Physiology of Urinary system

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Urine Formation III: Water Conservation

- the kidney eliminates metabolic wastes from the body, but also prevents excessive water loss as well
- as the kidney returns water to the tissue fluid and bloodstream, the fluid remaining in the renal tubules passes as urine, and becomes more concentrated

Collecting Duct Concentrates Urine

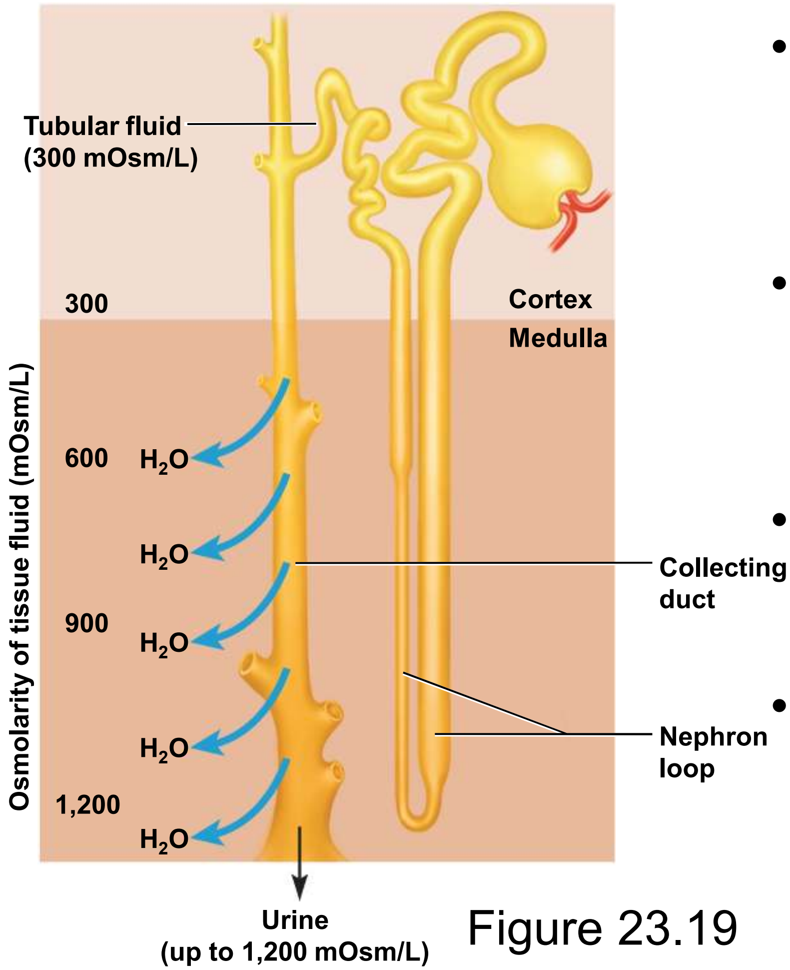


Figure 23.19

- collecting duct (CD) begins in the cortex where it receives tubular fluid from several nephrons
- as CD passes through the medulla, it reabsorbs water and concentrates urine up to four times
- medullary portion of CD is more permeable to water than to NaCl
- as urine passes through the increasingly salty medulla, water leaves by osmosis concentrating urine

Control of Water Loss

- how concentrated the urine becomes depends on body's state of hydration
- **water diuresis** – drinking large volumes of water will produce a large volume of **hypotonic urine**
  - cortical portion of CD reabsorbs NaCl, but it is impermeable to water
  - salt removed from the urine stays in the CD
  - urine concentration may be as low as 50 mOsm/L
- producing **hypertonic urine**
  - dehydration causes the urine to become scanty and more concentrated
  - high blood osmolarity stimulates posterior pituitary to release ADH and then an increase in synthesis of aquaporin channels by renal tubule cells
  - more water is reabsorbed by collecting duct
  - urine is more concentrated
- If BP is low in a dehydrated person, GFR will be low.
  - filtrate moves more slowly and more time for reabsorption –
  - more salt removed, more water reabsorbed and less urine produced

