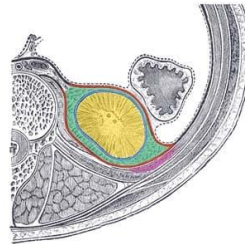


Topic 20: Introduction to Kidney Physiology

- Systems: Renal, Endocrine, Cardiovascular, Fluid & Electrolyte
- **Filtration:** Blood is filtered in the glomerulus to form initial filtrate.
- **Reabsorption:** Useful water, ions, and nutrients are returned to the bloodstream.
- **Secretion:** Additional wastes, acids, and drugs are moved from blood into the tubule.
- _____: Final urine is eliminated from the body.

Major Functions of the Kidney

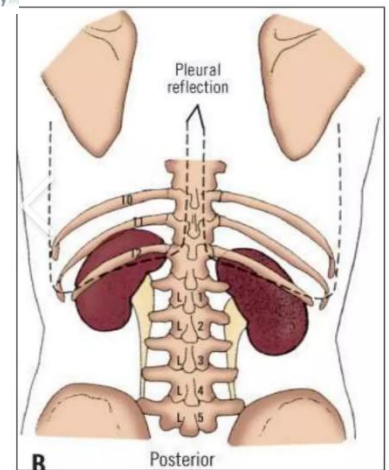
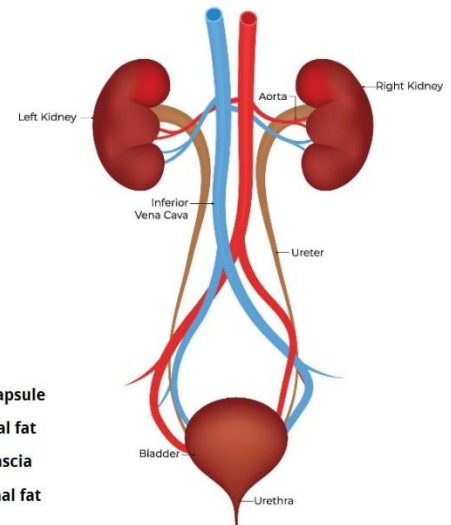
- _____: Removal of metabolic wastes (urea, creatinine)
- Fluid balance: Regulation of total body water
- Electrolyte regulation: Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^-
- Acid-base homeostasis: Maintaining blood _____
- Endocrine function:
 - Erythropoietin (EPO): stimulates RBC formation
 - Renin: regulates blood pressure
 - Calcitriol: active vitamin D for calcium absorption (Calcitriol is the active form of Vit D and your kidneys make Vit D you get from the sunlight, food and supplements) Calcitriol (from kidneys) helps the intestines absorb more calcium by increasing the number of transport protein in the intestinal wall.
 - Calcitonin (different): (from the thyroid gland) lowers blood calcium via inhibiting osteoclasts in the bone and increasing calcium excretion in the kidney. Calcitonin is not as powerful as PTH or calcitriol in everyday calcium control.



- Kidney
- Renal capsule
- Perirenal fat
- Renal fascia
- Pararenal fat

© TeachMeAnatomy

Urinary System Diagram



Homeostasis: The body's ability to maintain stable internal conditions

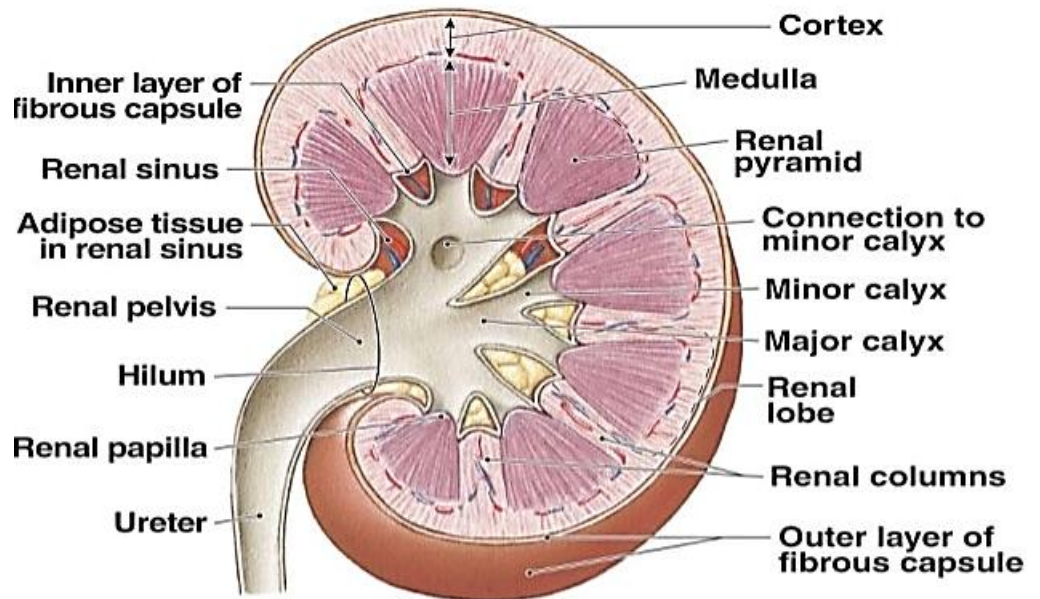
- Kidneys play a primary role by adjusting urine volume and composition

