Urinary System

- Urinary System

  - Functions

    - Regulate blood volume and composition
      - Electrolytes
      - pH
      - Nutrients
      - Volume – blood pressure
      - Erythropoiesis
      - Remove nitrogenous waste products
      - Excretion of wastes and metabolites
      - Gluconeogenesis via glutamine acid

- Vitamin D synthesis
Urinary System

- Organs of the Urinary System

- Diaphragm
- Esophagus
- Left adrenal (suprarenal) gland
- Abdominal aorta
- Inferior vena cava
- Rectum
- Left ovary
- Uterus
Urinary System

Inferior view of transverse section of abdomen (L2)
Urinary System

- Gross Anatomy of the Kidney

- Renal hilus
- Nephron
- Path of urine drainage:
  - Papillary duct in renal pyramid
  - Minor calyx
  - Renal artery
  - Major calyx
  - Renal pelvis
  - Renal vein
  - Ureter
  - Urinary bladder

- Renal cortex
- Renal medulla
- Renal column
- Renal pyramid in renal medulla
- Renal sinus
- Renal papilla
- Fat in renal sinus
- Renal capsule
Urinary System

- Structure of a Cortical Nephron – 85%

FLOW OF FLUID THROUGH A CORTICAL NEPHRON

1. Glomerular (Bowman's) capsule
2. Proximal convoluted tubule
3. Descending limb of the loop of Henle
4. Ascending limb of the loop of Henle
5. Distal convoluted tubule (drains into collecting duct)

(a) Cortical nephron and vascular supply

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Urinary System

- Structure of a Juxtaglomerular Nephron

FLOW OF FLUID THROUGH A JUXTAMEDULLARY NEPHRON
Glomerular (Bowman's) capsule
  Proximal convoluted tubule
    Descending limb of the loop of Henle
    Thin ascending limb of the loop of Henle
    Thick ascending limb of the loop of Henle
    Distal convoluted tubule (drains into collecting duct)
  Vasa recta
  Renal cortex
  Renal medulla
  Renal papilla
  Minor calyx
  Proximal convoluted tubule
  Peritubular capillary
  Renal capsule
  Distal convoluted tubule
  Renal corpuscle:
    Glomerular (Bowman's) capsule
    Glomerulus
    Afferent arteriole
    Efferent arteriole
    Interlobular artery
    Interlobular vein
    Arcuate vein
    Arcuate artery
    Corticomedullary junction
    Collecting duct
    Loop of Henle:
      Descending limb
      Thick ascending limb
      Thin ascending limb
    Papillary duct
    Renal papilla
    Minor calyx
    Urine
(b) Juxtamedullary nephron and vascular supply
Urinary System

- Histological Features of the Renal Tubule and collecting Duct
Urinary System

- Urine Formation – the result of three processes: glomerular filtration, tubular reabsorption, and tubular secretion.
Urinary System

- **Glomerular Filtration**

  - Glomerular filtrate – plasma minus blood cells and most blood proteins (about 99% is reabsorbed)

- **Filtration Membrane**
  - Fenestrated endothelium
  - Basement membrane
  - Slitlike pores formed by podocytes
Urinary System

- Filtration Pressure

1. GLOMERULAR BLOOD HYDROSTATIC PRESSURE (GBHP) = 55 mm Hg
2. CAPSULAR HYDROSTATIC PRESSURE (CHP) = 15 mm Hg
3. BLOOD COLLOID OSMOTIC PRESSURE (BCOP) = 30 mm Hg

NET FILTRATION PRESSURE (NFP) = 10 mm Hg

Key:
- NFP = GBHP – CHP – BCOP
- GBHP = Glomerular blood hydrostatic pressure
- CHP = Capsular hydrostatic pressure
- BCOP = Blood colloid osmotic pressure
**PROXIMAL CONVOLUTED TUBULE**

**Reabsorption** (into blood) of filtered:
- Water 65% (osmosis)
- Na⁺ 65% (sodium pumps, symporters, antiporters)
- K⁺ 65% (diffusion)
- Glucose 100% (symporters and facilitated diffusion)
- Amino acids 100% (symporters and facilitated diffusion)
- Cl⁻ 50% (diffusion)
- HCO₃⁻ 80–90% (facilitated diffusion)
- Urea 50% (diffusion)
- Ca²⁺, Mg²⁺ variable (diffusion)

**Secretion** (into urine) of:
- H⁺ variable (antiporters)
- NH₄⁺ variable, increases in acidosis (antiporters)
- Urea variable (diffusion)
- Creatinine small amount

At end of PCT, tubular fluid is still isotonic to blood (300 mOsm/liter).