Countercurrent Multiplier

- the ability of kidney to concentrate urine depends on salinity gradient in renal medulla
  - four times as salty in the renal medulla than the cortex
- nephron loop acts as **countercurrent multiplier**
  - **multiplier** - continually recaptures salt and returns it to extracellular fluid of medulla which multiplies the salinity in adrenal medulla
  - **countercurrent** - because of fluid flowing in opposite directions in adjacent tubules of nephron loop
- fluid flowing downward in **descending limb**
  - passes through environment of increasing osmolarity
  - most of descending limb very permeable to water but not to NaCl
  - water passes from tubule into the ECF leaving salt behind
  - concentrates tubular fluid to 1,200 mOsm/L at lower end of loop
- fluid flowing upward in **ascending limb**
  - impermeable to water
  - reabsorbs Na^+, K^+, and Cl^- by active transport pumps into ECF
  - maintains high osmolarity of renal medulla
  - tubular fluid becomes hypotonic – 100 mOsm/L at top of loop
- **recycling of urea**: lower end of CD permeable to urea
  - urea contributes to the osmolarity of deep medullary tissue
  - continually cycled from collecting duct to the nephron loop and back
  - urea remains concentrated in the collecting duct and some of it always diffuses out into the medulla adding to osmolarity

Countercurrent Multiplier of Nephron Loop

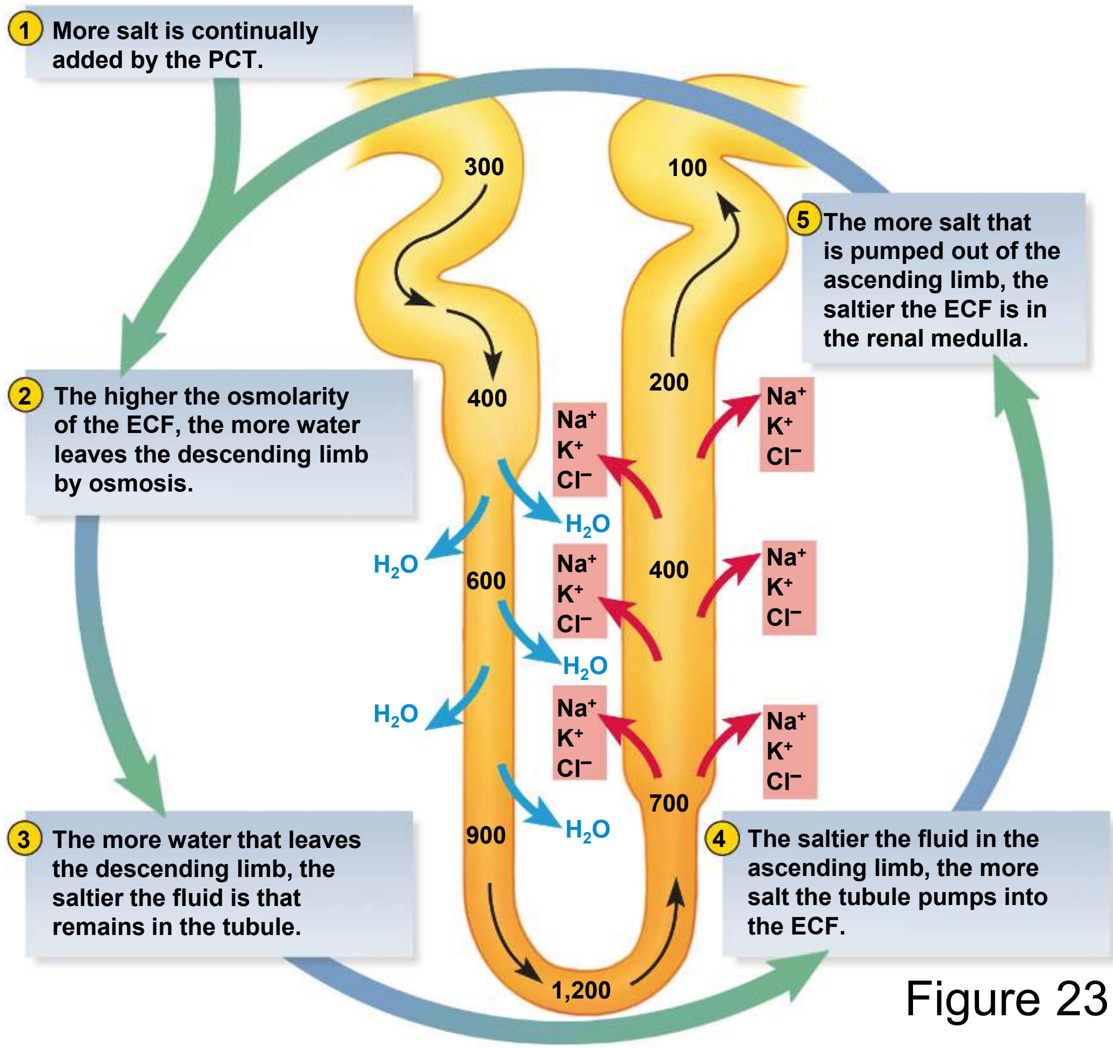


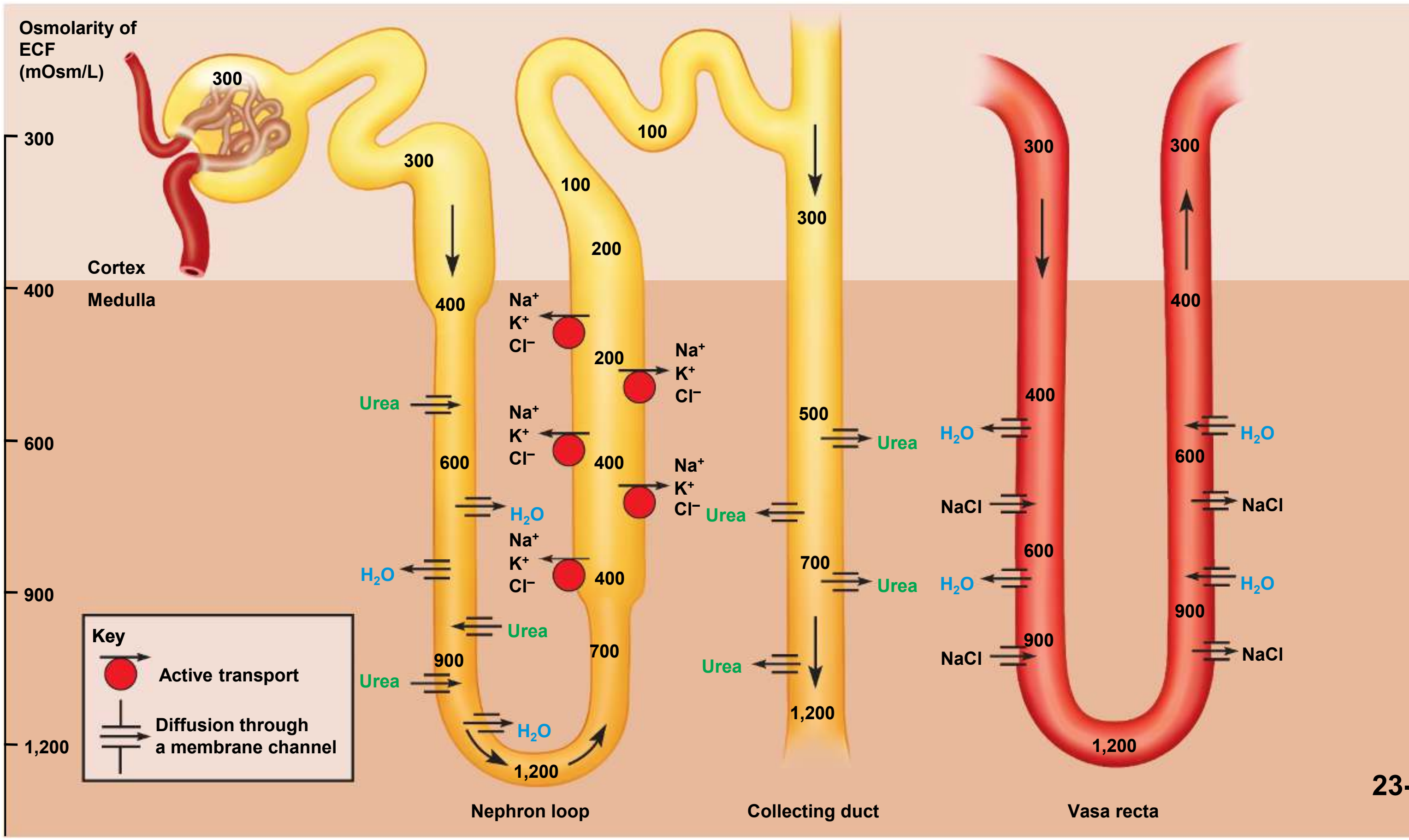
Figure 23.20

Countercurrent Exchange System

- **vasa recta** – capillary branching off efferent arteriole in medulla
  - provides blood supply to medulla and does not remove NaCl and urea from medullary ECF
- **countercurrent system** - formed by blood flowing in opposite directions in adjacent parallel capillaries
- **descending capillaries**
  - exchanges water for salt
  - water diffuses out of capillaries and salt diffuses in
- as blood flows back up to the cortex the opposite occurs
- **ascending capillaries**
  - exchanges salt for water
  - water diffuses into and NaCl diffuses out of blood
  - the vasa recta gives the salt back and does not subtract from the osmolarity of the medulla
- absorb more water on way out than the way in, and thus they carry away water reabsorbed from the urine by collecting duct and nephron loop