Kidney Location & Protection

- _____:
- Behind the peritoneum (abdominal lining)
- Location: T12–L3 vertebrae
- Protection: Renal capsule, adipose capsule, renal fascia

Kidney Internal Anatomy

- Cortex: outer region → contains most nephrons
- Medulla: pyramids → concentrates urine
- Renal pelvis: funnel to ureter
- Hilum: entry/exit point for blood vessels & ureter

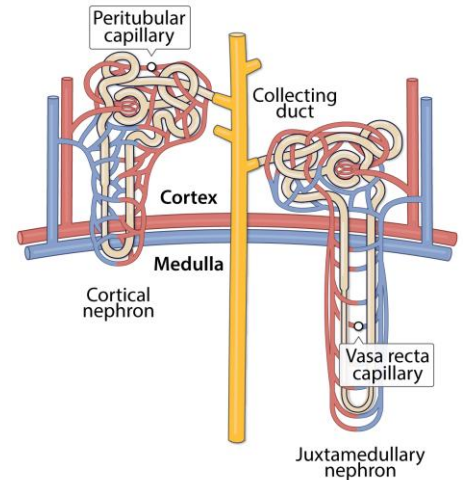


(a) Frontal section of left kidney, anterior view

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Nephron Overview

- Nephron: Functional filtration unit of kidney
- 1.2 million per kidney
- Two types:
 - _____ nephrons: Short loops → standard filtration
 - Juxtamedullary nephrons: Long loops → create concentrated urine



Blood Supply to Nephrons

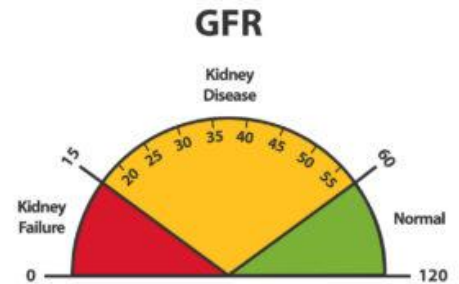
- Renal artery → afferent arteriole → glomerulus → efferent arteriole
- Two capillary networks:
 - Peritubular capillaries: reabsorption
 - Vasa recta: preserves medullary gradient

Glomerulus Structure

- _____: specialized cells with filtration slits
- Fenestrated capillaries: allow plasma movement but block cells
- Basement membrane: negatively charged → prevents protein loss

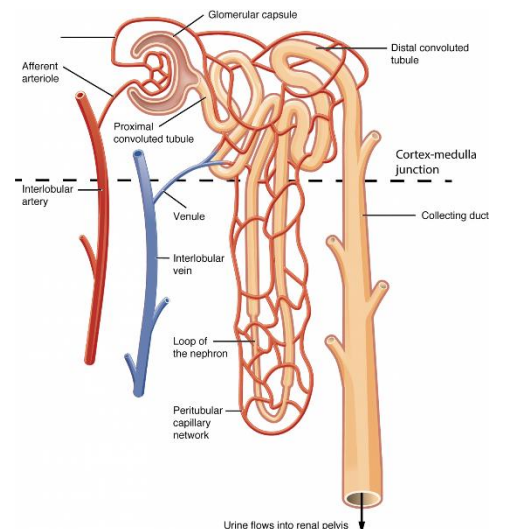
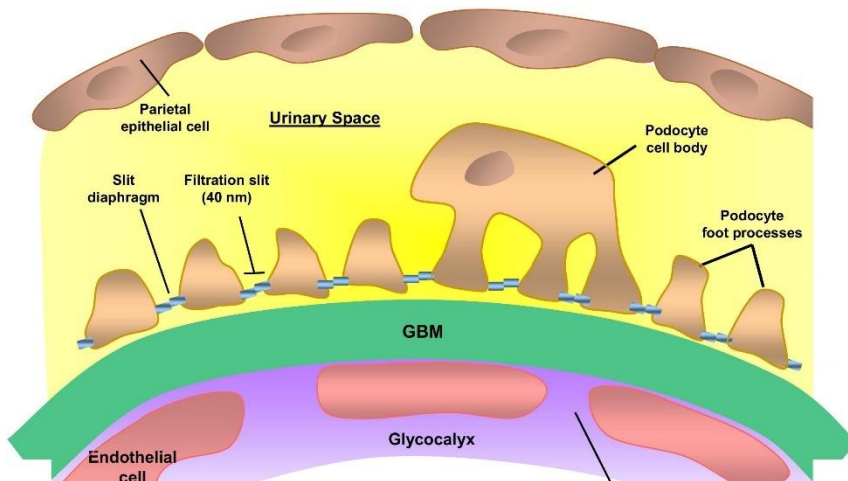
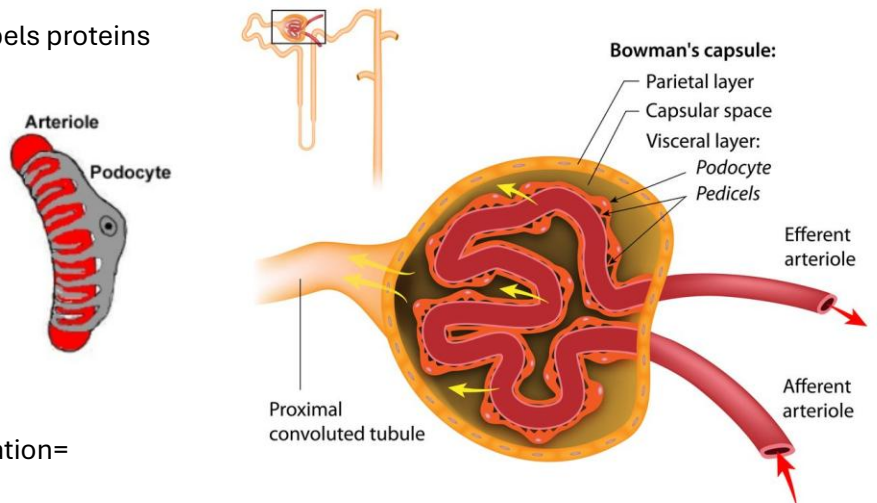
Filtration Membrane

