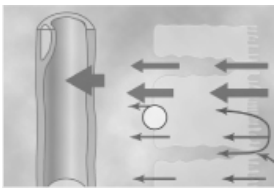
27 Urine Formation by the Kidneys: II. Tubular Processing of the Glomerular Filtrate



pages 327 - 347

OBJECTIVES

At the end of this lecture you should be able to describe:

- Absortive Characteristics of different parts of nephrons
- Transport Mechanisms operating in nephrons
- Tubular Reabsoprtion and Secretion

Characteristics

Volume	1 – 2 liters (quarts) per day (influenced by many factors)
Color	Yellow or Amber (varies with concentration and diet)
Turbidity	Transparent when fresh (becomes cloudy)
Odor	Aromatic (becomes ammonia-like)
pH	Averages 6.0 (ranges between 4.6 and 8.0)
Specific Gravity	1.001 – 1.035 (denser than water)

Organic Solutes

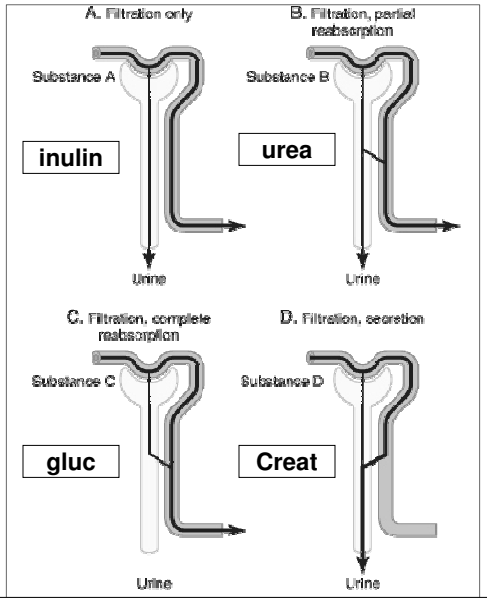
Nitrogenous Wastes	Urea; Creatinine; Uric Acid
Hippuric Acid	Derived from Benzoic Acid
Indican	Derived from Indole
Ketone Bodies	Derived from Triglycerides

Inorganic Solutes

Cations	Sodium; Potassium; Ammonium; Magnesium; Calcium
Anions	Chloride; Sulfate; Phosphates

URINE COMPOSITION

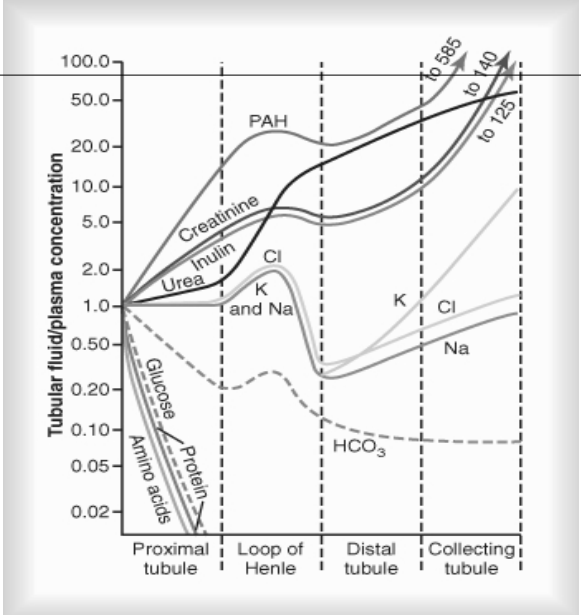
pH	freshly voided urine is usually acidic (around pH 6), range=4.8 and 7.5
Colour	Bright Yellow & transparent
Specific Gravity	1.002 to 1.030
Volume	1 - 2 L per day
Albumin	20 μg of albumin per minute (30 mg in 24 hours)
Glucose	None



Urinary Excretion Rate = Filtration Rate – Reabsorption Rate + Secretion Rate

	Amount Filtered	Amount Reabsorbed	Amount Excreted	% of Filtered Load Reabsorbed
Glucose (g/day)	180	180	0	100
Bicarbonate (mEq/day)	4,320	4,318	2	>99.9
Sodium (mEq/day)	25,560	25,410	150	99.4
Chloride (mEq/day)	19,440	19,260	180	99.1
Potassium (mEq/day)	756	664	92	87.8
Urea (g/day)	46.8	23.4	23.4	50
Creatinine (g/day)	1.8	0	1.8	0

Changes in Average Concentration of Different Substances at Different Points in Tubular System Relative to Glomerular Filtrate



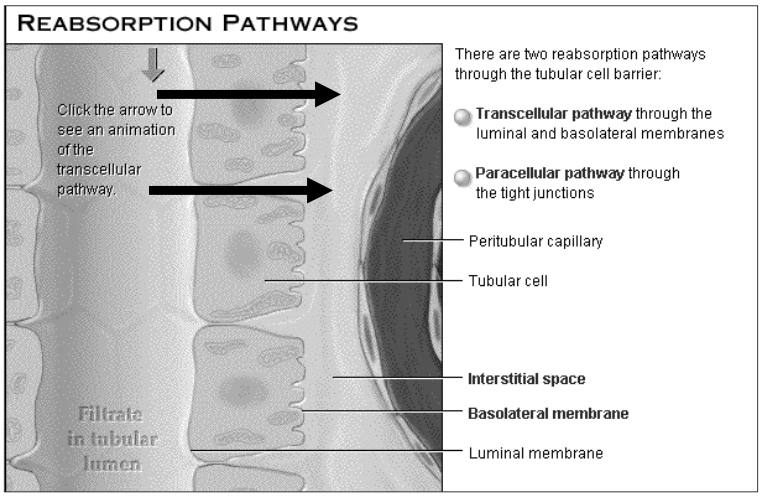
CLASSIFICATION OF TRANSPORT MECHANISMS

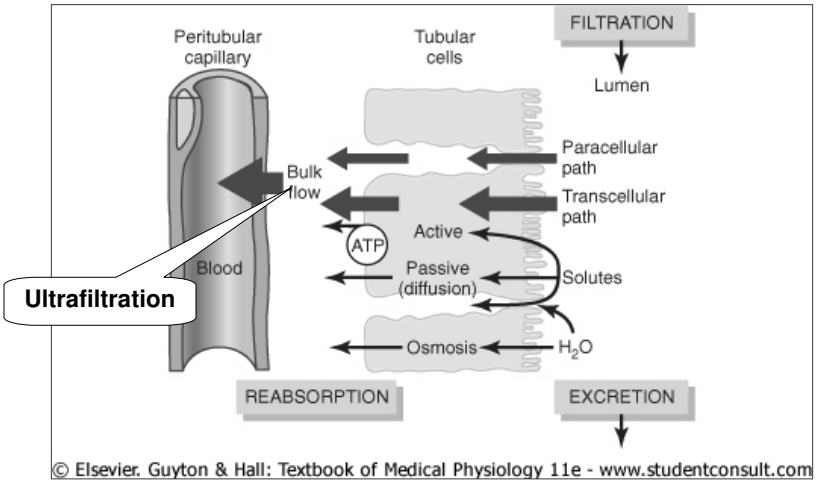
- **SIMPE DIFFUSION**
- **FACILITATED DIFFUSION**
- **BULK FLOW**
- **PRIMARY ACTIVE TRANSPORT**
- **SECONDARY ACTIVE TRANSPORT**
- **PINOCYTOSIS**

