Chapter 26
The Urinary System

- Kidneys, ureters, urinary bladder & urethra
- Urine flows from each kidney, down its ureter to the bladder and to the outside via the urethra
- Filter the blood and return most of water and solutes to the bloodstream
Overview of Kidney Functions

• Helps regulation of blood ionic composition
  – $\text{Na}^+$, $\text{K}^+$, $\text{Ca}^{+2}$, $\text{Cl}^-$ and phosphate ions
• Regulation of blood pH, osmolarity & glucose
• Regulation of blood volume
  – conserving (keep in blood) or eliminating water
• Regulation of blood pressure
  – secreting the enzyme renin
• Production of hormones
  – Release of Erythropoietin & Calcitrol (Vitamin D)
• Excretion of wastes & foreign substances
External Anatomy of Kidney

• Paired kidney-bean-shaped organ

• Found just above the waist between the peritoneum & posterior wall of abdomen – retroperitoneal along with adrenal glands & ureters

• Protected by 11th & 12th ribs with right kidney lower
Internal Anatomy of Kidney / Know Major Structures and Pathway of Urine Flow
• **Nephron** - Functional unit of the kidney
  – consists of Renal Corpuscle & a Renal Tubule

1. Renal Corpuscle - glomerulus & glomerular Capsule (Bowman’s Capsule)
2. Renal Tubule - proximal convoluted tubule (PCT), loop of Henle, distal convoluted tubule
Blood Supply to the Nephron

- Afferent arteriole
- Efferent arteriole
- Glomerulus
- Peritubular capillaries
- Vasa recta
Blood & Nerve Supply of Kidney

• Abundantly supplied with blood vessels
  – receive 25% of resting cardiac output via renal arteries

• Functions of the different capillary beds
  – Glomerular capillaries where filtration of blood occurs
    • vasoconstriction & vasodilation of afferent & efferent arterioles produce large changes in renal filtration
  – Peritubular capillaries that carry away reabsorbed substances from filtrate

• Nervous Supply
  – Sympathetic vasomotor nerves regulate blood flow & renal resistance by altering arterioles(dilate vs constr.)
Structure of Renal Corpuscle

- Bowman’s capsule surrounds capsular space
  - podocytes cover capillaries to form visceral layer
  - simple squamous cells form parietal layer of capsule
- Glomerular capillaries arise from afferent arteriole & form a ball before emptying into efferent arteriole
Juxtaglomerular Apparatus

- Structure where afferent arteriole makes contact with ascending limb of loop of Henle
  - Macula densa is thickened part of ascending limb that detects NaCl levels
  - Juxtaglomerular cells are modified smooth muscle cells in arteriole that secrete renin / Renin causes vasoconstriction & increased BP
Number of Nephrons

• Remains constant from birth
  – any increase in size of kidney is size increase of individual nephrons

• If injured, no replacement occurs

• Dysfunction is not evident until function declines by 25% of normal (other nephrons handle the extra work)

• Removal of one kidney causes enlargement of the remaining until it can filter at 80% of normal rate of 2 kidneys
Overview of Renal Physiology

1. Glomerular Filtration of Plasma
2. Tubular Reabsorption
3. Tubular Secretion
Overview of Renal Physiology

- Nephrons and collecting ducts perform 3 basic processes

  1. Glomerular Filtration
     - a large portion of the blood plasma is filtered into the “urine space”

  2. Tubular Re-absorption
     - water & useful substances are reabsorbed from the “urine space” and put back into the blood

  3. Tubular Secretion
     - wastes are removed from the blood & secreted into urine

- Rate of excretion of any substance is its rate of filtration, plus its rate of secretion, minus its rate of reabsorption
1ST Process of Urine Formation - Glomerular Filtration

- Blood pressure produces glomerular filtrate

- 48 Gallons/day filtrate reabsorbed to 1-2 qt. urine

- Filtering capacity enhanced by:
  - thinness of membrane capillaries
  - glomerular capillary BP is high due to small size of efferent arteriole
Filtration Membrane

1. Endothelial fenestration (pore) of glomerulus: prevents filtration of blood cells but allows all components of blood plasma to pass through.
2. Basal lamina of glomerulus: prevents filtration of larger proteins.