- 3 layers: endothelium → basement membrane → podocyte slit diaphragm
- Selectivity:
 - Size: small molecules pass
 - Charge: negative membrane repels proteins

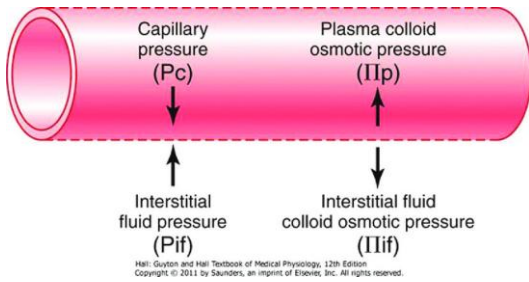


GFR (Glomerular Filtration Rate)

- Definition: Volume of plasma filtered per minute
- Normal: ~125 mL/min
- Measured by: creatinine, inulin, cystatin C
- Clinical importance: early indicator of kidney disease
- What affects GFR: afferent arteriole dilation = increases GFR; Afferent arteriole constriction = decreases GFR

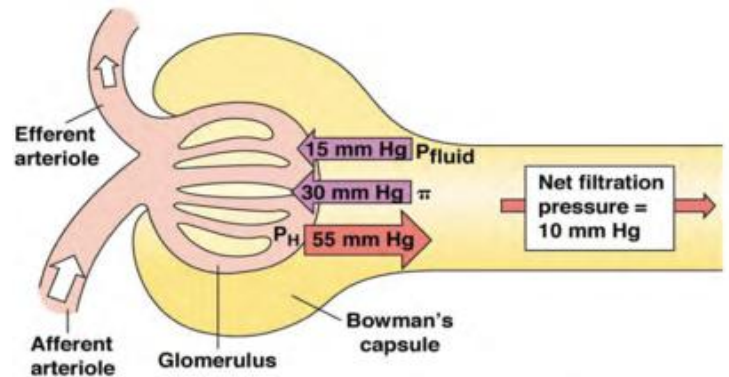


REGULATION OF FILTRATION



Starling Forces in KIDNEY (The 3 that matter)

- Forces favoring filtration (Increases GFR)
 - Glomerular capillary hydrostatic pressure (P_{Gc}) → *major driver*
 - Pushes fluid out of the capillary → into Bowman's space
 - The blood pressure inside the glomerulus
 - Usually around 55mmHg
- Forces opposing filtration (these decrease GFR)
 - Bowman's space hydrostatic pressure (P_{Bs})
 - Pushes fluid back into the capillary
 - This is from the pressure of fluid already in bowman's space, about 15mmHg
 - Glomerular capillary oncotic pressure (π^{Gc})
 - Pulls water back into the blood, caused by proteins in the glomerular capillaries, starts around 30mmHg and increases as plasma water leaves
 - Bowman's space oncotic pressure (π^{Bs}) → ≈ zero, usually ignored (due to the 3 filtration layers)
- Net filtration Pressure (NFP) = determines the filtration rate (forces favoring filtration – forces opposing filtration)



$$P_H - \pi - P_{fluid} = \text{net filtration pressure}$$

$$55 \text{ mm Hg} - 30 \text{ mm Hg} - 15 \text{ mm Hg} = 10 \text{ mm Hg}$$

KEY

- P_H = Hydrostatic pressure (blood pressure)
- π = Colloid osmotic pressure gradient due to proteins in plasma but not in Bowman's capsule
- P_{fluid} = Fluid pressure created by fluid in Bowman's capsule