TRANPORT PATHWAYS

- **PARACELLULAR**
- **TRANSCELLULAR**

REABSORTION PATHWAYS




Peritubular capillary
Tubular cells
FILTRATION
Lumen
Paracellular path
Transcellular path
Bulk flow
ATP
Active
Passive (diffusion)
Solutes
Osmosis
H_2O
Blood
Ultrafiltration
REABSORPTION
EXCRETION
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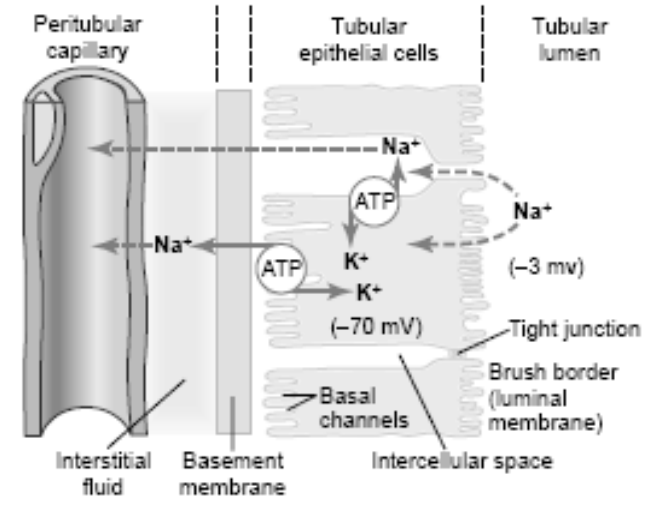

Peritubular capillary
Tubular epithelial cells
Tubular lumen
Na^+
ATP
Na^+
Na^+
ATP
K^+
(–3 mv)
K^+
(–70 mV)
Tight junction
Brush border (luminal membrane)
Basal channels
Interstitial fluid
Basement membrane
Intercellular space

Figure 27–2

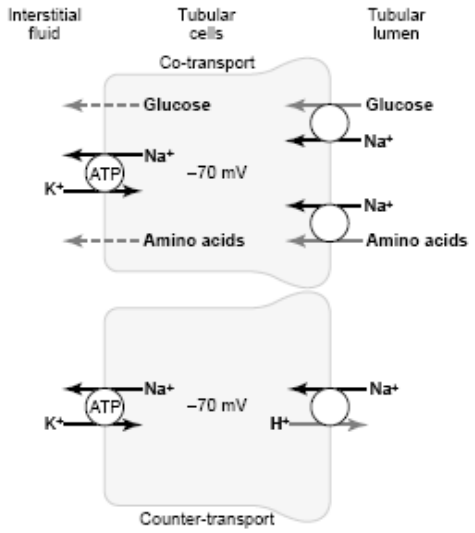
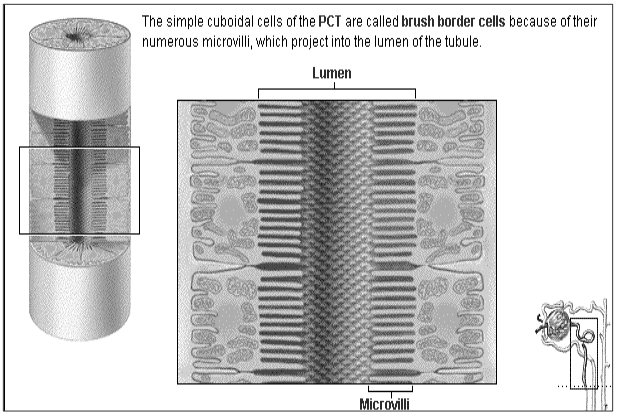
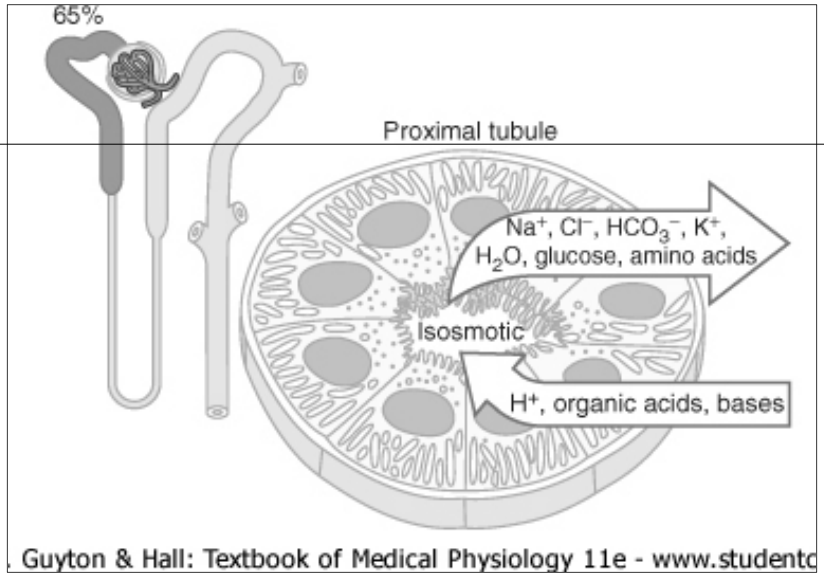


Figure 27–3

PROXIMAL CONVOLUTED TUBULE

- **many mitochondria**
- **brush border multiplies the surface area about 20-fold.**
- **tight junctions**
- **lateral intercellular spaces.**





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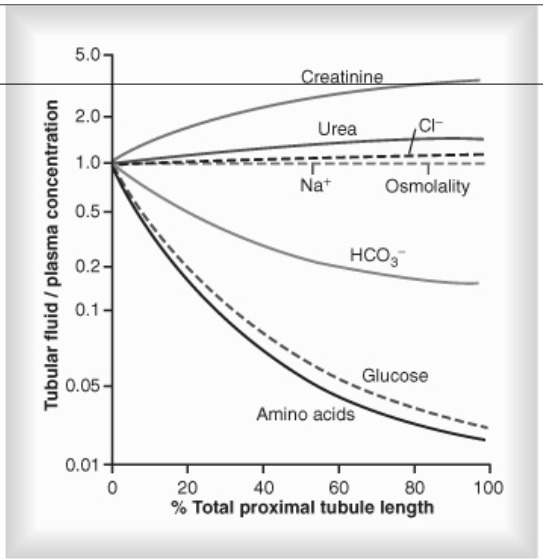
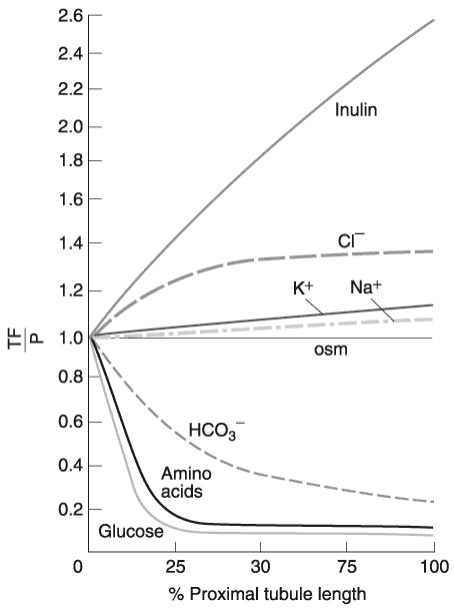
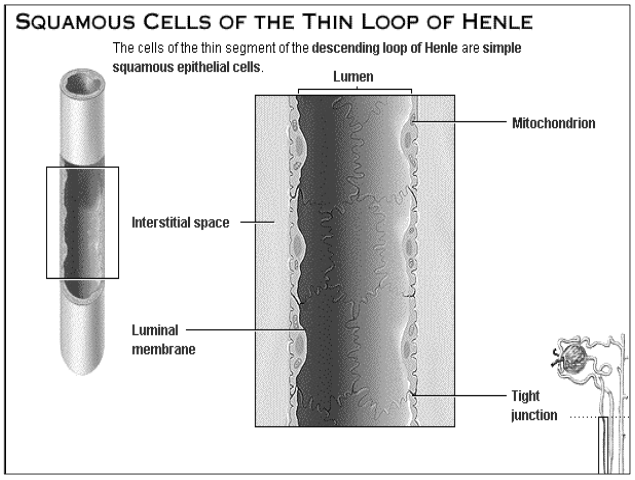




