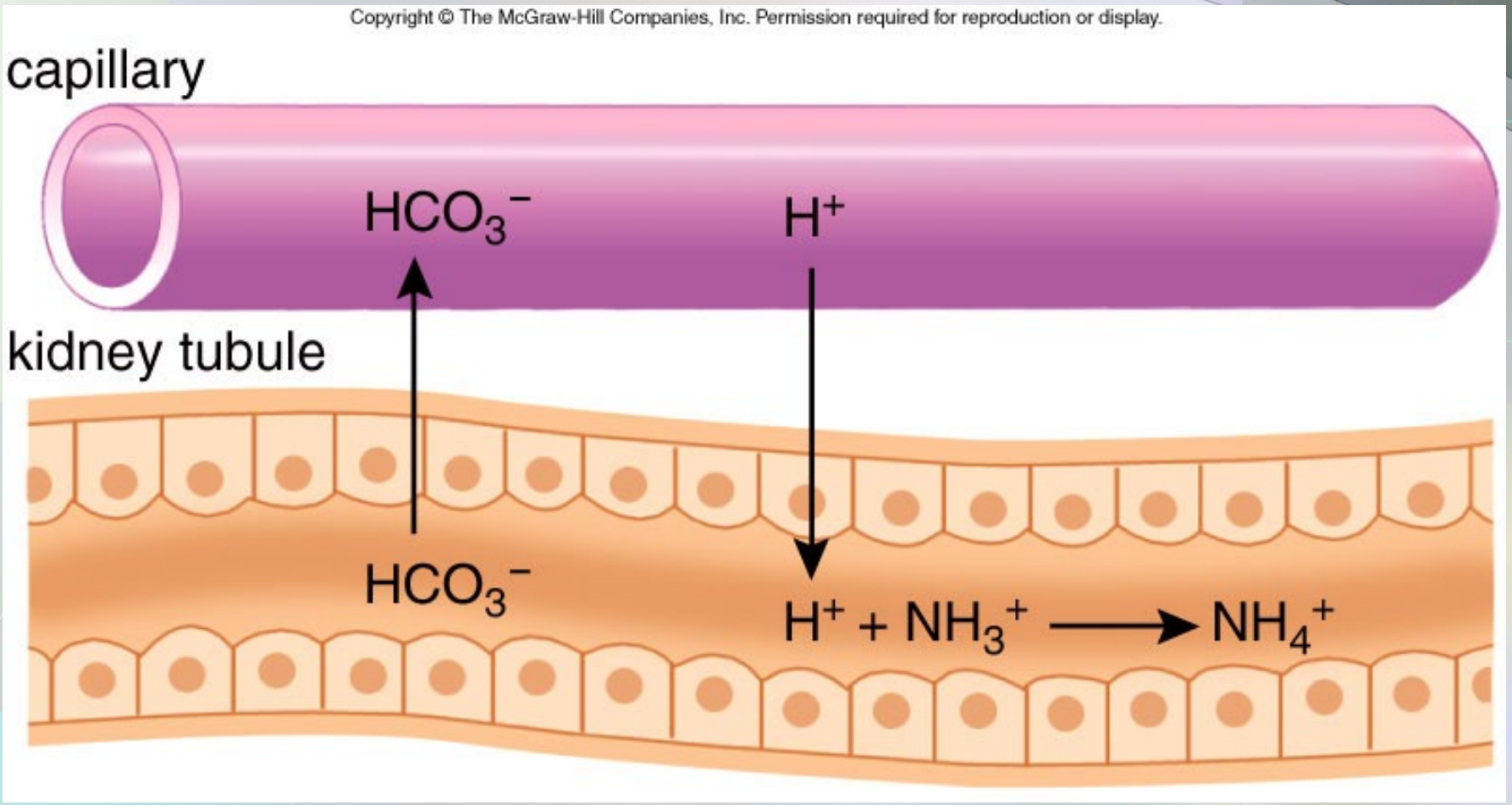
pH decreases

pH increases

Kidneys Regulating Blood pH

- The kidneys help to maintain this balance by balancing H^+ and HCO_3^-
- If the blood is too acidic, H^+ is excreted and HCO_3^- is reabsorbed and returned to the blood (and vice versa)
- Buffer system is basically the same as in respiratory system!
  - slower acting but more powerful