Maintenance of Osmolarity in Renal Medulla

Figure 23.21



Summary of Tubular Reabsorption and Secretion

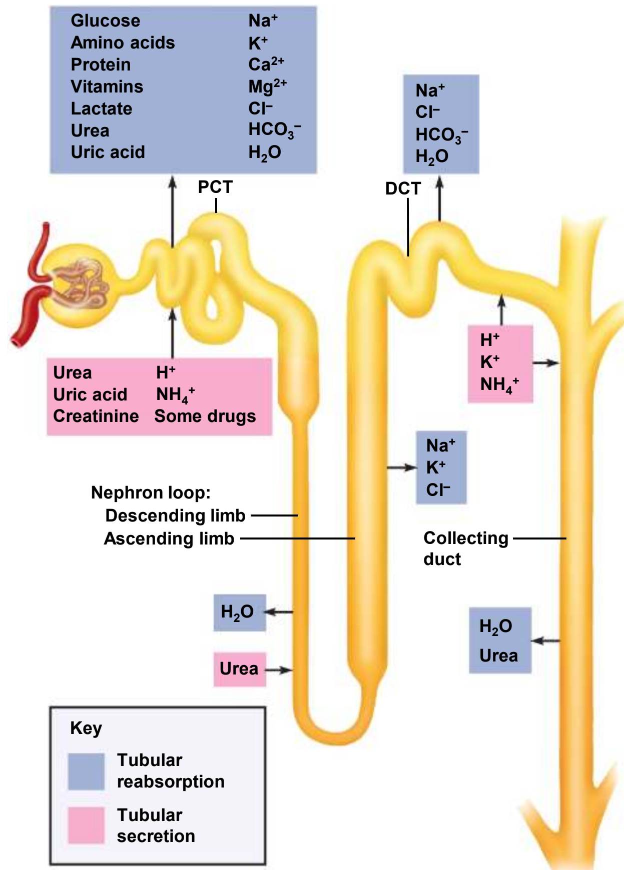


Figure 23.22

Composition and Properties of Urine

- **urinalysis –** the examination of the physical and chemical properties of urine
- **appearance -** clear, almost colorless to deep amber - yellow color due to urochrome pigment from breakdown of hemoglobin (RBCs) – other colors from foods, drugs or diseases
  - cloudiness or blood could suggest urinary tract infection, trauma or stones
  - **pyuria** – pus in the urine
  - **hematuria** – blood in urine due to urinary tract infection, trauma, or kidney stones
- **odor -** bacteria degrade urea to ammonia, some foods impart aroma
- **specific gravity -** compared to distilled water
  - density of urine ranges from 1.001 -1.028
- **osmolarity** - (blood = 300 mOsm/L)
  - ranges from 50 mOsm/L to 1,200 mOsm/L in dehydrated person
- **pH** - range: 4.5 to 8.2, usually 6.0 (mildly acidic)
- **chemical composition**: 95% water, 5% solutes
  - **normal** to find - urea, NaCl, KCl, creatinine, uric acid, phosphates, sulfates, traces of calcium, magnesium, and sometimes bicarbonate, urochrome and a trace of bilirubin
  - **abnormal** to find – glucose, free hemoglobin, albumin, ketones, bile pigments

Urine Volume

- **normal** volume for average adult - **1 to 2 L/day**
- **polyuria** - output in excess of 2 L/day
- **oliguria** – output of less than 500 mL/day
- **anuria** - 0 to 100 mL/day
  - low output from kidney disease, dehydration, circulatory shock, prostate enlargement
  - low urine output of less than **400 mL/day,** the body cannot maintain a safe, low concentration of waste in the plasma

Diabetes

- **diabetes** – any metabolic disorder resulting in chronic polyuria
- at least four forms of diabetes
  - **diabetes mellitus type 1**, **type 2**, and **gestational diabetes**
    - high concentration of glucose in renal tubule
    - glucose opposes the osmotic reabsorption of water
    - more water passes in urine (osmotic diuresis)
    - glycosuria – glucose in the urine
  - **diabetes insipidus**
    - **ADH hyposecretion** causing not enough water to be reabsorbed in the collecting duct
    - more water passes in urine

Diuretics

- **diuretics** – any chemical that increases urine volume
  - some increase GFR
    - caffeine dilates the afferent arteriole
  - reduce tubular reabsorption of water
    - alcohol inhibits ADH secretion
  - act on nephron loop (loop diuretic) - inhibit Na^+ - K^+ - Cl^- symport
    - impairs countercurrent multiplier reducing the osmotic gradient in the renal medulla
    - collecting duct unable to reabsorb as much water as usual
- commonly used to treat hypertension and congestive heart failure by reducing the body's fluid volume and blood pressure

Renal Function Tests

- tests for diagnosing kidney disease
- evaluating their severity
- monitoring their progress
- determine renal clearance
- determine glomerular filtration rate

Renal Clearance

- **renal clearance** – the volume of blood plasma from which a particular waste is completely removed in 1 minute
- represents the net effect of three processes:
  - **glomerular filtration** of the waste
  + amount added by **tubular secretion**
  - amount removed by **tubular reabsorption**

    renal clearance
- **determine renal clearance** (C) by collecting blood and urine samples, measuring the waste concentration in each, and measuring the rate of urine output:
  - U - waste concentration in urine – 6.0 mg/mL (urea example)
  - V - rate of urine output – 2 mL/min
  - P - waste concentration in plasma – 0.2 mg/mL
  - C – renal clearance in mL/min of waste cleared
  - C = UV/P = 60 mL/min (60 mL of blood plasma is completely cleared of urea per minute
- compare C to normal GFR of 125 mL/min to see if normal rate of clearance is occurring - 48% which is normal for urea

