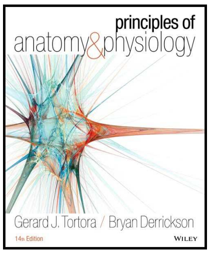



# Principles of Anatomy and Physiology

14th Edition

**CHAPTER 26**

The Urinary System



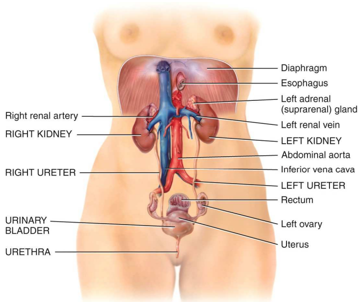
## The Urinary System

Consists of the kidneys, ureters, bladder, and urethra

Maintains homeostasis by managing the volume and composition of fluid reservoirs, primarily blood



## Organs of the urinary system in a female




(a) Anterior view of urinary system

## Homeostatic Kidney Functions

Regulation of blood ionic composition

- Na+, $K^+$, $Cl^-$

Regulation of blood pH

- $H^+$, $HCO_3^-$

Regulation of blood volume

- $H_20$

Regulation of blood pressure



## Homeostatic Kidney Functions

Maintenance of blood osmolarity

Production of hormones

- Calcitrol and Erythropoietin

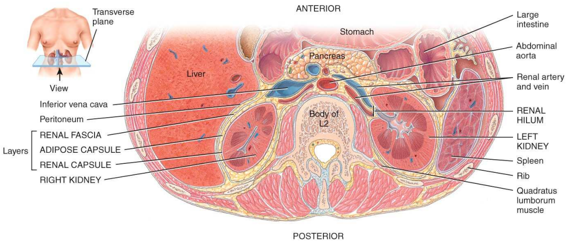
Regulation of blood glucose level

Excretion of metabolic wastes and foreign substances (drugs or toxins)



## Renal Anatomy

The kidneys are retroperitoneal, partly protected by the lower ribs.

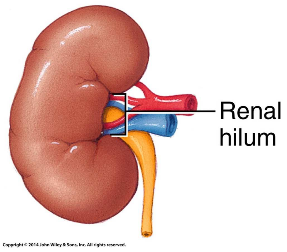



(a) Inferior view of transverse section of abdomen (L2)

## Renal Anatomy

The indented area is called the Hilum.

This is the entrance for:
- Renal Artery
- Renal Vein
- Ureter
- Nerves
- Lymphatics






## External Layers

Connective Tissue, Superficial to Deep
- Renal Fascia - Anchors to other structures
- Adipose Capsule – Protects and anchors
- Renal Capsule – Continuous with Ureter



## Internal Renal Anatomy

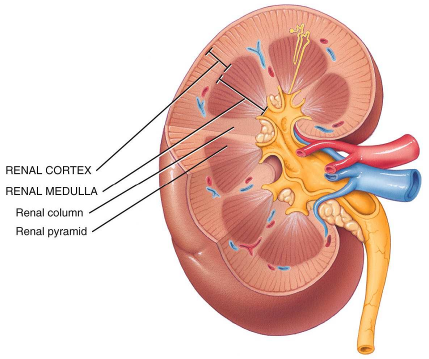
Renal Cortex – Outer layer

Renal Medulla – Inner region

Renal Pyramids – Secreting Apparatus and Tubules

Renal Columns – Anchor the Cortex

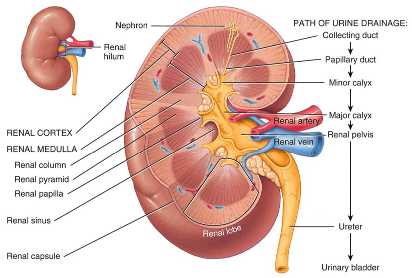
## Internal Renal Anatomy






## Internal Renal Anatomy

Papillary ducts empty urine into calyces
Calyces pass urine to the Ureter




(a) Anterior view of dissection of right kidney



## Blood and Nerve supply of the Kidneys

Blood supply

- Although kidneys constitute less than 0.5% of total body mass, they receive 20–25% of resting cardiac output

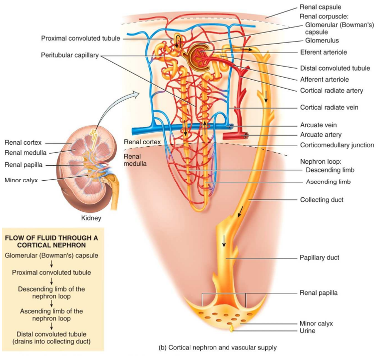
Nerve Supply

- Renal Nerves primarily carry sympathetic outflow
- They regulate blood flow through the kidneys

## The Nephron

Renal corpuscle filters the blood plasma

Renal tubule modifies the filtrate



(b) Cortical nephron and vascular supply





## The Renal Corpuscle

The Renal Corpuscle consists of two parts:

The Glomerulus is a mass of capillaries.