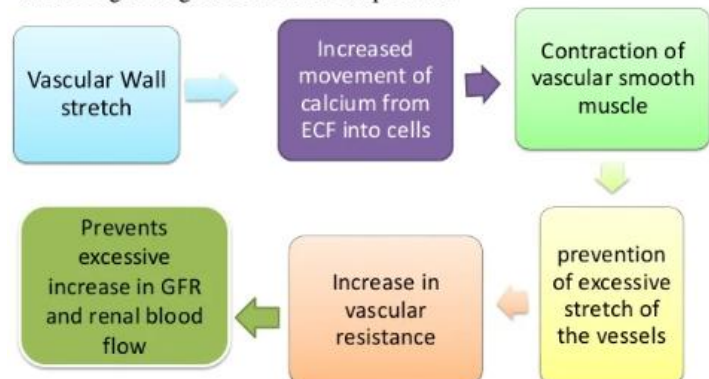
Juxtaglomerular Apparatus (JGA)

- _____ : monitors tubular sodium
- JG cells: release renin
- Mesangial cells: regulate filtration surface area

Autoregulation: Myogenic Mechanism

- Definition: Vessel responds to stretch
- ↑ BP → arteriole constricts automatically → protects glomerulus
- The myogenic mechanism is the kidney's automatic response where the afferent arteriole adjusts (contracts or relaxes) to keep GFR constant despite changes in blood pressure.
- Why it matters:
 - Prevent damage to the glomerulus from high pressure
 - Maintain stable GFR
 - Works intrinsically
 - Based on stretch of the smooth muscle (no nerves/hormones)

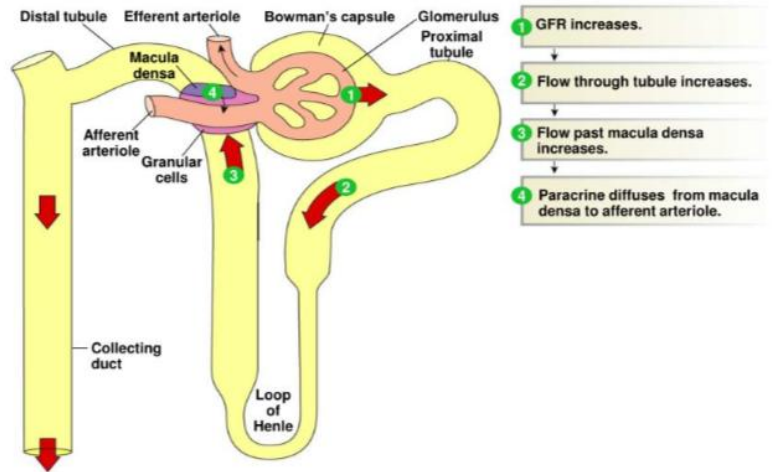
Ability of individual blood vessels (small arterioles) to resist wall stretching during increased arterial pressure



- Blood pressure rises → afferent arteriole stretches → smooth muscle contracts → reduces blood flow into glomerulus → keeps GFR stable
- Blood pressure falls → afferent arteriole relaxes → smooth muscle dilates → increases blood flow into glomerulus → keeps GFR stable

Tubuloglomerular Feedback

- Macula densa senses NaCl in distal tubule
- If NaCl ↑ → afferent arteriole constricts → ↓ GFR
- Maintains stable filtration despite BP changes

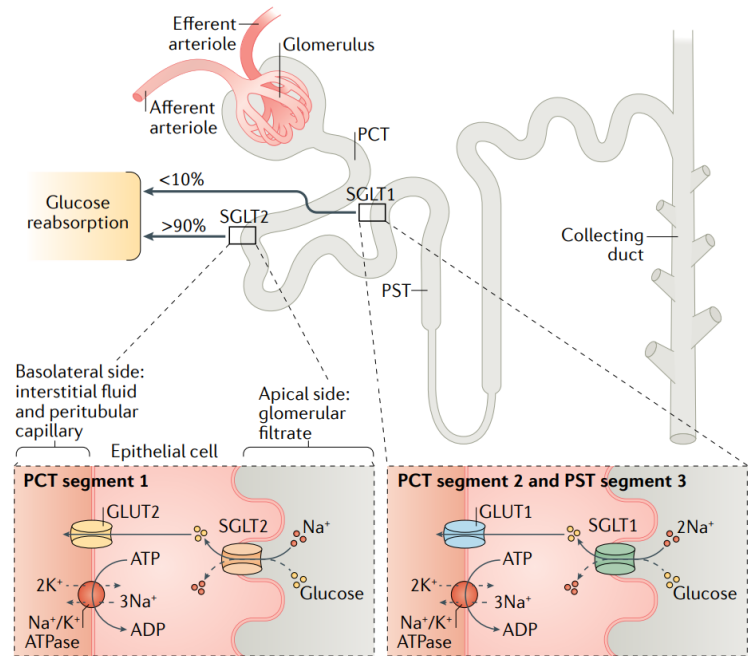


Proximal Tubule Importance

- Reabsorbs ~65% of filtrate
- Na⁺/K⁺ ATPase pump: drives all reabsorption
- Reabsorbs: glucose, amino acids, bicarbonate, water. Secretes: drugs, toxins, H⁺ ions