Glomerular Filtration Rate

- kidney disease often results in lowering of GFR –need to measure patient's GFR
  - can not use clearance rate of urea
    - some urea filtered by glomerulus is reabsorbed in the tubule
    - some urea is secreted into the tubule
- need a substance that is not secreted or reabsorbed at all so that all of it in the urine gets there by glomerular filtration
- use **inulin,** a plant polysaccharide to determine GFR
  - neither reabsorbed or secreted by the renal tubule
  - inulin GFR = renal clearance on inulin
- clinically GFR is estimated from **creatinine excretion**
  - does not require injecting a substance or drawing blood to determine its blood concentration

Urine Storage and Elimination

- urine is produced continually
- does not drain continually from the body
- urination is episodic – occurring when we allow it
- made possible by storage apparatus
- and neural controls of this timely release

Voiding Urine

- between acts of urination, the bladder is filling
  - **detrusor** muscle relaxes
  - **urethral sphincters** are tightly closed
    - accomplished by sympathetic pathway from upper lumbar spinal cord
    - postganglionic fibers travel through the hypogastric nerve to the detrusor muscle (*relax*) and internal urethral sphincter (*excite*)
  - **somatic motor fibers** from upper sacral spinal cord through pudendal nerve to supply the **external sphincter** give us voluntary control
- **micturition** – the act of urinating
- **micturition reflex** - spinal reflex that partly controls urination

Voiding Urine – Micturition Reflex

- **involuntary control** (steps 1 – 4)
  - filling of the bladder to about 200 mL excites stretch receptors in the bladder wall
  - send sensory signals through fibers in pelvic nerve to sacral spinal cord (S_2 or S_3)
  - motor signals travel back from the spinal cord to the bladder by way of motor fibers in pelvic nerve and parasympathetic ganglion in bladder wall
  - excites detrusor muscle and relaxes internal urethral sphincter
  - results in emptying bladder
  - if there was no voluntary control over urination, this reflex would be the only means of control

Voiding Urine – Micturition Reflex

- **voluntary control** (steps 5 – 8)
  - **micturition center -** nucleus in the pons that receives some input from bladder stretch receptors that ascends the spinal cord
  - nucleus integrates information about bladder tension with information from other brain centers
    - urination can be prompted by fear
    - inhibited by knowledge that the circumstances are inappropriate for urination
  - fibers from micturition center descend the spinal cord
    - through reticulospinal tracts
  - some fibers inhibit sympathetic fibers than normally keep internal urethral sphincter contracted
  - others descend farther to sacral spinal cord
    - excite parasympathetic neurons that stimulate the detrusor to contract and relax the internal urethral sphincter
  - initial detrusor contraction raises pressure in bladder, stimulate stretch receptors, bringing about more forceful contraction
  - external urethral sphincter receives nerve fibers from cerebral cortex by way of corticospinal tract
    - inhibit somatic motor neurons that normally keep that sphincter constricted

Voiding Urine – Micturition Reflex

- urge to urinate usually arises at an inconvenient time
  - one must suppress it
  - stretch receptors fatigue and stop firing
- as bladder tension increases
  - signals return with increasing frequency and persistence
- there are times when the bladder is not full enough to trigger the micturition reflex but one wishes to 'go' anyway
  - **Valsalva maneuver** used to compress bladder
  - excites stretch receptors early getting the reflex started