- #1 Stops all cells and platelets
- #2 Stops large plasma proteins
- #3 Stops medium-sized proteins, not small ones
- Proteins lost to urine causes interstitial edema
Glomerular Filtration Rate

• Amount of filtrate formed in all renal corpuscles of both kidneys / minute
  – average adult male rate is 125 mL/min

• Homeostasis requires GFR that is constant
  – too high & useful substances are lost due to the speed of fluid passage through nephron
  – too low and sufficient waste products may not be removed from the body

• Changes in “Net Filtration Pressure” affects GFR
  – filtration stops if GBHP drops to 45mm Hg
  – functions normally with mean arterial pressures 80-180
  – Prolonged shock may damage kidney / alter filtration
3 Factors Affect Glomerular Filtration

- **NFP** = total pressure that promotes filtration
- **NFP** = GBHP - (CHP + BCOP) = 10 mm Hg

Moves fluid out

Moves fluid back into blood
Regulation of GFR

- 4 Mechanisms that maintain a constant GFR despite changes in arterial BP

1. Myogenic Mechanism - Autoregulation
   - If systemic increase in BP, stretch the afferent arteriole (aa)
   - Then smooth muscle contraction reduces the diameter of the aa to reduce GFR back to its previous level in seconds

2. Tubuloglomerular Feedback - Autoregulation
   - If elevated systemic BP raises the GFR so that fluid flows too rapidly through the renal tubule & Na+, Cl- and water are not reabsorbed / increased Na, Cl, & water in filtrate
   - Macula densa detects that difference & releases an unknown vasoconstrictor from the juxtaglomerular apparatus
   - Afferent arterioles constrict & this reduces GFR
3. Neural Regulation of GFR

- Blood vessels of the kidney are supplied by sympathetic fibers that cause vasoconstriction of afferent arterioles
- At rest, renal BV are maximally dilated because sympathetic activity is minimal
  - renal autoregulation prevails
- With moderate sympathetic stimulation, both afferent & efferent arterioles constrict equally
  - decreasing GFR equally
- With extreme sympathetic stimulation (exercise or hemorrhage), vasoconstriction of afferent arterioles reduces GFR that causes blood volume to increase
  - lowers urine output & permits blood flow to other tissues
4. Hormonal Regulation of GFR

Stretching of the atria that occurs with an increase in blood volume causes release of “Atrial Natriuretic Peptide” from the heart

- This hormone relaxes glomerular mesangial cells (contractile cells within the glomerulus) increasing capillary surface area and increasing GFR

- Angiotensin II reduces GFR
  - Potent Vasoconstrictor that narrows afferent arterioles reducing GFR
2ND Process of Urine Formation Is “Tubular Reabsorption” / “Stuff Back To Blood”
Tubular Reabsorption Cont’d.

- Normal GFR is so high that volume of filtrate in capsular space in half an hour is greater than the total plasma volume.
- About 48 gallons of filtrate produced a day. See table 26.3 page 930.
- Nephron must reabsorb 99% of the filtrate.
  - Proximal Convoluted Tubule with their microvilli do most of work with rest of nephron doing just the fine-tuning.
    - Solute reabsorbed by active & passive processes.
    - Water follows by osmosis.
    - Small proteins by pinocytosis.
Reabsorption / Back Into The Blood

- Primary Active Transport of Na creates an electrochemical gradient

- Cl-, K+, Ca+2, Mg+2 and urea follow the Na & passively diffuse into the peritubular capillaries

- This promotes osmosis of 90% of water back into the blood space of the peritubular capillary
Reabsorption Continued

- Na+ symporters help reabsorb materials from the tubular filtrate
- Glucose, amino acids, lactic acid, water-soluble vitamins and other nutrients are completely reabsorbed in the first half of the proximal convoluted tubule
- The # of symporters are fixed so they have a limit as to how much of a substance can be reabsorbed

Reabsorption of Nutrients

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3rd Process of Urine Formation is Tubular Secretion

- Substance moves from the blood back to the urine
- Secretion of H ions into urine lowers urine pH and raises blood pH
- An exchange of ions occurs
- If Na removed from blood then exchanges with K or H
Hormonal Regulation of Tubular Reabsorption & Tubular Secretion

