CHAPTER 26
URINARY SYSTEM

CHAPTER OVERVIEW: This chapter describes the location, structure and functions of the organs of the urinary system and their constituent parts. The process of urine formation is described in detail. The nervous and cellular mechanisms responsible for determining the final composition of urine are explained in detail and urine composition is related to the homeostatic control of blood and interstitial fluid composition.

OUTLINE (two or three fifty-minute lectures):
Seeley, A&P, 5/e

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<th>apt.</th>
<th>Topic Outline, Chapter 26</th>
<th>Figures &amp; Tables</th>
<th>Transparency Acetates</th>
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<tbody>
<tr>
<td>1</td>
<td>I. Urinary System, p. 861</td>
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<td>2</td>
<td>A. Kidneys</td>
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<td>1. General Size</td>
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<td>a. 11 cm X 5 cm X 3 cm</td>
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<td>b. 130 g</td>
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<td>2. Located in Renal Fat Pad</td>
<td>Fig. 26.2, p.862</td>
<td>TA-536</td>
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<td>3. Internally - Hilum to Renal Sinus</td>
<td>Fig. 26.1, p.861</td>
<td>TA-535</td>
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<td>a. Renal Artery</td>
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<td>c. Ureter</td>
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<td>4. Outer Region = Cortex</td>
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<td>5. Inner Region = Medulla</td>
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<td>a. Renal Pyramids</td>
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<td>c. Renal Columns</td>
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<td>6. Tube System from Pyramids</td>
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<td>a. Renal Papillae</td>
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<td>c. Major Calyces</td>
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<td>d. Renal Pelvis</td>
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<td>e. Ureter</td>
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<td>7. Functional Unit is the Nephron</td>
<td>Fig. 26.3, p.863</td>
<td>TA-537</td>
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<td>a. Juxtamedullary and Cortical Nephrons</td>
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<td>8. Renal Corpuscle</td>
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<td>a. Glomerulus and Fenestrated Capillaries</td>
<td>Fig. 26.4, p.865</td>
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<td>1). Afferent Arteriole</td>
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<td>2). Efferent Arteriole</td>
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<td>b. Bowman's Capsule</td>
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<td>1). Parietal Layer</td>
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<td>2). Podocytes of Visceral Layer</td>
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<td>9. Filtration Membrane</td>
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<td>a. Capillary Epithelium (Fenestrated)</td>
<td>Fig. 26.4c.d, p.865</td>
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<td>b. Basement Membrane</td>
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<td>c. Podocytes and Filtration Slits</td>
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<td>10</td>
<td>10. Juxtaglomerular Apparatus</td>
<td>Fig. 26.4b, p.865</td>
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<td>a. Modified Smooth Muscle Cells = Juxtaglomerular Cells</td>
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<td>b. Macula Densa Cells of Distal Convoluted Tubule</td>
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<td>11. Tubules</td>
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<td>a. Proximal Convoluted Tubule</td>
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<td>1). 14 cm Long X 60 µm</td>
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<td>b. Loops of Henle</td>
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<td>1). Descending Limb - Simple Cuboidal to Simple Squamous Epithelium</td>
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<td>2). Ascending Limb - Simple Squamous to Simple Cuboidal</td>
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Epithelium

c. Distal Convoluted Tubule
   1). Shorter than Proximal Tubule
   2). Smaller Cuboidal Cells, Fewer Microvilli
   d. Collecting Ducts
      1). Simple Cuboidal Epithelium
      2). Form Medullary Ray
      3). Extend Through Tip of Renal Pyramid

B. Arteries and Veins of the Kidney

1. Renal Artery
2. Segmental Arteries
3. Interlobar Arteries
4. Arcuate Arteries
5. Interlobular Arteries
6. Afferent Arterioles
7. Glomerular Capillaries
8. Efferent Arterioles
9. Peritubular Capillaries & Vasa Recta
10. Interlobular Veins
11. Arcuate Veins
12. Interlobular Veins
13. Renal Veins

C. Ureters and Urinary Bladder

1. Two Ureters, One from Each Renal Pelvis to Urinary Bladder
2. Trigone Region of Bladder
   a. Ureters Enter Urinary Bladder Posteriorly
   b. Urethra Leaves Anteriorly