Glucose Reabsorption

- _____ transporter: early PCT (90%)
- _____ transporter: late PCT (10%)
- Transport maximum (T_m): limit to glucose handling → glycosuria in diabetes mellitus

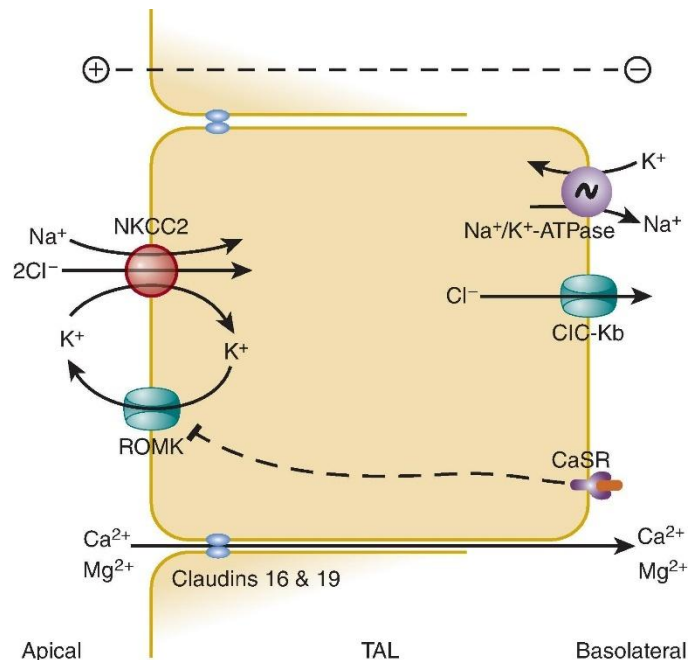
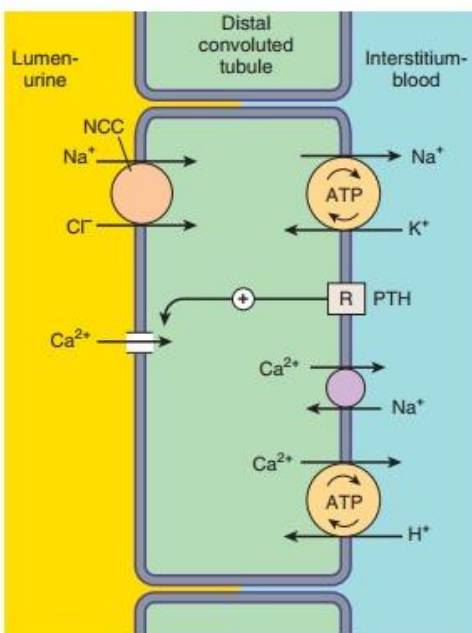


Loop of Henle: Descending Limb

- Permeable to water only
- Concentrates filtrate

Loop of Henle: Ascending Limb

- Impermeable to water
- Na⁺, K⁺, Cl⁻ reabsorption via NKCC2 transporter
- Dilutes filtrate



Distal Convolved Tubule

- Fine regulation of Na^+ and Ca^{2+}
- PTH: increases Ca^{2+} reabsorption
- Thiazide diuretics: block NaCl transporter

Collecting Duct Overview

- Principal cells: water & sodium handling
- Intercalated cells: acid-base balance
- Final urine concentration determined here

ADH: Antidiuretic Hormone

- Released from posterior pituitary
- Inserts aquaporin water channels
- Triggered by:
 - \uparrow plasma osmolality
 - \downarrow blood pressure
 - dehydration

Aldosterone

- Released from adrenal cortex (zona glomerulosa)
- Increases Na^+ reabsorption, K^+ secretion
- Triggered by:
 - \uparrow K^+ , Angiotensin II
- Increases ENaC Channels (DT and CD)