- 1. Renin induced production of angiotensin II from low blood pressure or low blood volume causing increased reabsorption of Na\(^+\) by proximal convoluted tubule

- 2. Angiotensin II & increased plasma K\(^+\) promote release of aldosterone that causes increased secretion of K\(^+\) & reabsorption of Na\(^+\), Cl\(^-\) & H\(_2\)O thus increasing blood volume
Hormonal Regulation Continued

3. Increased osmolarity of plasma & increased angiotensin II promote release of ADH from posterior pituitary that causes reabsorption of $H_2O$ & a lowering of osmolarity of plasma.

4. Over stretching of atria causes release of atrial natriuretic peptide (ANP) that increases $Na^+$ excretion (natriuresis) increasing urine output and decreasing blood volume and blood pressure.
Regulation of Urine Production Using Angiotensin II

1. Dehydration, Na⁺ deficiency, or hemorrhage
   - This Reduces GFR

2. Decrease in blood volume

3. Decrease in blood pressure

4. Juxtaglomerular cells of kidneys

5. Increased renin

6. Angiotensinogen

7. Increased angiotensin I

8. Lungs (ACE = Angiotensin converting enzyme)

9. Increased angiotensin II

10. Adrenal cortex
   - Increased K⁺ in extracellular fluid

11. Increased aldosterone

12. In kidneys, increased Na⁺ and water reabsorption; increased K⁺ secretion into urine

13. Increased blood volume

14. Increased blood pressure

15. Vasoconstriction of arterioles

16. Increased K⁺ in extracellular fluid

Effect of GFR

- Increases NaCl Reabsorption
- Increases release of ADH
- Decreased urine production
Antidiuretic Hormone From Post. P.G.

ADH causes the collecting duct to become permeable to water / Water leaves tubule (urine space) and reabsorbed into the blood / this increases blood pressure

Alcohol blocks release of ADH & increases urine output / dilute urine / vascular dehydration

Increased osmotic pressure of blood causes release of ADH
Production of Dilute or Concentrated Urine

• Homeostasis of body fluids despite variable fluid intake

• Kidneys regulate water loss in urine

• ADH controls whether dilute or concentrated urine is formed
  – if ADH is missing, urine becomes dilute (contains high ratio of water to solutes)
Diuretics

- Substances that slow renal reabsorption of water & cause diuresis (increased urine flow rate)
  - caffeine which inhibits Na reabsorption
  - alcohol which inhibits secretion of ADH
  - prescription medicines can act on the PCT, Loop of Henle or DCT
Evaluation of Kidney Function

• Urinalysis
  – analysis of the volume and properties of urine
  – normal urine is protein free, but includes filtered & secreted electrolytes
    • Urea(ammonia&CO2), creatine phosphate, uric acid, urobilinogen, fatty acids, enzymes & hormones

• Blood tests
  1. blood urea nitrogen test (BUN) measures the blood nitrogen that is part of the urea from the break down of protein
     – kidney disease / limit protein intake to reduce BUN
  2. plasma creatinine--from skeletal muscle breakdown/kidneys remove from blood
  3. renal plasma clearance - volume of blood in ml/minute that is cleaned of a substance(important in drug dosages)
Anatomy of Ureters

- 10 to 12 in long
- Extends from renal pelvis to bladder
- Retroperitoneal
- Enters posterior wall of bladder
Anatomy of Urinary Bladder

• Hollow, distensible muscular organ with capacity of 700 - 800 mL
• Trigone is smooth flat area bordered by 2 ureteral openings and one urethral opening
Micturition Reflex

• Micturition or urination (voiding)
• Both voluntary and involuntary

• Stretch receptors signal spinal cord and brain
  – when volume exceeds 200-400 mL

• Impulses sent to micturition center in sacral spinal cord (S2 and S3) & reflex is triggered
  – parasympathetic fibers cause detrusor muscle to contract & relaxation of internal urethral sphincter muscles

• Filling causes a sensation of fullness that initiates a desire to urinate before the reflex actually occurs
  – conscious control of external sphincter
  – cerebral cortex can initiate micturition or delay its occurrence for a limited period of time