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**RENAL CORPUSCLE**

**Glomerular filtration rate:**
105–125 ml/min of fluid that is isotonic to blood

**Filtered substances:** water and all solutes present in blood (except proteins) including ions, glucose, amino acids, creatinine, uric acid

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**DISTAL CONVOLUTED TUBULE**

**Reabsorption** (into blood) of:
- Water 10–15% (osmosis)
- Na⁺ 5% (symporters)
- Cl⁻ 5% (symporters)
- Ca²⁺ variable (stimulated by parathyroid hormone)

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**LOOP OF HENLE**

**Reabsorption** (into blood) of:
- Water 15% (osmosis in descending limb)
- Na⁺ 20–30% (symporters in ascending limb)
- K⁺ 20–30% (symporters in ascending limb)
- Cl⁻ 35% (symporters in ascending limb)
- HCO₃⁻ 10–20% (facilitated diffusion)
- Ca²⁺, Mg²⁺ variable (diffusion)

**Secretion** (into urine) of:
- Urea variable (recycling from collecting duct)

At end of loop of Henle, tubular fluid is hypotonic (100–150 mOsm/liter).

---

**PRINCIPAL CELLS IN LATE DISTAL TUBULE AND COLLECTING DUCT**

**Reabsorption** (into blood) of:
- Water 5–9% (insertion of water channels stimulated by ADH)
- Na⁺ 1–4% (sodium pumps)
- Urea variable (recycling to loop of Henle)

**Secretion** (into urine) of:
- K⁺ variable amount to adjust for dietary intake (leakage channels)
- Tubular fluid leaving the collecting duct is dilute when ADH level is low and concentrated when ADH level is high.

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**INTERCALATED CELLS IN LATE DISTAL TUBULE AND COLLECTING DUCT**

**Reabsorption** (into blood) of:
- HCO₃⁻ variable amount, depends on H⁺ secretion (antiporters)
- Urea variable (recycling to loop of Henle)

**Secretion** (into urine) of:
- H⁺ variable amounts to maintain acid-base homeostasis (H⁺ pumps)
Urinary System

- Glomerular Filtration Rate – about 125 ml/min

- Regulation of GFR
  - Renal Autoregulation
    - Myogenic Mechanism
    - Tubuloglomerular Feedback
  - Neural Regulation
    - Sympathetic Nervous System
      » Vasoconstriction
      » Secretion of Renin
  - Hormonal Regulation
    - Angiotensin II
Urinary System

- Hormonal Regulation of Tubular Reabsorption and Tubular Secretion
  - Renin-Angiotensin System – angiotensin II affects physiology in four (4) ways
    - Vasoconstriction of afferent arterioles
    - Enhances the reabsorption of sodium and chloride by stimulating sodium/hydrogen antiporters in PCT
    - Stimulates the release of aldosterone
    - Stimulates the release of ADH
Urinary System

- ADH
Urinary System

- Atrial Natriuretic Peptide (ANP)
  
  • Inhibits the reabsorption of sodium and water in the PCT, and collecting duct
  
  • Suppresses the secretion of aldosterone and ADH

- Production of Dilute and Concentrated Urine – which depends upon ADH
  
  - Formation of a Concentrated Urine
Renal Blood Flow and Glomerular Filtration

- Case Study – Acute Renal Failure

  - Mr. D, mid-70’s, on a psych ward for years (diagnosed with dementia)

  - 10 years ago had an MI, currently taking digoxin (for CHF) and indomethacine for arthritis