The Glomerular (Bowman's) Capsule has a visceral layer of podocytes which wrap around the capillaries.



## The Renal Corpuscle

The Glomerulus is a mass of capillaries.

It is fed by the Afferent Arteriole and drains into the Efferent Arteriole.

Mesangial cells are contractile and help regulate glomerular filtration.

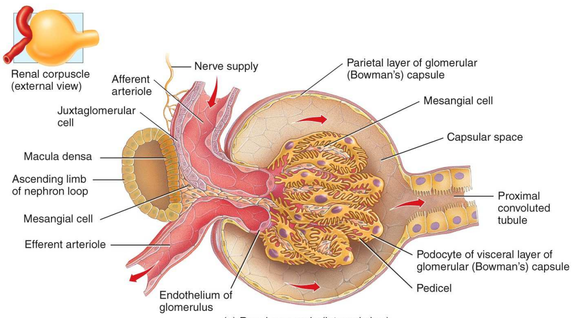
## The Renal Corpuscle

The Glomerular (Bowman's) Capsule has a visceral layer of podocytes which wrap around the capillaries.

The filtrate is collected between the visceral and parietal layers.



## Histology of a Renal Corpuscle




(a) Renal corpuscle (internal view)





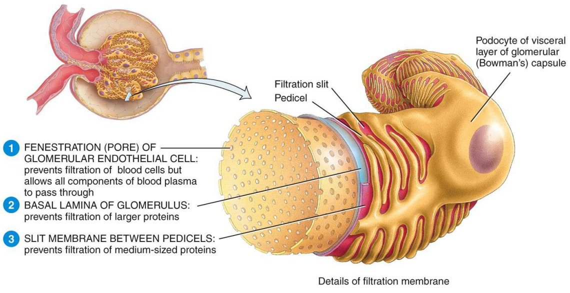
## The Renal Corpuscle

The glomerular endothelial cells have large pores (fenestrations) and are leaky.

Basal lamina lies between endothelium and podocytes.

Podocytes form pedicels, between which are filtration slits.

## The Renal Corpuscle





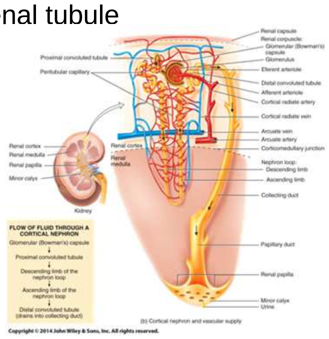

## The Renal Tubule

The filtrate passes from the glomerular capsule to the renal tubule

Proximal Convoluted Tubule

Nephron Loop
- Descending Loop
- Ascending Loop

Distal Convoluted Tubule





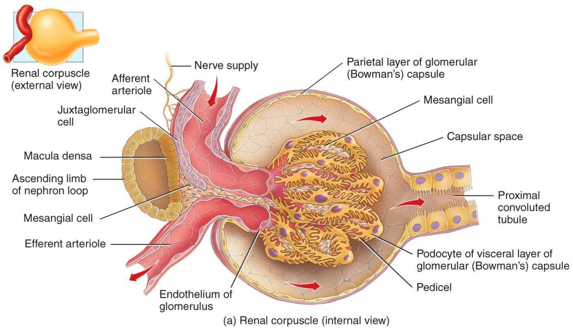

## The Juxtaglomerular Apparatus

The ascending loop contacts the afferent arteriole at the macula densa.

The wall of the arteriole contains smooth muscle cells; juxtaglomerular cells.

The apparatus regulates blood pressure in the kidney in conjunction with the ANS.