II. Urinary Production

A. Filtration

1. Renal Fraction = % of Cardiac Output Passing through Kidneys, 12-30 %
2. Renal Blood Flow Rate - Vol. (ml) of Blood Passing through Kidney per min.
3. Filtration Fraction = % of Plasma becoming Filtrate, about 1 %
4. Glomerular Filtration Rate (GFR) = ml of Filtrate Formed per min, about 125 ml / min
5. About 99 % of Filtrate Volume Reabsorbed in Nephron

6. Filtration Barrier
   a. 100 to 1000 Times More Permeable than Typical Capillary
   b. Molecular Diameters ≤ 7 nm or Molecular Weights to 40,000 Daltons

7. Filtration Pressure, about 10 mm Hg
   a. Glomerular Capillary Pressure Promotes Filtration (+60 mm Hg)
      1). Decreased by Constriction of Afferent Arteriole
      2). Increased by Constriction of Efferent Arteriole
   b. Colloid Osmotic Pressure Resists filtration (-32 mm Hg)
   c. Capsule Pressure Resists Filtration (-18 mm Hg)

B. Tubular Reabsorption

1. Movement from Filtrate Back into Blood
   a. 99 % of Water Reabsorbed
   b. 40-60 % of Urea

2. Endocytosis
3. Active Transport and Cotransport Mechanisms

4. Transport in the Proximal Tubule
   a. Most Reabsorption of Nutrients and Ions
   Total Volume of Filtrate Reduced by 65% Apical Membrane
   Contains Carrier Molecules

5. Transport in the Loop of Henle
   a. Thin Descending Limb
   b. Thick Ascending Limb

6. Transport in the Distal Tubule and Collecting Duct
   a. Active Transport of Na⁺ and Cl⁻
   b. Impermeable to Water in Absence of ADH
   c. Final 19% of Water Reabsorbed when ADH Present

7. Changes in the Concentration of Solutes in the Nephron

8. C. Tubular Secretion
   1. Active or Passive Movement into Filtrate Across Proximal or Distal Convoluted Tubules
   2. Normal Cellular Products - Ex. Ammonia
   3. Drugs and Toxins - Ex. Penicillin, PAH

9. D. Urine Concentration Mechanism
   1. Medullary Concentration Gradient
      a. 300 mOsmol in Cortex
      b. 1200 mOsmol in Deepest Medulla
   2. Counter-Current System Maintains Gradient
      a. Vasa Recta
      b. Loop of Henle
      c. Variable Permeability to Urea
   3. Urea Contributes to High Medullary Concentration
      1. Summary of Changes in Filtrate Volume and Concentration
         a. Decrease in Filtrate Volume
         b. Increase in Filtrate Osmolality
         c. Marked Change in Filtrate Composition

III. Regulation of Urine Concentration and Volume

10. A. Hormonal Mechanisms
    1. Antidiuretic Hormone (ADH)
       a. From Anterior Pituitary
       b. Targets Distal Convoluted Tubules and Collecting Ducts
       c. Action is to Increase Cell Permeability to Water
       d. Secretion Increased when

11. 2. Renin-Angiotensin-Aldosterone
     a. Renin from Juxtaglomerular Apparatus when
        1). Na⁺ in DCT Decreased
        2). BP in Afferent Arteriole Decreased
           b. Renin Converts Angiotensinogen to Angiotensin I
           c. Angiotensin Converting Enzyme (ACE) Converts Angiotensin I to Angiotensin II
           d. Actions of Angiotensin II
              1). Potent Vasoconstrictor
              2). Increases Aldosterone Secretion
           e. Aldosterone From Adrenal Cortex
           f. Targets Distal Convoluted Tubules and Collecting Ducts
              g. Action Increases Active Transport of Na⁺ and Cl⁻ into Blood
              h. Aldosterone Secretion Increased When
                 1). Blood Na⁺ Increased

12. 3. Other Hormones
     a. Atrial Natriuretic Hormone Source Right Atrium of Heart
     b. Action is Decreased ADH Secretion
     c. Prostaglandins and Kinins - Precise Roles as Yet Unclear
B. Autoregulation
1. Results in Stable GFR
2. Largely Independent of Systemic Arteriolar BP
3. Involves Afferent and Efferent Arterioles
   a. Constriction of Afferent Arteriole Decreases Glomerular Capillary Pressure = Increased Filtration
   b. Constriction of Efferent Arteriole Increases Glomerular Capillary Pressure = Decreased Filtration