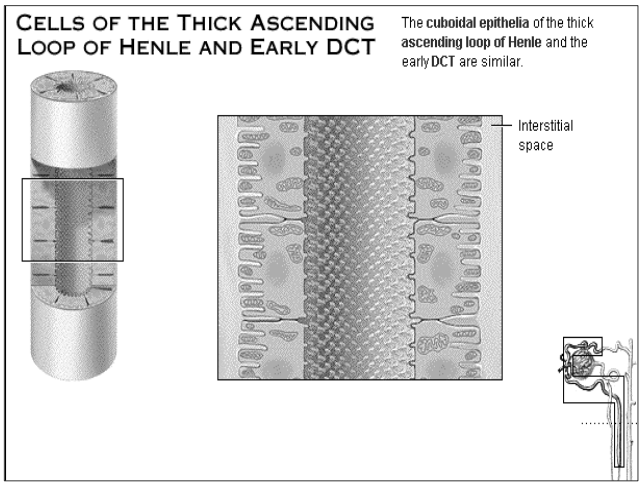
THIN LOOP OF HENLE

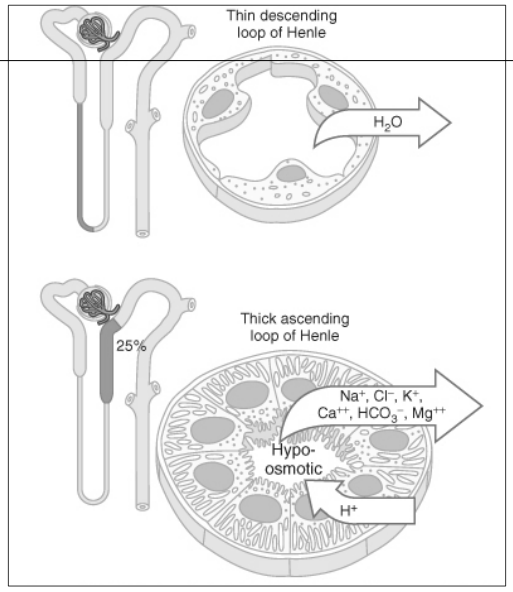
- **few mitochondria**
- **flattened with few microvilli**

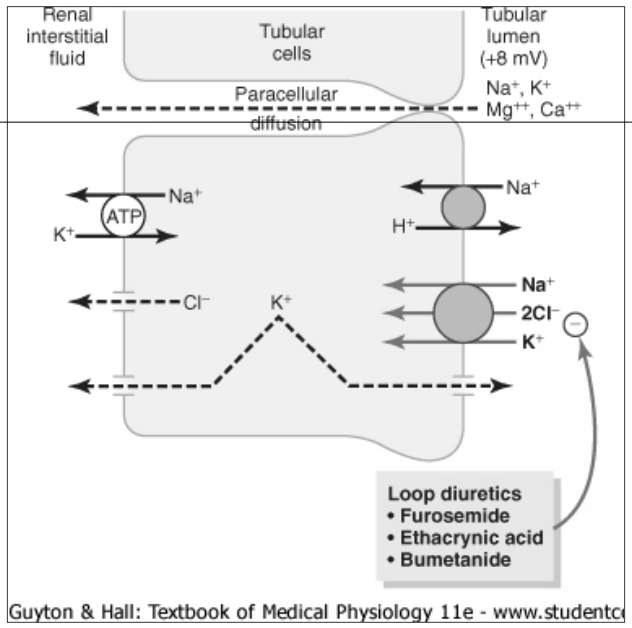


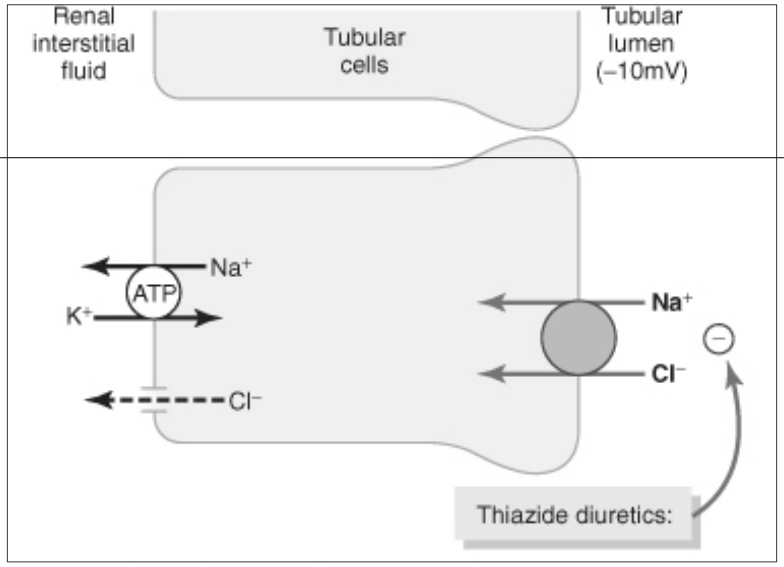
THICK ASCENDING LOOP OF HANLE AND EARLY DCT