## Histology of a Renal Corpuscle



(a) Renal corpuscle (internal view)

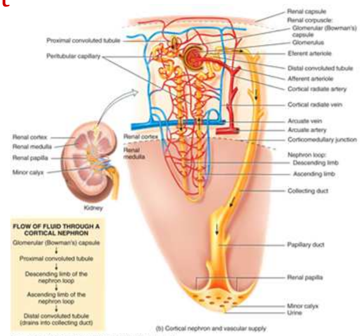




## The Distal Collecting Tubule and Collecting Duct

Principal Cells – receptors for ADH and aldosterone

Intercalated Cells – help to manage blood pH



(b) Cortical nephron and vascular supply





## Two Kinds of Nephrons

Cortical nephrons – 80-85% of nephrons

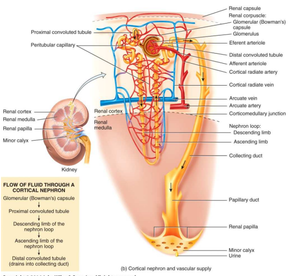
- Renal corpuscle in outer portion of cortex
- Short loops of Henle extend only into outer region of medulla
- Create urine with osmolarity similar to blood

## Juxtamedullary Nephrons

- Renal corpuscle deep in cortex with long nephron loops
- Receive blood from peritubular capillaries and vasa recta
- Ascending limb has thick and thin regions
- Enable kidney to secrete very concentrated urine

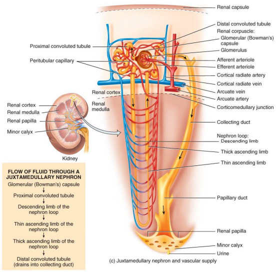


## Cortical Juxtamedullary




(b) Cortical nephron and vascular supply





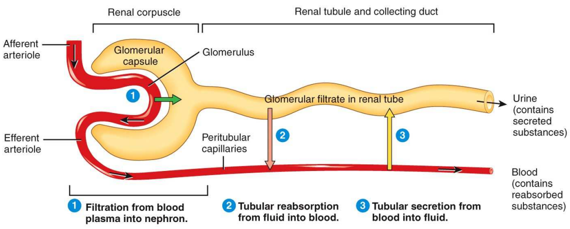

(c) Juxtamedullary nephron and vascular supply





## Renal Physiology - Urine Formation

- Glomerular filtration
- Tubular reabsorption
- Tubular secretion






Excretion of a solute = glomerular filtration + secretion - reabsorption

## Glomerular Filtration

Driven by blood pressure

Opposed by capsular hydrostatic pressure and blood colloid osmotic pressure

Water and small molecules move out of the glomerulus.

In one day, 150–180 liters of water pass out into the glomerular capsule.



## Glomerular filtration

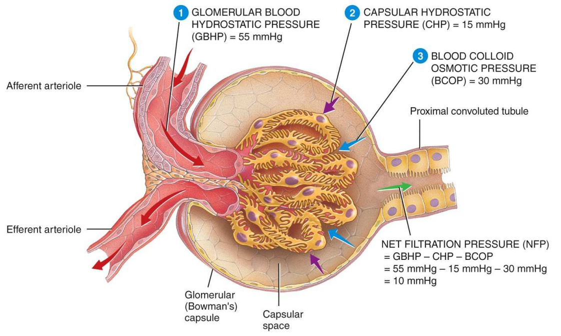
Glomerular filtration rate – amount of filtrate formed by both kidneys each minute

Homeostasis requires kidneys to maintain a relatively constant GFR

- Too high – substances pass too quickly and are not reabsorbed
- Too low – nearly all reabsorbed and some waste products not adequately excreted



## Glomerular Filtration




Renal corpuscle (internal view)

## Glomerular Filtration

Interactions Animation:

- Renal Filtration

You must be connected to the Internet and in Slideshow Mode to run this animation.



## Glomerular Filtration Rate

GFR averages 125mL/min in males and 105mL/min in females

Controlled by:

- Renal Autoregulation
- Neural Regulation
- Hormonal Regulation



## Renal Autoregulation

Myogenic Mechanism

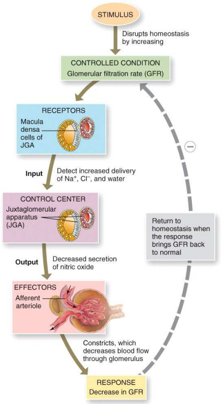
- Smooth muscle cells in afferent arterioles contract in response to elevated blood pressure

Tubuloglomerular Feedback

- High GFR diminishes reabsorption
- Macula Densa inhibits release of nitric oxide
- Afferent arterioles constrict

## Renal Autoregulation

Tubuloglomerular Feedback








## Neural Regulation

Kidneys are richly supplied by sympathetic fibers.