pH Balance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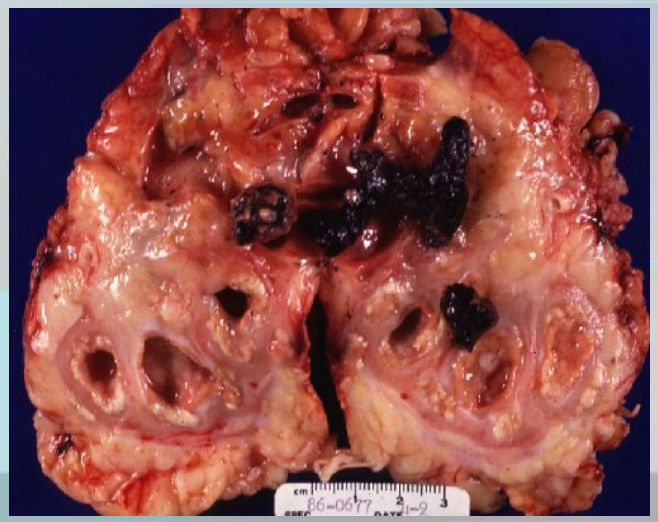
capillary
HCO_3^-
H^+
kidney tubule
HCO_3^-
$H^+ + NH_3^+ \longrightarrow NH_4^+$

Kidney Disorders

- Signs of kidney disease
  - Albumin (protein) in urine
  - Glucose in urine
  - Blood in urine
- Kidney stones
  - Caused by precipitation of minerals from blood
  - UTI, enlarged prostate, pH imbalance, ingestion of too much calcium can all cause kidney stones
  - If these stones lodge in the renal pelvis they may block urine from reaching the ureter and being excreted by the body.
  - Stones can move and tear tissue, causing severe pain
  - Treated with ultrasound break up or, if necessary, surgery

Kidney Stones



Diabetes Mellitus – Type 1 & 2

- Diabetes mellitus is caused by low to zero secretion of insulin from the islet cells in the pancreas
- Without insulin, blood sugar levels rise, so there is a lot of glucose that can't be reabsorbed into the blood. As a result, glucose is excreted in their urine.
- This sets up an osmotic gradient causing a lot of water to be excreted in urine and more frequent urination.
- Therefore, sufferers are often dehydrated and thirsty.

Type 1 vs. Type 2 Diabetes

- Type 1 is when islet cells get attacked by immune system leading to no insulin production – autoimmune disorder
- Type 2 is when the islet cells either can't produce enough insulin, or the body experiences insulin resistance (doesn't work on cells)
- Both result in too much sugar in the blood (insulin reduces blood sugar) and more in the urine as a result.

Diabetes Insipidus – Something Different

- This is caused by the undersecretion of ADH from the hypothalamus / pituitary
- ADH causes a direct reabsorption of water from the DCT and collecting ducts, making urine more concentrated
- Insipidus causes a dramatic increase in urine output (up to 20 L of urine per day!)
- People with this disease are often dehydrated and must drink huge volumes of water to maintain fluid balance

Nephritis

- This collection of diseases is characterized by inflammation of the nephrons
- Capillaries in the nephron break and allow blood cells and other large components of blood to find way into the Bowman's capsule, and eventually, urine.
- These molecules cannot be reabsorbed, creating an osmotic pressure that pulls water into the nephron, increasing urine production
- Can lead to kidney failure or death if not treated

Kidney Technologies - Dialysis

- If a kidney loses its function, then the patient may be in danger of dying from uric acid poisoning
- One solution for this condition is to perform dialysis – where a person's blood is filtered using a machine
- Two types:
  1. Hemodialysis
  2. Peritoneal Dialysis

Dialysis Machines (Hemodialysis)

- A dialysis machine consists of a long tube made from a semipermeable membrane immersed in a solution
- This solution contains the same ingredients as clean blood plasma (called dialysate)
- The patient's blood is passed through this tube and the wastes diffuse into the surrounding dialysate and is filtered

Dialysis Dialysis 2

Kidney Technologies - Dialysis

- Dialysis treatments take between 4 and 8 hours, and may be repeated up to three times a week
- As well, patients must have a strictly regulated diet to prevent excess levels of toxins to build up in their systems
- During dialysis, hormones the kidneys normally make (like erythropoietin) get added to the patient's blood