Many mitochondria and microvilli, but fewer than in the proximal tubule



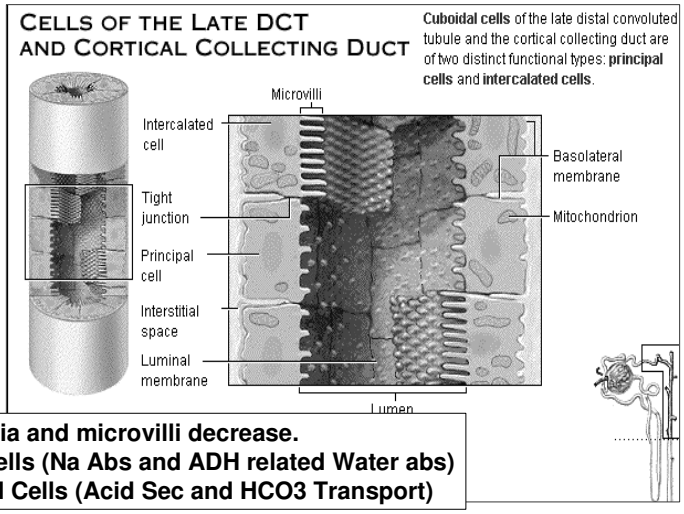




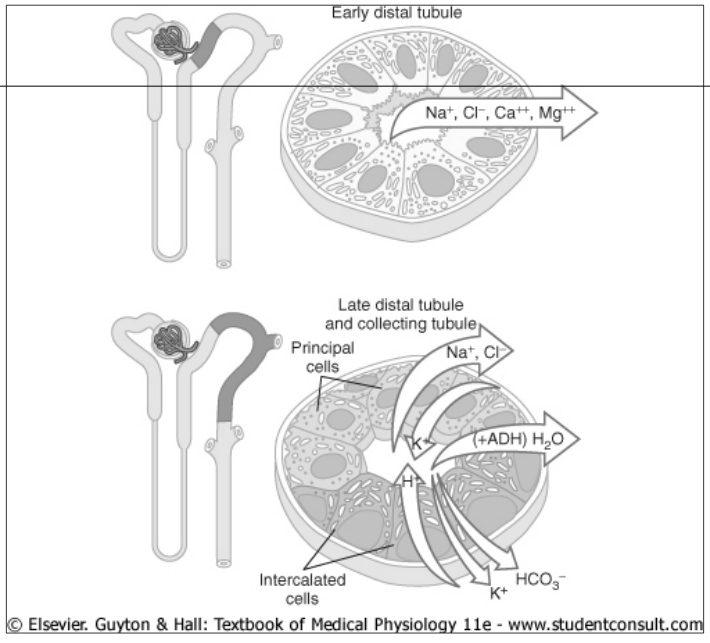


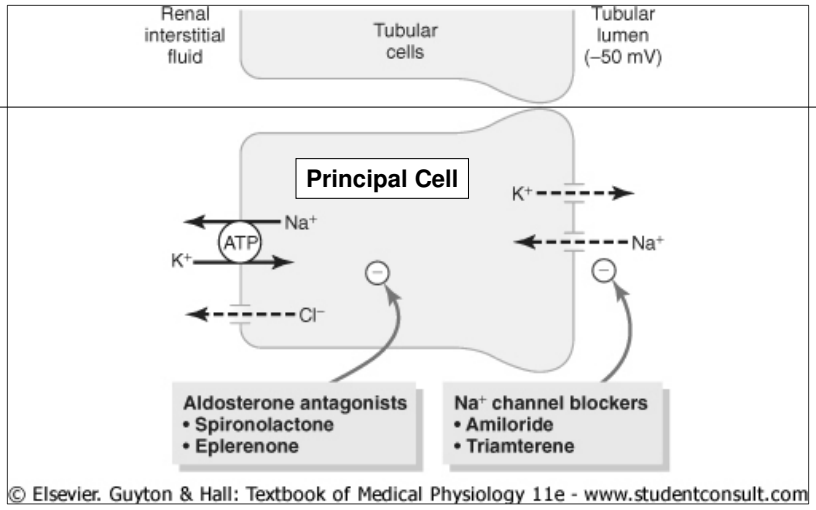
Mechanism of sodium chloride transport in the early distal tubule

LATE DCT AND CORTICAL COLLECTING DUCT



- **Mitochondria and microvilli decrease.**
- **Principal Cells (Na Abs and ADH related Water abs)**
- **Intercalated Cells (Acid Sec and HCO3 Transport)**




Renal interstitial fluid
Tubular cells
Tubular lumen (–50 mV)
Principal Cell
Na+
ATP
K+
Cl–
K+
Na+
Aldosterone antagonists
• Spironolactone
• Eplerenone
Na+ channel blockers
• Amiloride
• Triamterene
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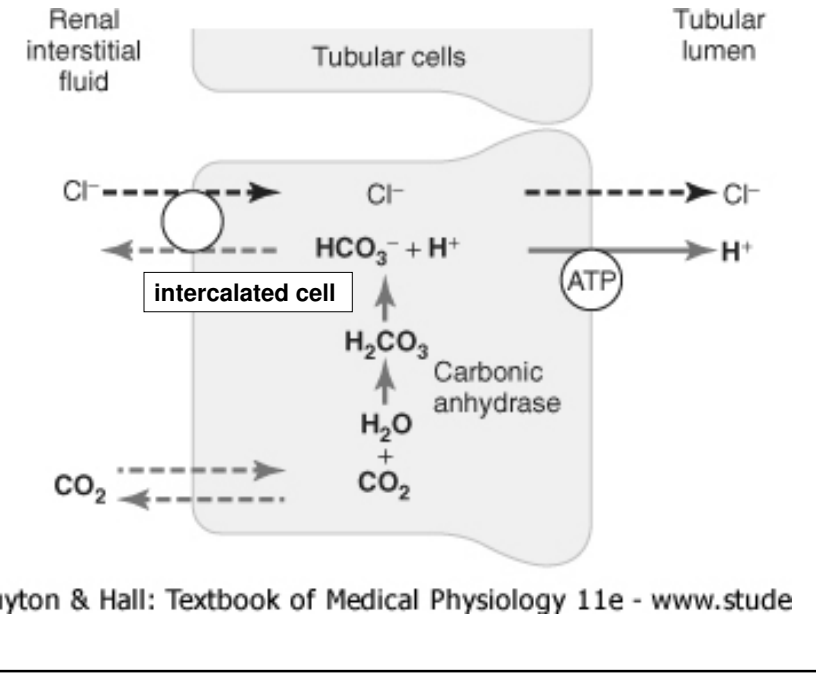
Renal interstitial fluid
Tubular cells
Tubular lumen
Cl–
Cl–
Cl–
HCO3– + H+
H+
ATP
intercalated cell
H2CO3
Carbonic anhydrase
H2O
+
CO2
CO2
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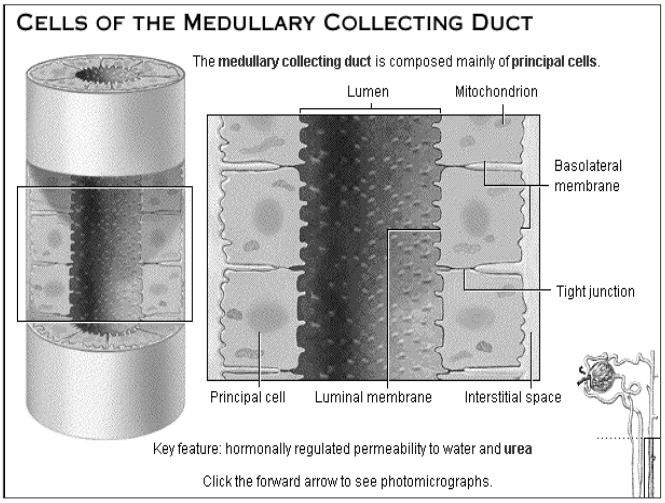
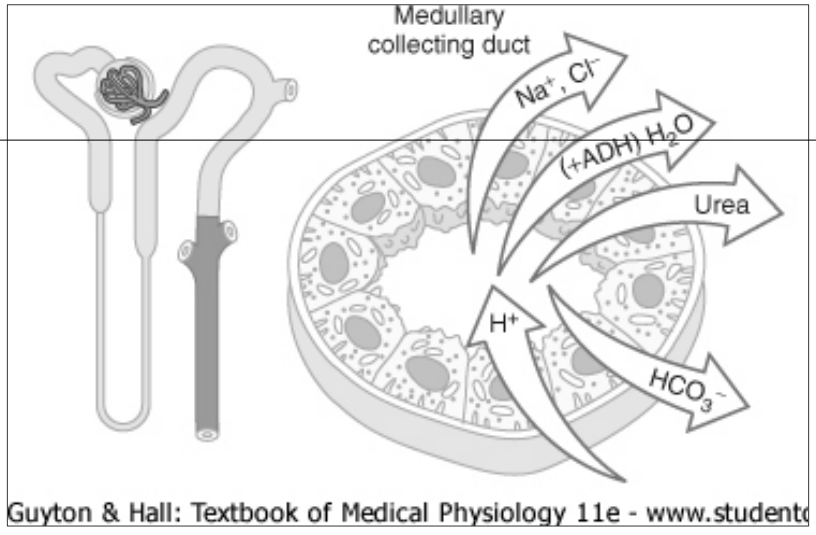
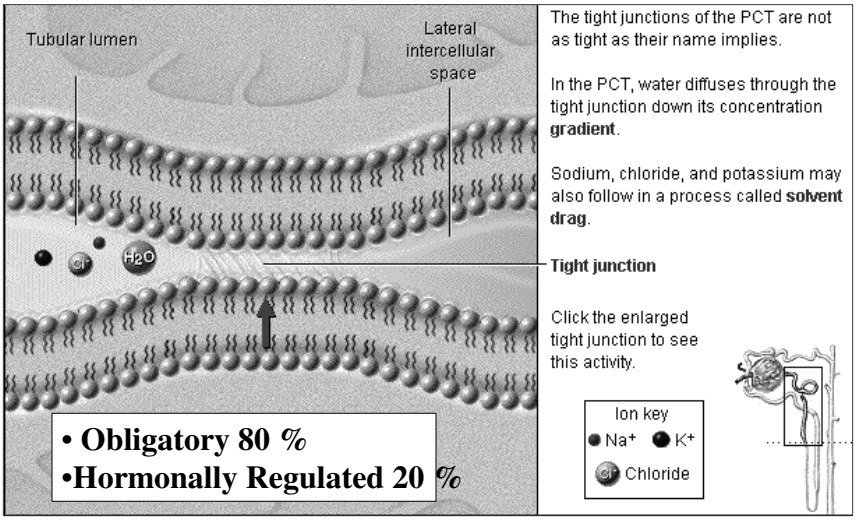
MEDULLARY COLLECTING DUCT