Neural Control of Micturition

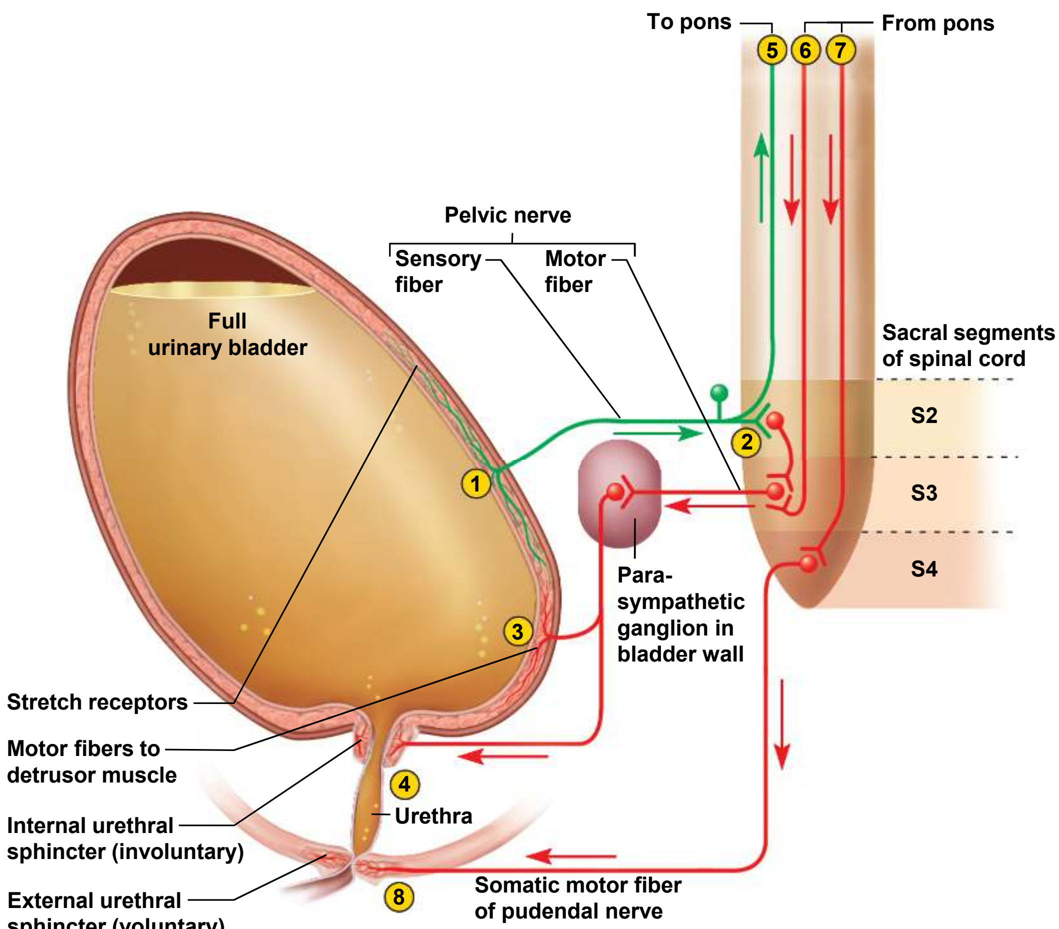


Figure 23.24

Involuntary micturition reflex

1. Stretch receptors detect filling of bladder, transmit afferent signals to spinal cord.
2. Signals return to bladder from spinal cord segments S2 and S3 via parasympathetic fibers in pelvic nerve.
3. Efferent signals excite detrusor muscle.
4. Efferent signals relax internal urethral sphincter. Urine is involuntarily voided if not inhibited by brain.

Voluntary control

5. For voluntary control, micturition center in pons receives signals from stretch receptors.
6. If it is timely to urinate, pons returns signals to spinal interneurons that excite detrusor and relax internal urethral sphincter. Urine is voided.
7. If it is untimely to urinate, signals from pons excite spinal interneurons that keep external urethral sphincter contracted. Urine is retained in bladder.
8. If it is timely to urinate, signals from pons cease and external urethral sphincter relaxes. Urine is voided.