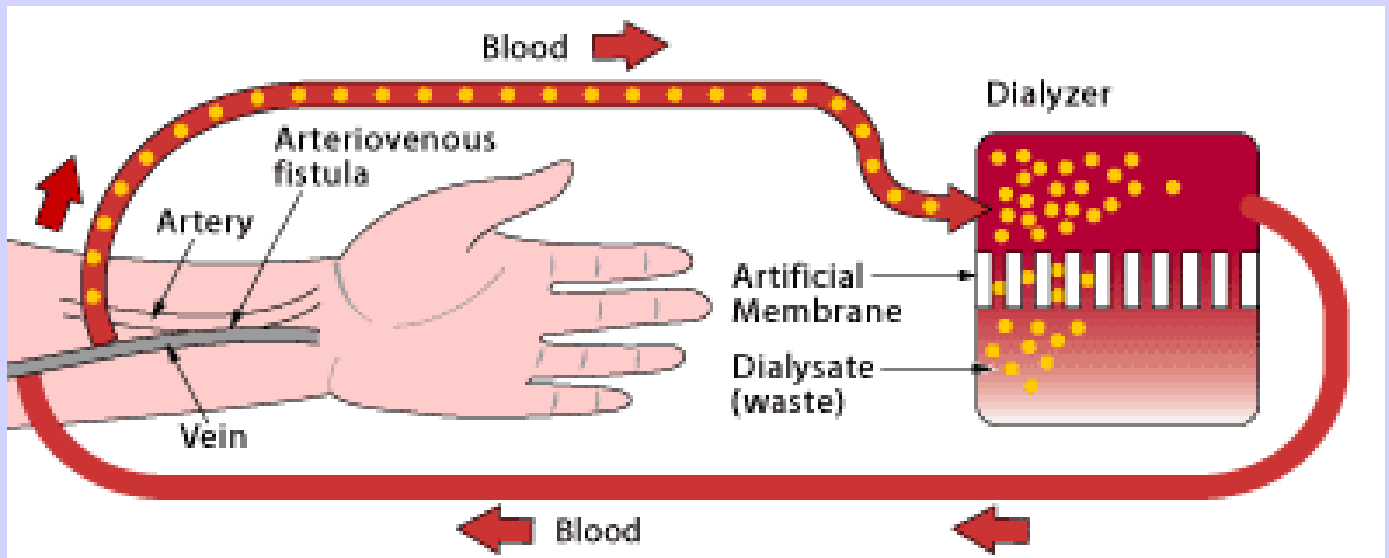


Figure 1 Hemodialysis

Peritoneal Dialysis

- Peritoneal dialysis uses the lining of the intestines (the peritoneum) as the dialysis membrane
- The dialysate is introduced into the abdominal cavity, where the large surface area and the rich supply of capillaries slowly filter the blood of urea and other wastes