Strong stimulation (exercise or hemorrhage)–afferent arterioles are constricted.

Urine output is reduced, and more blood is available for other organs.



## Hormonal Regulation

Angiotensin II constricts afferents and efferents, diminishing GFR.

Atrial Natriuretic Peptide relaxes mesangial cells, increasing capillary surface area and GFR.

ANP is secreted in response to stretch of the cardiac atria.

## Tubular Reabsorption and Secretion

Much of the filtrate is reabsorbed

Especially water, glucose, amino acids, and ions

Secretion helps to mange pH and rid the body of toxic and foreign substances.



## Plasma, Filtrate and Urine Compositions

| | Total Amount in Plasma | Amount in 180 L of filtrate (/day) | Amount returned to blood/d (Reabsorbed) | Amount in Urine (/day) |
|---|---|---|---|---|
| Water (passive) | 3 L | 180 L | 178-179 L | 1-2 L |
| Protein (active) | 200 g | 2 g | 1.9 g | 0.1 g |
| Glucose (active) | 3 g | 162 g | 162 g | 0 g |
| Urea (passive) | 1 g | 54 g | 24 g (about 1/2) | 30 g (about 1/2) |
| Creatinine | 0.03 g | 1.6 g | 0 g (all filtered) | 1.6 g (none reabsorbed) |



## Tubular Reabsorption and Secretion

Much of the filtrate is reabsorbed by both active and passive processes.

Especially water, glucose, amino acids, and ions

Secretion helps to mange pH and rid the body of toxic and foreign substances.

# Reabsorption Routes

Paracellular Reabsorption

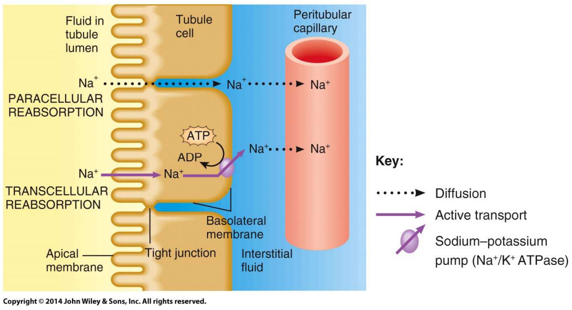
Passive fluid leakage between cells

Transcellular Reabsorption

Directly through the tubule cells



# Reabsorption Routes






# Transport Mechanisms

Primary Active Transport

Uses ATP, like $Na^+/K^+$ pumps

At rest, accounts for 6% total body ATP use

Secondary Active Transport

Driven by ion’s electrochemical gradient

Symporters move substances in same direction

Antiporters move substances in opposite directions

## Water Reabsorption

Obligatory Water Reabsorption – 90%

- Water follows the solutes that are reabsorbed

Facultative Water Reabsorption – 10%

- Regulated by ADH



## Reabsorption and Secretion in PCT

$Na^+$ - Glucose Symporters

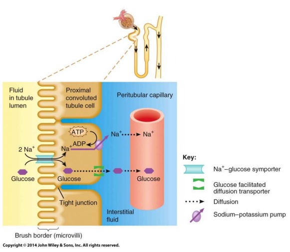
$Na^+$ - $H^+$ Antiporters

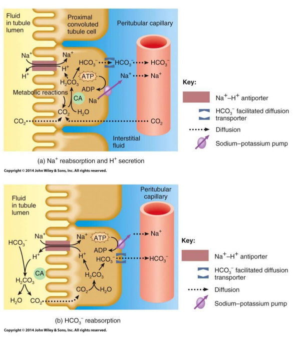
Aquaporin - 1

- Membrane protein permeable to water



## Transport Mechanisms

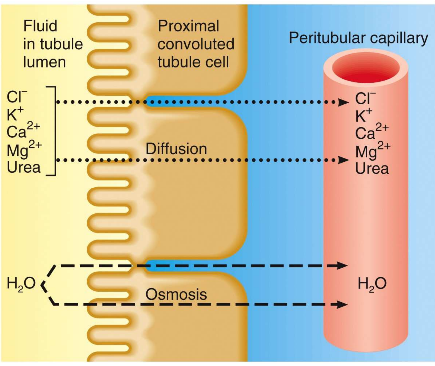



Symporter

Antiporter

## Passive Reabsorption in the late PCT








## Reabsorption in the Loop of Henle

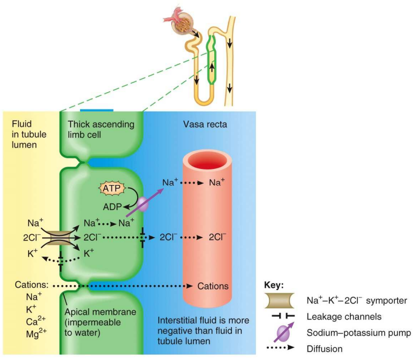
Relatively impermeable to water, especially the ascending limb