PCT PARACELLULAR PATHWAY



REABSORPTION OF WATER IN DIFFERENT SEGMENTS OF TUBULES

PART OF NEPHRON	PERCENTAGE REABSORBED
Proximal tubules	65
Loop of Henle	15
Distal tubules	10
Collecting ducts	9.3
Passing into urine	0.7

REABSORPTION OF WATER IN DIFFERENT SEGMENTS OF TUBULES

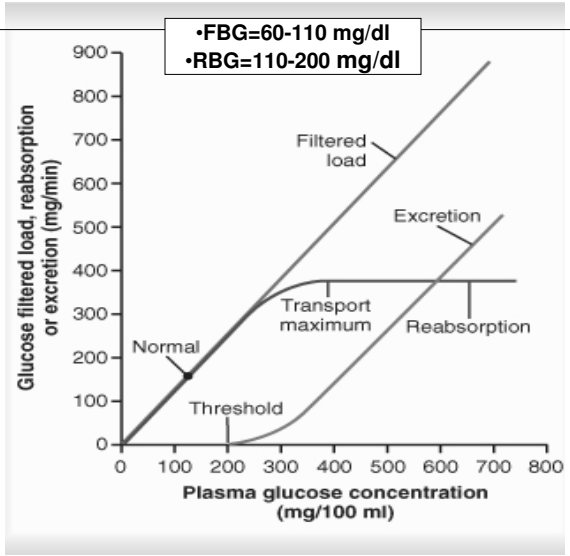
PART OF NEPHRON	AMOUNT REABSORBED
Glomerular Filtrate	125
Flowing into the loops of Henle	45
Flowing into the distal tubules	25
Flowing into the collecting tubules	12
Flowing into the urine	1

GLUCOSE REABSORPTION

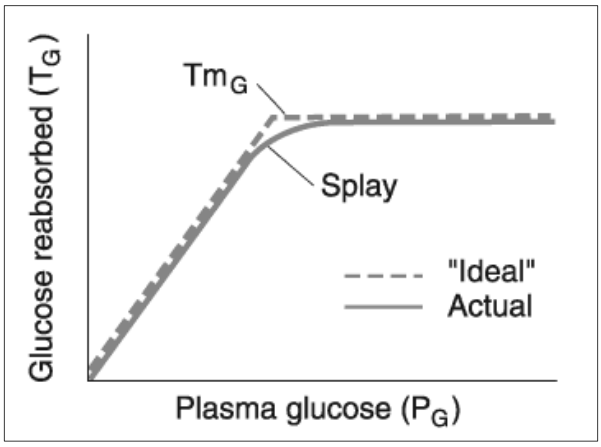
Tmax
375 mg/min

Filtered Load
125 mg/min
(GFRxPlasmaGlu)

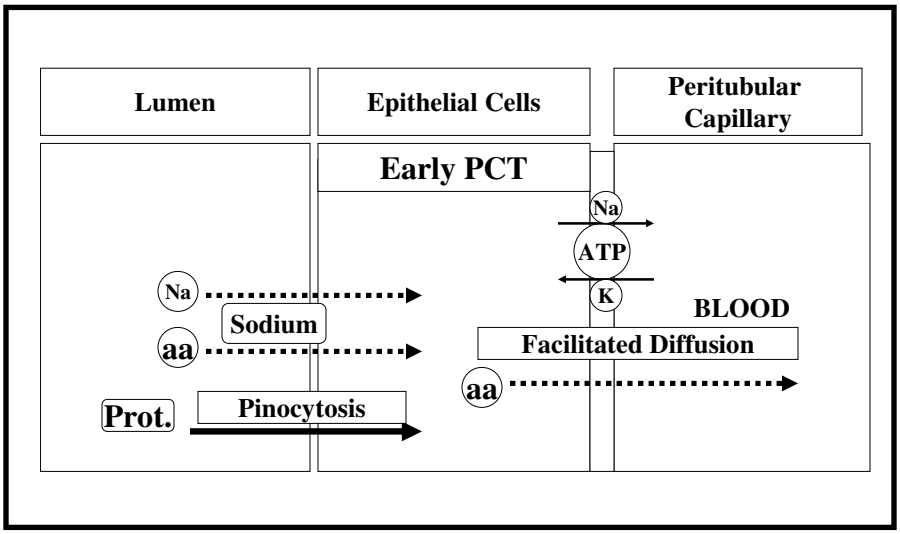
Renal Threshold
200mg/dl



GLUCOSE REABSORPTION



AMINO ACIDS REABSORPTION IN NEPHRON



TUBULAR TRANSPORT MAXIMUM

- **The Maximum limit/rate at which a solute can be transported across the tubular cells of kidneys is called TUBULAR TRANSPORT MAXIMUM**

Tm for Glucose is 375 mg/min

TUBULAR TRANSPORT MAXIMUM FOR DIFFERENT SUBSTANCES

SUBSTANCE	Tm
Glucose	375 mg/min
Phosphate	0.1 mM/min
Sulfate	0.06 mM/min
Amino Acids	1.5 mM/min
Urate	15 mg/min
Plasma Protein	30 mg/min
Hemoglobin	1 mg/min
Lactate	75 mg/min
Acetoacetate	variable

Transport Maximums for Substances That Are Actively Secreted

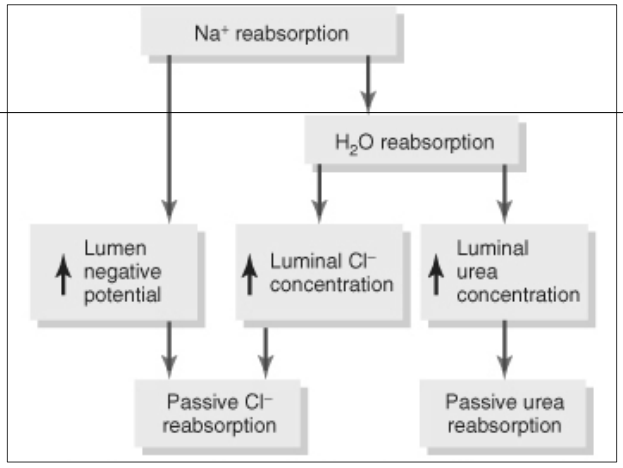
Substance	Transport Maximum
Creatinine	16 mg/min
Para-aminohippuric acid	80 mg/min

gradient-time transport

- (1) the electrochemical gradient for
- diffusion of the substance across the membrane,
- (2) the permeability of the membrane for the substance,
- and (3) the time that the fluid containing the substance remains within the tubule.