Sodium Balance

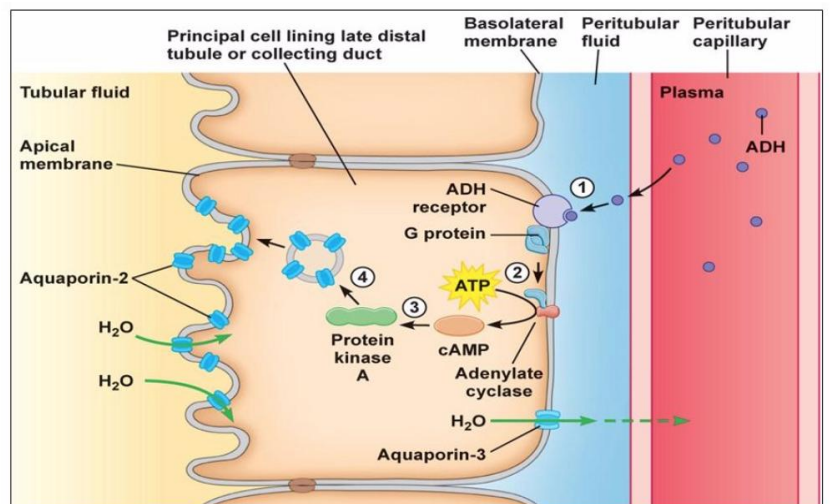
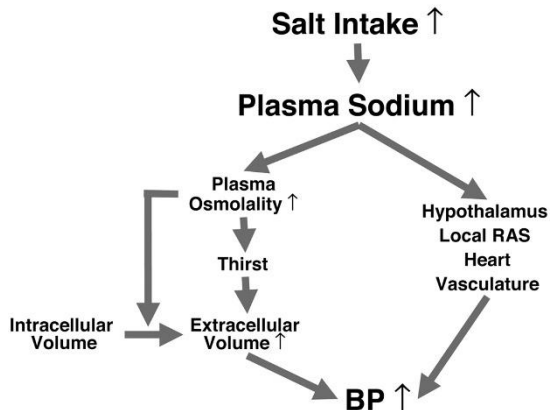
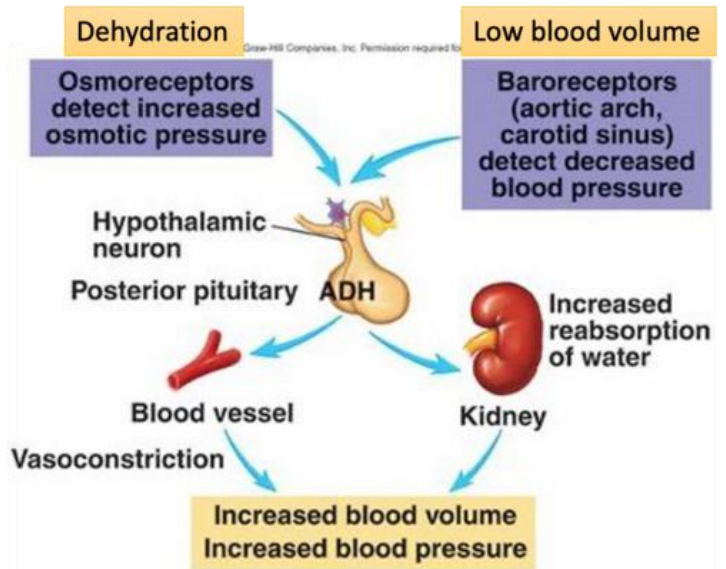
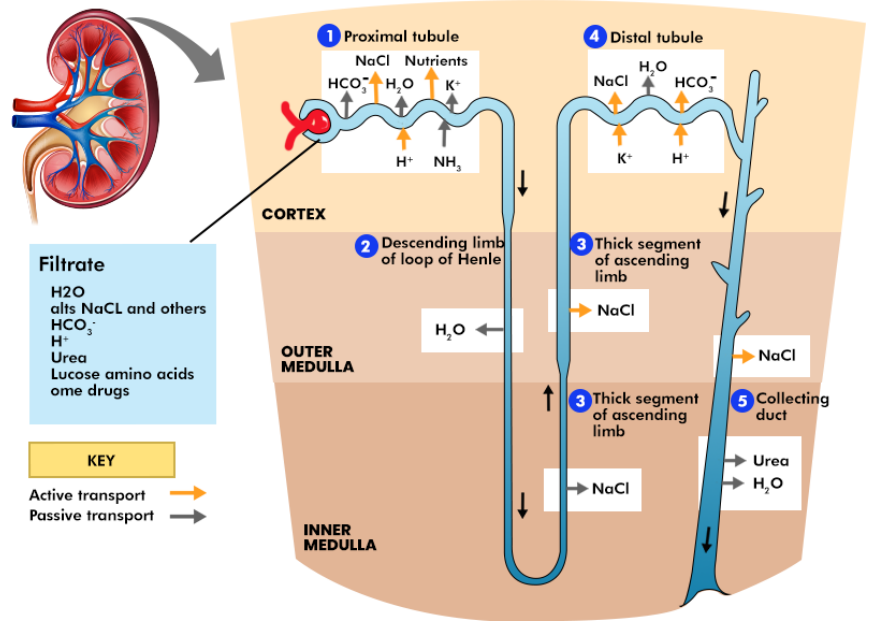
- Na^+ determines extracellular fluid volume
- High Na^+ \rightarrow water retention \rightarrow \uparrow blood pressure
- Hormonal controls: aldosterone, ANP, ADH