Little obligatory water reabsorption

$Na^+$ - $K^+$ - $2Cl^-$ symporters



## Reabsorption in the Nephron Loop



## Reabsorption in early DCT

Na$^{+}$ - Cl$^{-}$ symporters reabsorb ions

PTH stimulates reabsorption of Ca$^{2+}$

It also inhibits phosphate reabsorption in the PCT, enhancing its excretion



## Late DCT and Collecting Duct

Principal Cells

- Na$^{+}$-K$^{+}$ pumps reabsorb Na$^{+}$
- Aquaporin – 2 reabsorbs water
  - Stimulated by ADH

Intercalated Cells

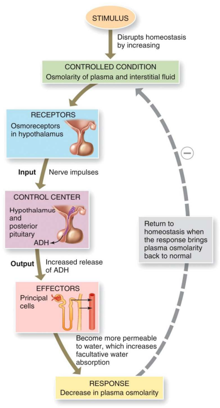
- Reabsorb K$^{+}$ + $HCO_3^{-}$, secrete H$^{+}$



## Regulation of Water Reabsorption by ADH

Facultative Reabsorption

Negative Feedback



## Urine Production

Fluid intake is highly variable.

Homeostasis requires maintenance of fluid volumes within specific limits.

Urine concentration varies with ADH.



## Urine Production

High intake – Dilute urine of high volume

Low intake – Concentrated urine of low volume



## Formation of Dilute Urine

Glomerular filtrate and blood have the same osmolarity – 300mOsm/Liter

Tubular osmolarity changes due to a concentration gradient in the medulla

## Formation of Dilute Urine

When dilute urine is formed, osmolarity in the tubule

1. Increases in the descending limb
2. Decreases in the ascending limb
3. Decreases more in the collecting duct



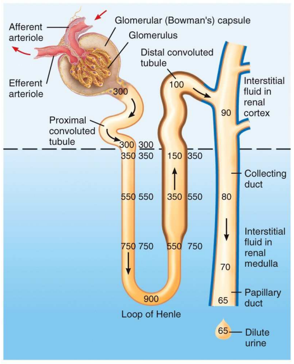
## Formation of Dilute Urine

Tubule Osmolarity

↑ in descending limb

↓ in ascending limb

↓ in collecting duct








## Formation of Dilute Urine

Thick Ascending Limb

- Symporters actively resorb $Na^+$, $K^+$, $Cl^-$
- Low water permeablility
- Solutes leave, water stays in tubule

Collecting Duct

- Low water permeability in absence of ADH

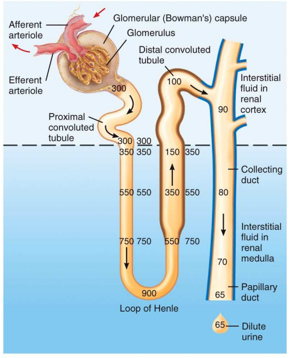
## Formation of Dilute Urine

Tubule Osmolarity

↑ in descending limb

↓ in ascending limb

↓ in collecting duct








## Formation of Concentrated Urine

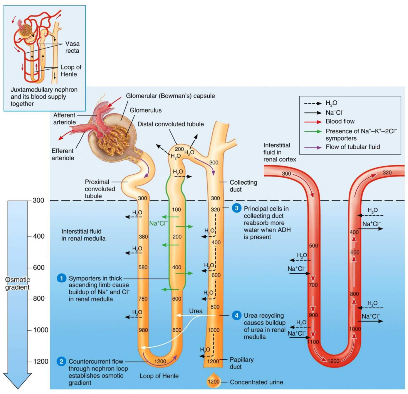
Juxtamedullary Nephrons with long loops

Osmotic gradient is created by the Countercurrent Multiplier

Solutes pumped out of ascending limb, but water stays in tubule

Medulla osmolarity is increased






(a) Reabsorption of $Na^+$, $Cl^-$, and water in long-loop juxtamedullary nephron