SODIUM HANDLING

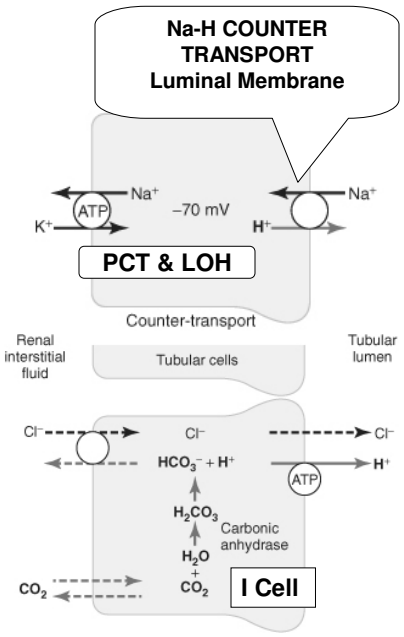
SITE	APICAL TRANSPORTER	FUNCTION
Proximal Tubule	•Na/Gluc CT •Na/Pi CT •Na/Amino Acid •Na/Lactate •Na/H Exchanger •Cl/Base Exchanger	•Na & Gluc Uptake •Na & Pi Uptake •Na & AA Uptake •Na & Lactate Uptake •Na Uptake and H Extrusion •Cl Uptake
Thick Ascending Limb	• Na, 2 Cl,, K CT •Na/H Exchanger •K Channels	•Na, 2 Cl,, K Uptake •Na Uptake and H Extrusion •K Extrusion
EarlyDCT	NaCl CT	Na & Cl Uptake
Late DCTCollecting Duct	Na Channel (ENaC)	Na Uptake

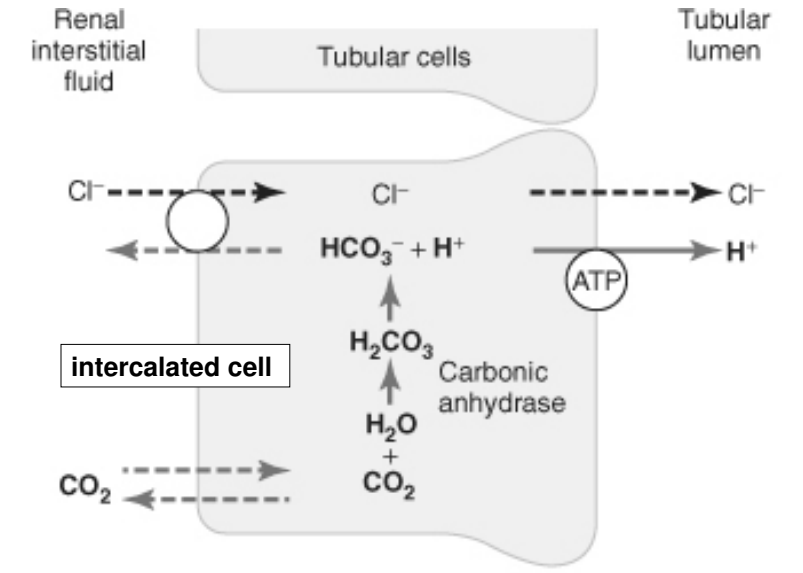


Active reabsorption of sodium coupled to the passive reabsorption of chloride

HYDROGEN

- **Secreted in Proximal Tubule and Thick ascending LOH by Counter Transport with Na**
- **Secreted in DCT by H ATP ase**





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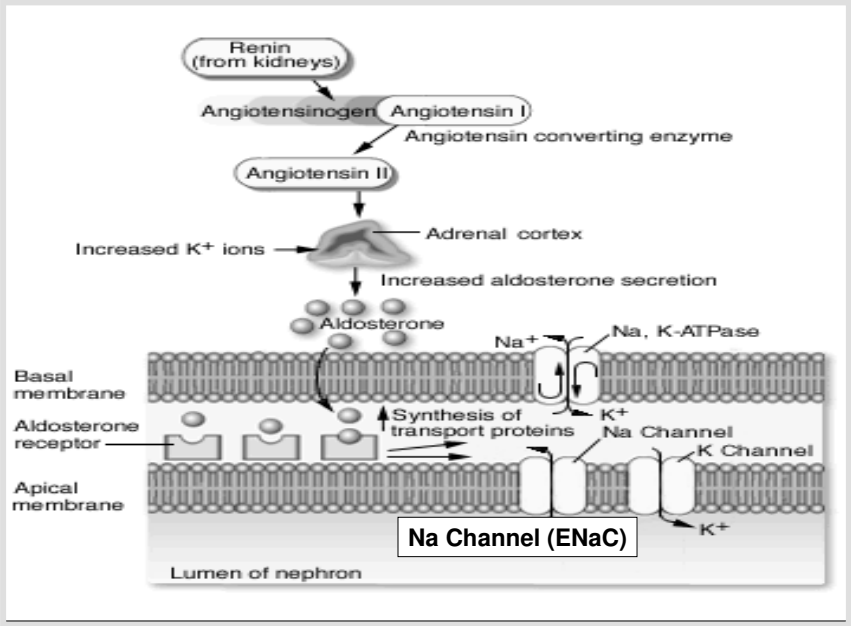
Effect Of Aldosterone On Cortical Collecting Duct



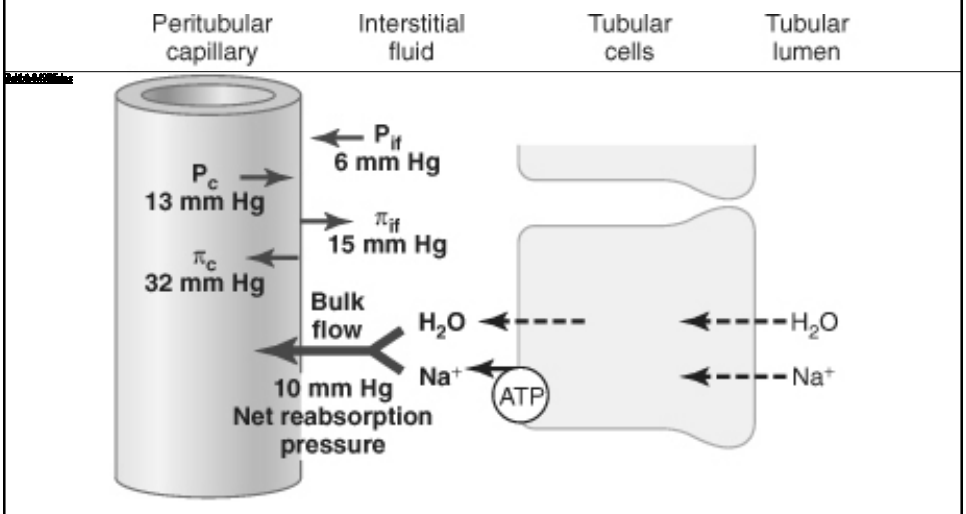
UREA

- **Plasma concentration is 2.5 – 7.5 mmol/L**
- **50 % is reabsorbed in PCT passively with water**
- **It is the only waste to be reabsorbed**
- **Creatinine and Phenol are not reabsorbed.**

POTASSIUM

- It is both reabasorbed and secreted
- 67% of filtered load is reabsorbed by PCT
  - solvent drag
- secreted by Thick Asc LOH, early distal tubule / collecting duct
  - correlated with dietary intake
    - 80% of filtered load appears in urine if dietary content high
    - 1% if dietary content low