  - Pulse low and not producing urine

  - Weight 70 kg (154 lbs)

  - BP 110/70 (lying down)

  - Pulse 50 and regular

  - Respiratory rate 16 b/min
Renal Blood Flow and Glomerular Filtration

- BP when standing fell to 95, pulse increased to 55
- Skin dry and tented upon pinching
- Neck veins flat
- Eyes appeared sunken
- No peripheral edema
- Abdomen soft, bladder not distended with urine

- ECG
  - Sinus rhythm 50/min
  - First degree AV block
  - Evidence of inferior myocardial infarction
Renal Blood Flow and Glomerular Filtration

- Over last 24 hrs urine production 250 ml

- Urine dip stick showed
  
  • ph 7.2  
  • 2+ protein  
  • No glucose

- Microscopic analysis
  
  • Tubular epithelial cells some clumped forming casts  
  • No WBC’s or RBC’s

- Chemical analysis
  
  • 42 meq/L sodium  
  • 102 meq/L creatinine  
  • Osmolarity 375 mOsm/L
Renal Blood Flow and Glomerular Filtration

- Venous blood sample
  
  - Creatinine 7.4 mg/dl
  - BUN 143 mg/dl
  - Glucose 85 mg/dl
  - Sodium 157 meq/dl
  - Potassium 5.9 meq/dl
  - Chloride 132 meq/dl
  - Bicarbonate 17 meq/dl

- 1 month previous blood sample showed normal levels
  
  - Creatinine 1.0
  - BUN 9
  - Glucose 96
  - Sodium 140
  - Potassium 4
  - Chloride 102
  - Bicarbonate 24
Renal Blood Flow and Glomerular Filtration

- Infused first with 1 L of 0.9% NaCl, then 5% dextrose in water at rate of 125 ml/hour

  - BP improved

  - No real increase in urine production

- Administered increasing doses of furosemide intravenously with no increase in urine production

- Low dose of dopamine was give, why?

  - No increase in urine production

- Initial diagnosis acute tubular necrosis
Renal Blood Flow and Glomerular Filtration

• Case Discussion
  - What is oliguria?
    - Normal urine production, at least 500 ml/24 hr, anything below this considered oliguria
  - What are the potential problems with oliguria?
    - Azotemia – build up of urea in the blood
    - Combination of oliguria and azotemia indicates acute renal failure - Mr. D:
      » 24 hr urine production 250 ml
      » BUN 144 (normal 9)
    - Causes of azotemia
      » Prerenal caused by kidney not receiving their normal blood (shock)
      » Renal – structural changes in the glomeruli or tubules
      » Postrenal – blockage, preventing the loss of urine
Renal Blood Flow and Glomerular Filtration

- Was oliguria caused by urinary outflow obstruction? - Postrenal
  
  - Assume a single blocked ureter
    
    - With only 1 ureter blocked, BUN and creatinine would expect to double, Mr. D’s increased far beyond this
    
    - A stone moving to block a ureter would generate a great deal of pain and the patient would have reported this

  - Assume a blocked urethra, for example in cases of hypertrophy of the prostate
    
    - Bladder would have been full, Mr. D’s was empty

  - If in doubt an ultrasound is performed, this was not indicated in Mr. D’s case
Renal Blood Flow and Glomerular Filtration

- Was oliguria caused by decreased renal blood flow? – Prerenal
  
  • Was the cause decreased myocardial contractility?
    
    - No
      
      » Veins would have been fuller than normal
      » Evidence of peripheral edema
      » Possibly pulmonary edema with rales

  • Decrease in extracellular fluid volume, Mr. D showed evidence of this
    
    - His water deficit was calculated to be 5L

  • Increased BUN/Creatinine Ratio to determine if plasma volume depletion or intrinsic renal disease
    
    - In cases of diminished renal perfusion BUN increases more than creatinine as a result the ratio increases
    
    - In Mr. D’s case the ratio increased from 9:1 to 19:1 (indicated decreased renal perfusion)
Renal Blood Flow and Glomerular Filtration

- Was oliguria caused by acute tubular necrosis?