(b) Recycling of salts and urea in vasa recta

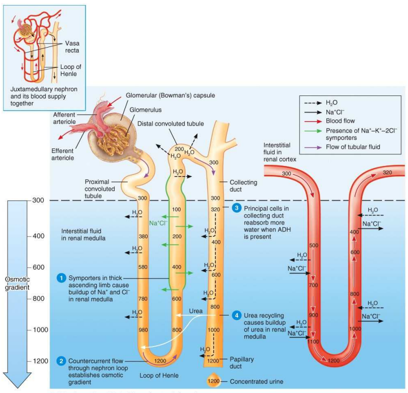
## Formation of Concentrated Urine

In presence of ADH, collecting ducts become very permeable to water.

Tubular fluid there becomes very concentrated.

Movement of water also carries urea into the medulla, contributing to its osmolarity.





(a) Reabsorption of $Na^+$, $Cl^-$, and water in long-loop juxtamedullary nephron

(b) Recycling of salts and urea in vasa recta



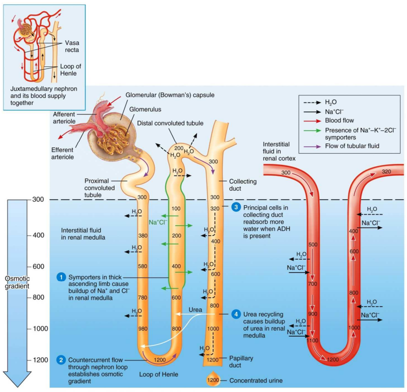
## Countercurrent Exchange

Loop and duct cells require nutrients and oxygen from blood supply.

Capillaries that feed them (vasa recta) form loops like those of nephron loops in the medulla.

Incoming and outgoing blood will have similar osmolarity.

This <u>maintains</u> medulla concentration gradient.




(a) Reabsorption of $Na^+$, $Cl^-$, and water in long-loop juxtamedullary nephron

(b) Recycling of salts and urea in vasa recta





# Tubular Reabsorption

## Interactions Animation:

Water Homeostasis

You must be connected to the Internet and in Slideshow Mode to run this animation.



# Evaluation of Kidney Function

Routine urinalysis primarily evaluates for the presence of abnormalities in the urine:

- Albumin
- Glucose
- Red blood cells
- Ketone bodies
- Microbes

## Urine Transportation and Storage

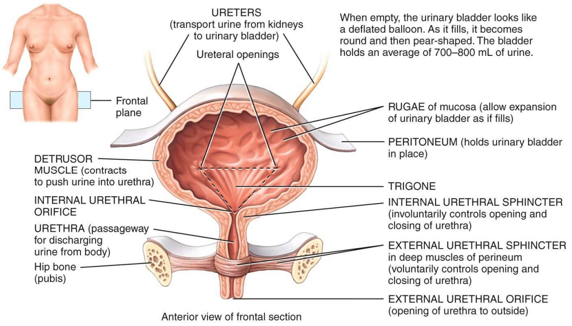
Each ureter transports urine from a renal pelvis by peristaltic waves, hydrostatic pressure, and gravity.

No anatomical valve at the opening of the ureter into bladder – when bladder fills, it compresses the opening and prevents backflow.

The bladder is a hollow, distensible, muscular organ with a capacity averaging 700–800 mL.



## Ureters, Bladder, and Urethra in a female








## Micturition

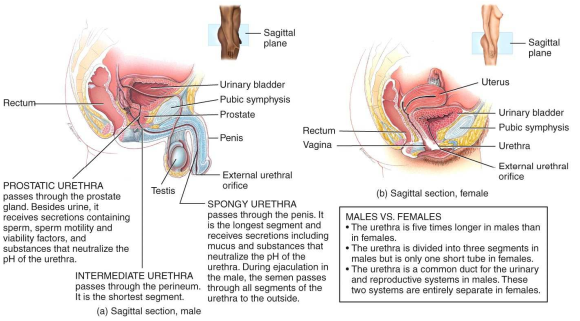
The discharge of urine involves voluntary and involuntary muscle contractions.

Stretch receptors trigger a spinal reflex, which we learn to control in childhood.

The urethra carries urine from the internal urethral orifice to the exterior of the body.

In males, it discharges semen as well as urine.

## Male and Female Urethras



(a) Sagittal section, male

(b) Sagittal section, female





## End of Chapter 26