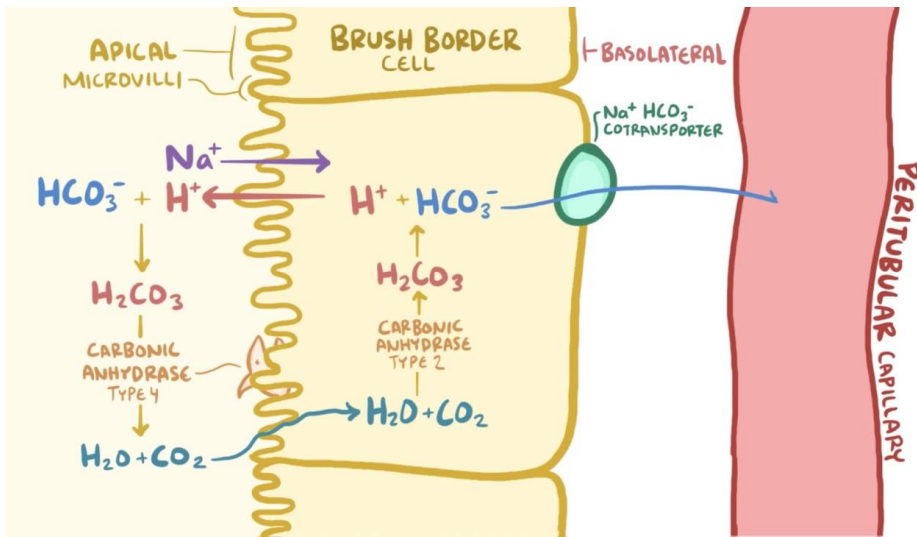
Potassium Physiology

- Main intracellular cation
- Regulated by aldosterone
- Acidosis \rightarrow shifts K^+ out of cells
- Alkalosis \rightarrow shifts K^+ into cells

Calcium & Phosphate Balance

- PTH increases Ca^{2+}
- Vitamin D increases Ca^{2+} AND phosphate
- Kidneys activate vitamin D \rightarrow "calcitriol"





Acid-Base Homeostasis

- Kidneys regulate H^+ secretion and HCO_3^- reabsorption
- Long-term pH regulation
- Disturbances: acidosis vs alkalosis

Bicarbonate Reabsorption

- PCT reabsorbs 90% of filtered bicarbonate
- Carbonic anhydrase converts $H_2CO_3 \rightarrow CO_2 + H_2O$
- CO_2 reabsorbed \rightarrow forms new HCO_3^- inside cells

Urea Recycling

- Helps maintain medullary osmotic gradient (conserves water, concentrates urine, pulls water out of CD)
- Urea comes from the liver (ammonia during metabolism) and then carried to the glomerulus
- Allows concentration of urine

Renal Clearance (not on the slides)

- Definition: Volume of plasma completely cleared of a substance per minute
- Used to estimate GFR, renal blood flow, secretion, and reabsorption

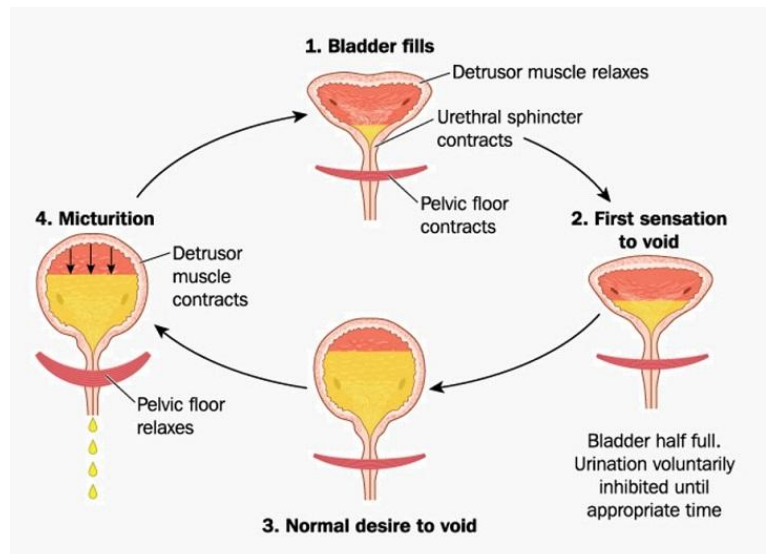
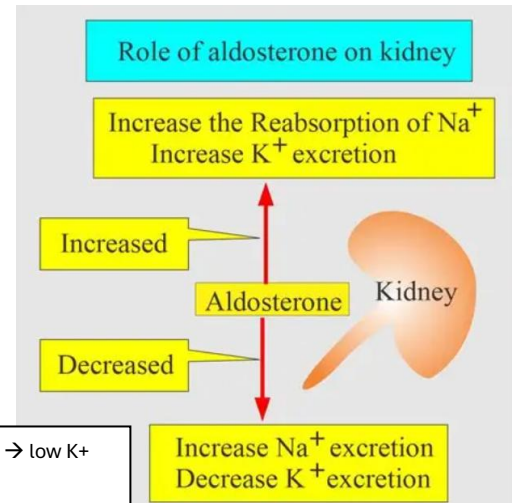
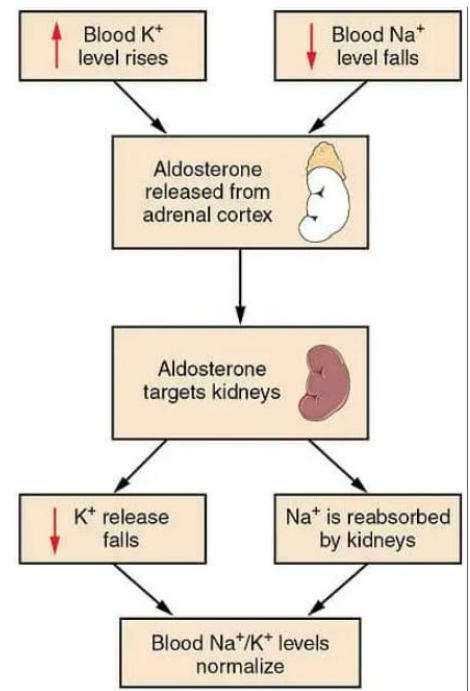
Creatinine as GFR Marker