  - Casts of epithelial cells present, indicates some tubules were not getting enough blood (cells became hypoxic and sloughed off)

  - To see how damaged Mr. D’s tubules were damaged several renal functions were evaluated

    - Urine Concentrating Ability – in this case diminished

      » In cases of depleted volume what would you expect the concentration of the urine to be and why?

      in this case Mr. D’s urine concentration was approximately the same as his blood plasma, the inability to concentrate urine beyond this is called isosthenuria

      isosthenuria one of the earliest signs of tubular dysfunction

    - Diminished capacity to reabsorb sodium

      » With respect to sodium what you expect Mr. D to be doing and why?

      in this case there was a great deal of sodium in the urine
Renal Blood Flow and Glomerular Filtration

- Decreased ability to eliminate potassium
  
  » With respect to potassium, what would you expect to see in Mr. D and why?
  
  blood levels of potassium should not be high because increased levels of potassium stimulate the secretion of aldosterone

- Diminished capacity to excrete hydrogen ions
  
  » Is Mr. D saving or losing hydrogen ions?
  
  » What affect would you expect this to have on Mr. D’s bicarbonate?

  it went from 24 meq/l to 17

  » Was Mr. D’s urine alkaline or acidic?

  alkaline, 7.2

  » What other condition, other than tubular dysfunction could cause this?

  urinary tract infection

  » Why was infection ruled out?

  no symptoms, no WBC’s in urine
Renal Blood Flow and Glomerular Filtration

- Is proteinuria a tubular or a glomerular defect?
  - Proteinuria defined as urine protein of 150 mg/day of protein loss, Mr. D’s was 100 mg/day.
  - This indicates not a glomerular problem but rather a problem with the tubular cells’ ability to metabolize any proteins that may have entered the tubules via filtration.

- What was the most likely cause of Mr. D’s acute tubular necrosis?
  - Most likely the result of decreased renal blood flow
    - Previous MI
      - His dementia made him less sensitive to thirst
  - If his problem was a decreased renal blood flow, what is your question here?
    - Prerenal azotemia diagnosis was missed
Renal Blood Flow and Glomerular Filtration

- As the kidneys began to fail they could no longer eliminate digoxin which caused conduction problems, bradycardia. What affect did this have on his problem?

- As a result of a drop in CO what would happen to BP?
  - It would drop

- How does the body respond to this drop?
  - Releases peripheral vasoconstriction

- What affect would this have on renal perfusion?
  - Decrease it

- Normally the kidney releases prostaglandins that act as vasodilators, why didn’t this work in Mr. D?
  - His arthritis medication, indomethacin interfered with this
Renal Blood Flow and Glomerular Filtration

- What was the rationale for infusing isotonic saline and dextrose solutions?
  
  • Why slowly?
  
  • Why dextrose?

- What was the rationale for administration of furosemide and why was a dopamine drip added?
  
  • To produce more urine and eliminate more toxins
  
  • Dopamine in low concentrations acts as a vasodilator, especially on renal blood vessels
  
  • With Furosemide tubular cells do not have to work as hard, diminishing their hypoxia and the increased fluid flow flushes any sloughed cells out so they do not clog the tubules further
Renal Blood Flow and Glomerular Filtration

- Physiologic Approach to the Treatment of Acute Renal Failure

  - Why would we decrease Mr. D’s protein intake via the diet?
    - Care must be taken in doing any sudden changes though since the kidneys are “sick” they will have problems making any sudden adjustments

  - Should weight the patient frequently
    - Looking for signs of too much water, could result in congestive heart failure

  - Adjust electrolyte levels, some drugs renal dialysis may be needed
Renal Blood Flow and Glomerular Filtration

- **LOOK AT PAGES 15-9 – 15-25 ON YOUR OWN THIS IS A BASIC REVIEW OF ANATOMY AND PHYSIOLOGY**

- **THERE ARE SOME NEW TERMS WITH RESPECT TO DISEASES AND DISEASE CONDITIONS – BE SURE YOU ARE COMFORTABLE WITH THE TERMS IN BOLD TEXT**