C. Effect of Sympathetic Stimulation on Kidney Function
1. Sympathetic Stimulation Constricts Afferent Arterioles
2. Decreases Renal Blood Flow
3. Decreases Filtrate Formation
4. Shock can Lead to Impairment of Blood Flow that Damages Kidney

IV. Regulation of Urine Concentration and Volume
1. Regulation of Extracellular Fluid Osmolality
2. Regulation of Extracellular Fluid Volume
   a. Neural Mechanisms
   b. Renin-Angiotensin-Aldosterone Mechanism
   c. Atrial Natriuretic Hormone Mechanism
d. Antidiuretic Hormone Mechanism

V. Clearance and Tubular Maximum, p. 890
A. Plasma Clearance (ml/min) = Quantity of Urine Produced (ml/min) X [Concentration of Substance in Urine / Concentration of Substance in Plasma]
B. Clearance of a Substance Estimates GFR if
   1. Substance Passes Freely Across Filtration Membrane
   2. Substance not Reabsorbed Along Nephron
   3. Substance not Secreted Along Nephron
   4. Inulin = Polysaccharide with these Characteristics
C. Clearance of a Substance Estimates Plasma Flow if
   1. Substance Passes Across Filtration Membrane
   2. Remaining Substance Secreted so Very Little Left in Blood Following Single Pass Through Kidneys
   3. Para-Aminohippuric Acid has these Characteristics
D. Blood Concentration Influences Clearance
   1. Tubular Load = Total Amount of Substance Passing Through Filtration Membrane into Nephron per min.
   2. Tubular Maximum = Maximum Rate of Active and Mediated Tubular Reabsorption of a Compound
   3. When Tubular Load > Tubular Maximum, the Excess Passes into the Urine

VI. Urine Movement, p. 892
A. Urine Flow Through the Nephron and Ureters
   1. Pressure Gradient Forces Fluid from Plasma to Bowman’s Capsule
   2. Pressure Gradient from Bowman’s Capsule to Renal Pelvis
   3. Peristaltic Contraction of Circular Smooth Muscle in Ureters
      a. Forces Urine to Urinary Bladder
      b. Rate Once Every 2-3 min.
      c. Rate Increased by Parasympathetic Stimulation
   4. Internal Bladder Pressure Increases
      a. Slowly from Volumes of 0-500 ml
      b. More Pronounced with Volume Increases Above 500 ml.
B. Micturition Reflex
   1. Neural Reflex Initiated by Stretch of Bladder or Irritation of Bladder/Urethra
   2. Afferent Paths to Sacral Region of Spinal Cord
   3. Spinal and Cranial Integration

Clinical Note, p.891
Table 26.2, p.870
Predict Quest. 8
Predict Quest. 9
Clinical Note, p.892
Clinical Note, p.894
a. Reflex Integration in Spinal Cord Predominates in Infants
b. Reflex Integration in Brainstem Predominates in Adults
4. Efferent Paths of Spinal Reflex in Parasympathetic Fibers
   a. Increase Smooth Muscle Contraction in Bladder
   b. Decrease Contraction in Internal Urethral Sphincter
5. Fibers from Motor Cortex
   a. Control Voluntary Skeletal Muscle of External Urethral Sphincter
   b. Conscious Override Develops by Age 2-3 yrs.

VII. Systems Pathology: Acute Renal Failure, p. 895

IMPORTANT CONSIDERATIONS: If there is a desire to cover the anatomical structures of the organs and the nephron in the laboratory, that frees up lecture time for clarifying the processes of urine formation and the hormonal controls on urine production and concentration. The three major segments are therefore the anatomy of the system, the processes and influences on urine formation, and the composition of final urine as a reflection of homeostatic needs.

The notion of countercurrent exchange mechanisms and the extracellular fluid concentration gradient in the medulla of the kidney will be totally new for most students. One problem is that most other examples of countercurrents, such as heat exchangers in refrigeration units and air conditioners, will also be unfamiliar to the students, so useful analogies are hard to come by.

SEE INSTRUCTOR'S MANUAL AND COURSE SOLUTIONS MANUAL FOR ADDITIONAL RESOURCES.