PERITUBULAR CAPILLARY AND RENAL INTERSTITIAL FLUID PHYSICAL FORCES



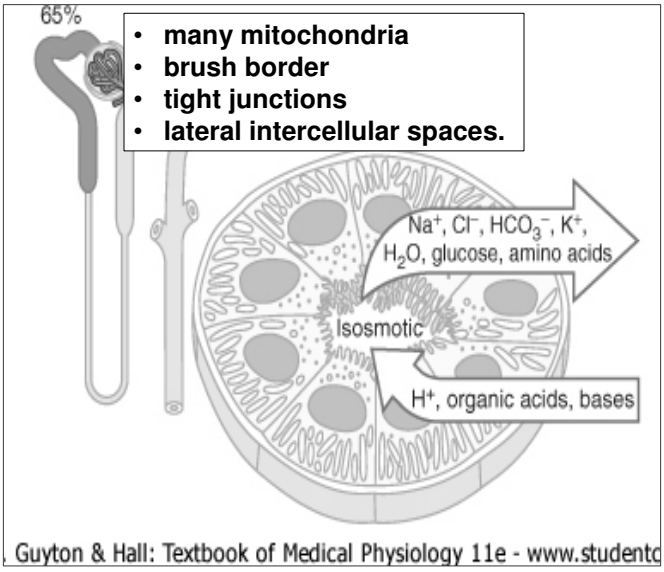
TUBULAR SECRETION

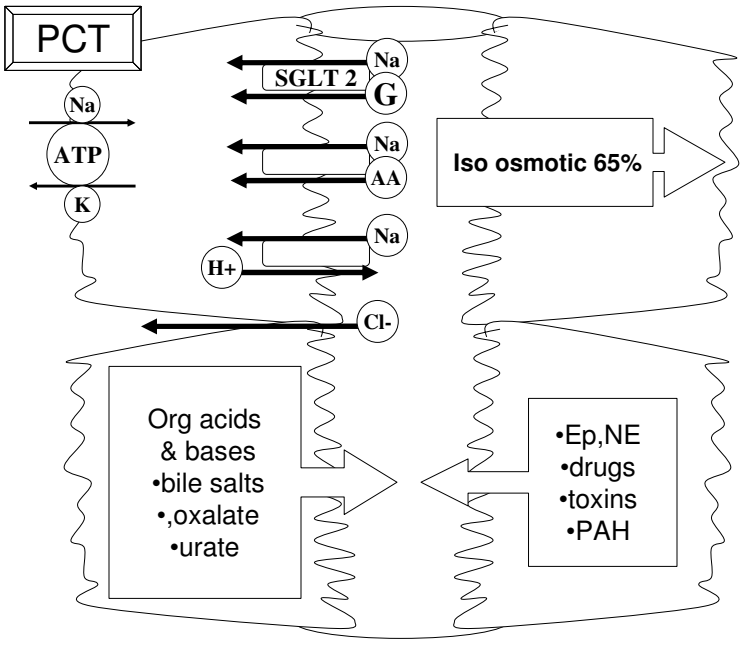
- Tubular Secretion may be by Passive or Active Mechanisms
- The most important secretory processes are for H, K and Organic Ions

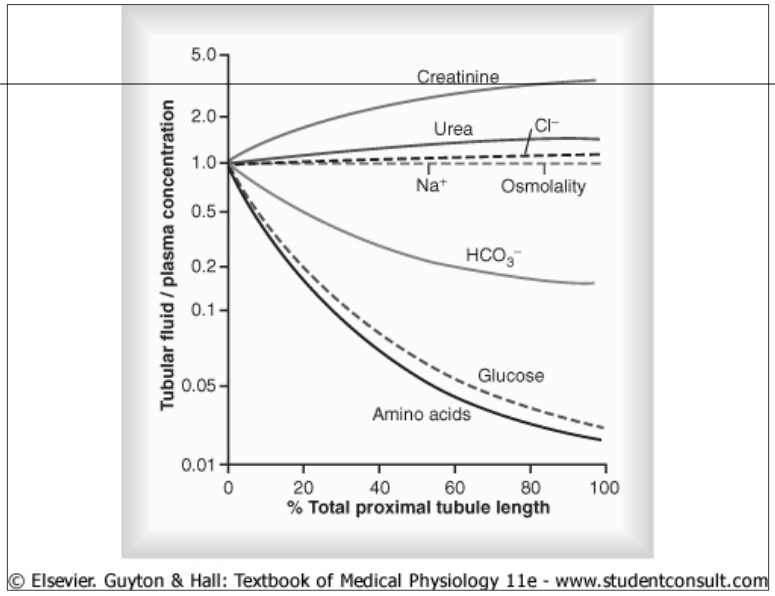
HYDROGEN

- Secreted in Proximal Tubule by Counter Transport with Na
- In DCT and CT it is secreted by Hydrogen ATP ase
- When body fluids are more acidic H secretory process is accelerated and Vice Versa

PROXIMAL CONVOLUTED TUBULE

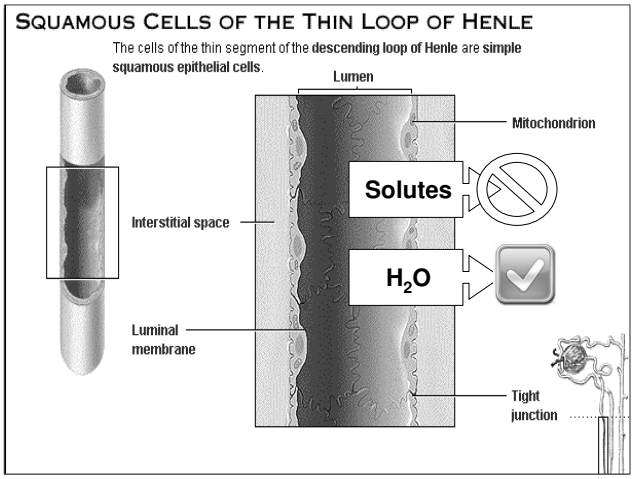






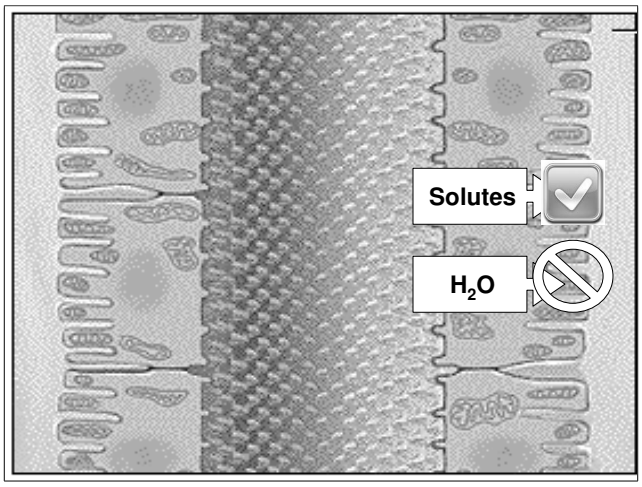
THIN DESCENDING SEGMENT OF LOOP OF HENLE