Hemodialysis vs. Peritoneal Dialysis

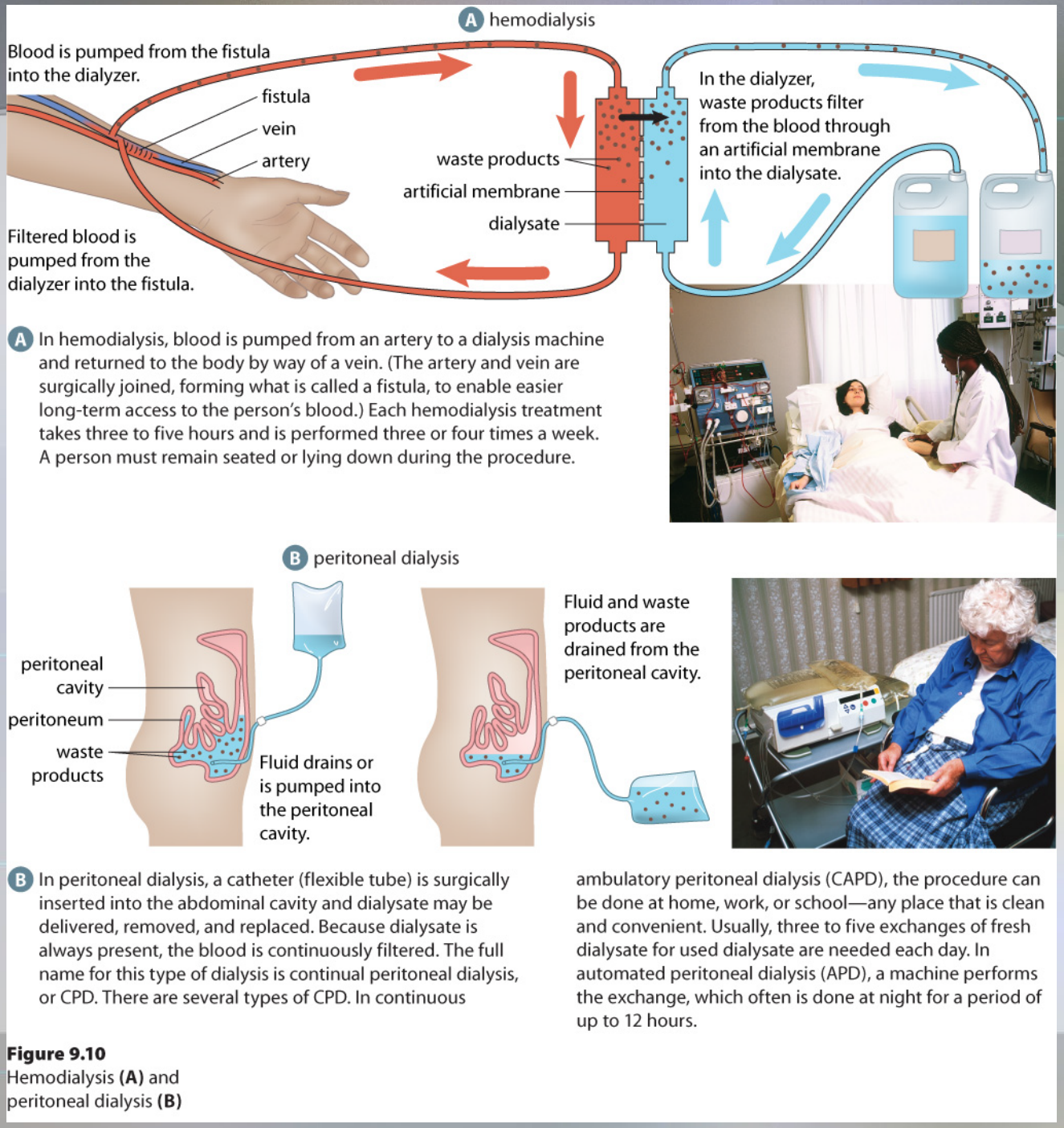


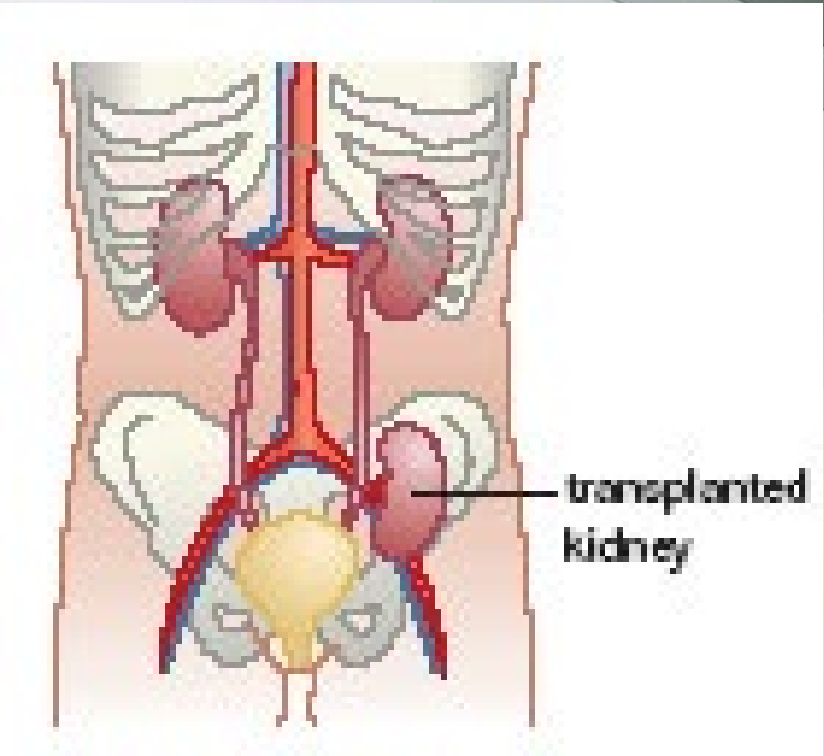
Figure 9.10
Hemodialysis **(A)** and peritoneal dialysis **(B)**

Kidney Transplant

- One permanent solution to dialysis is to replace the damaged kidney with a fully functional one
- Kidney transplants often involve a close family member donating one of their healthy kidneys to the patient
- As a result, both the donor and recipient will have one fully functional kidney

Kidney Transplant

- However, kidney transplant patients must take immunosuppressant drugs that have a host of complications. A simple cold becomes a big issue for a transplant patient.
- In a kidney transplant, a new kidney and new ureter are placed in the lower abdomen, near the groin.
- The old kidneys are rarely removed.



Well Mr. Osborne, it may not be kidney stones after all.