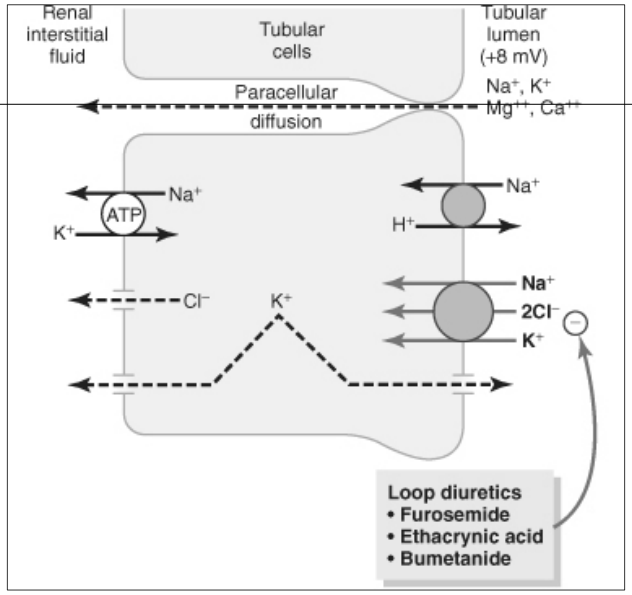
- **few mitochondria**
- **flattened with few microvilli**

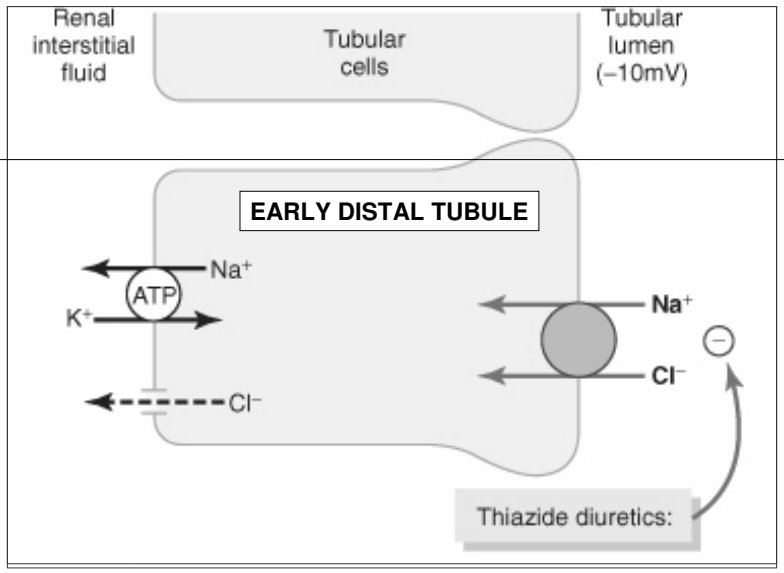


THICK ASCENDING LOOP OF HENLE AND EARLY DCT

Many mitochondria and microvilli, but fewer than in the proximal tubule

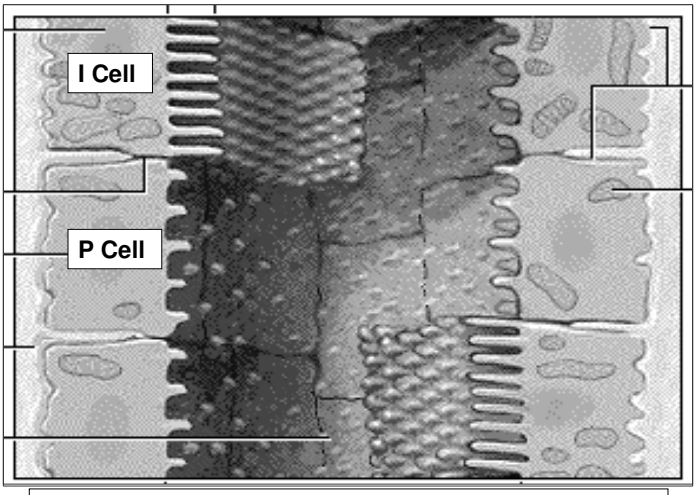




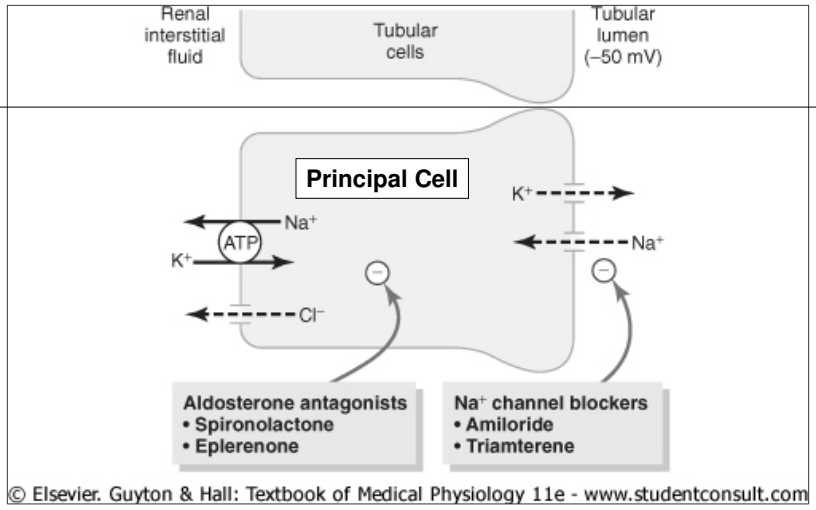


Mechanism of sodium chloride transport in the early distal tubule

LATE DCT AND CORTICAL COLLECTING DUCT



- **Principal Cells (Na Abs and ADH related Water abs)**
- **Intercalated Cells (Acid Sec and HCO3 Transport)**


Renal interstitial fluid
Tubular cells
Tubular lumen (–50 mV)
Principal Cell
Na+
ATP
K+
Cl–
K+
Na+
Aldosterone antagonists
• Spironolactone
• Eplerenone
Na+ channel blockers
• Amiloride
• Triamterene
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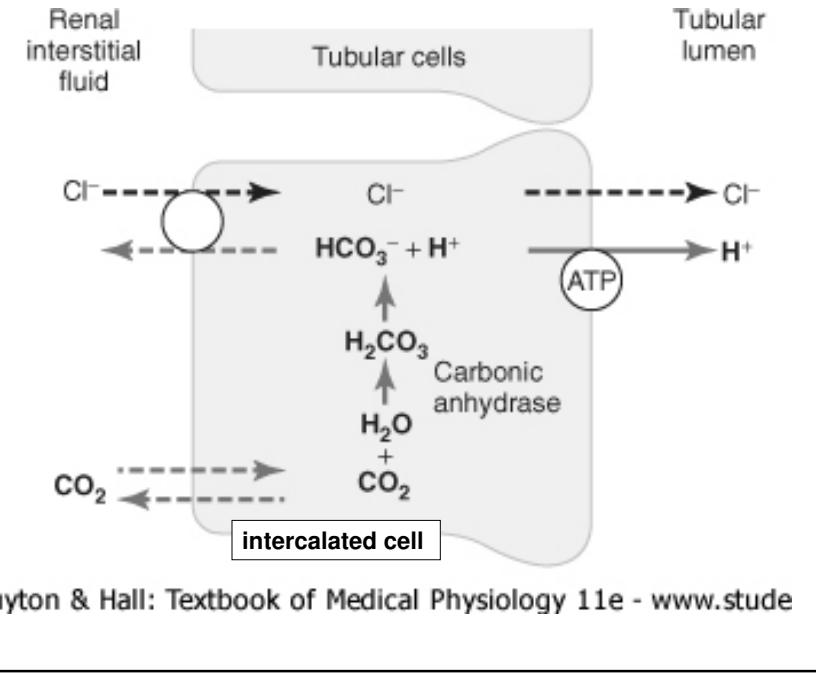
Renal interstitial fluid
Tubular cells
Tubular lumen
Cl–
Cl–
Cl–
HCO3– + H+
H+
ATP
H2CO3
Carbonic anhydrase
H2O
+
CO2
CO2
intercalated cell
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