- Byproduct of muscle metabolism
- Freely filtered, minimally secreted
- Used clinically to estimate GFR
- High creatinine \rightarrow kidneys aren't filtering = low GFR
- Low creatinine \rightarrow kidneys are filtering well = normal/high GFR

DISORDERS & HORMONAL SYSTEMS

Micturition (Urination)

- Bladder stretch receptors
- Parasympathetic activation \rightarrow detrusor contraction
- Voluntary control via external sphincter



Diabetes Mellitus vs. Diabetes Insipidus

Diabetes Mellitus:

- High blood glucose → glycosuria → osmotic diuresis

Diabetes Insipidus (DI):

- Definition: Inability to concentrate urine due to lack of or resistance to ADH
- Central DI: Low ADH production
- Nephrogenic DI: Kidneys do not respond to ADH
- Produces large volumes of dilute urine

Acute Kidney Injury (AKI)

- Prerenal: low perfusion
- Intrinsic: glomerular or tubular damage
- Postrenal: obstruction
- Rapid decrease in GFR

Chronic Kidney Disease (CKD)

- Progressive loss of function
- Stages defined by GFR
- Complications: anemia, bone disease, electrolyte imbalance

Proteinuria & Hematuria

- _____: glomerular damage (protein in urine)
- Hematuria: blood in urine (glomerular or post-renal causes)

RAAS Introduction

RAAS = Renin-Angiotensin-Aldosterone System

Critical hormonal system to regulate blood pressure & volume

Renin Release Triggers

- ↓ renal perfusion, ↓ NaCl at macula densa
- Sympathetic activation (β1 receptors)

Angiotensin II Effects

- Potent vasoconstriction
- Stimulates aldosterone release
- Increases thirst & ADH
- Constricts efferent arteriole → maintains GFR during low BP

Aldosterone Actions

- ↑ Na⁺ reabsorption; ↑ K⁺ secretion
- Works in distal nephron & collecting duct

Integrated RAAS Summary Diagram

- Renin → Angiotensin I → Angiotensin II → Aldosterone
- Maintains blood pressure, blood volume, and perfusion
- Works together with ADH and sympathetic nervous system

Diabetes Insipidus Lack of Response to ADH

- ✓ Polyuria, polydipsia. Hypernatremia if water is limited.



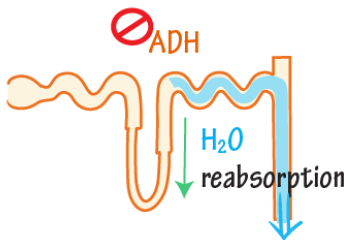
Central DI

- ✓ Lack ADH secretion.
- Idiopathic, brain injury, surgery, infiltrative infections/tumors.



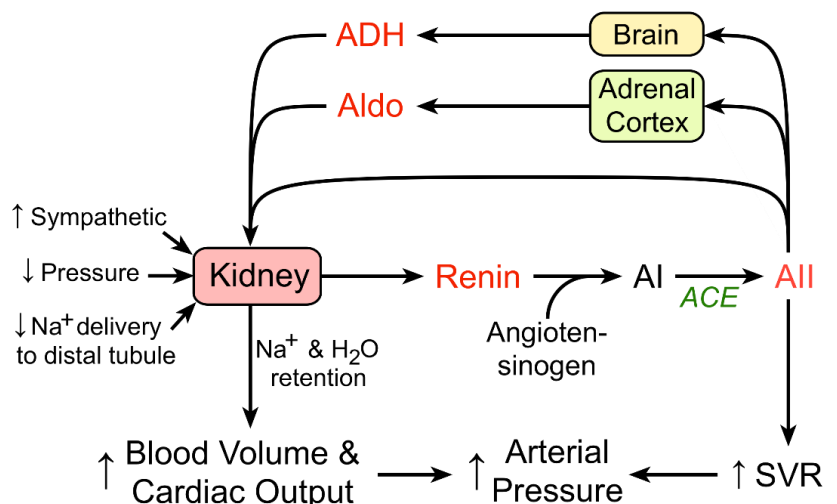
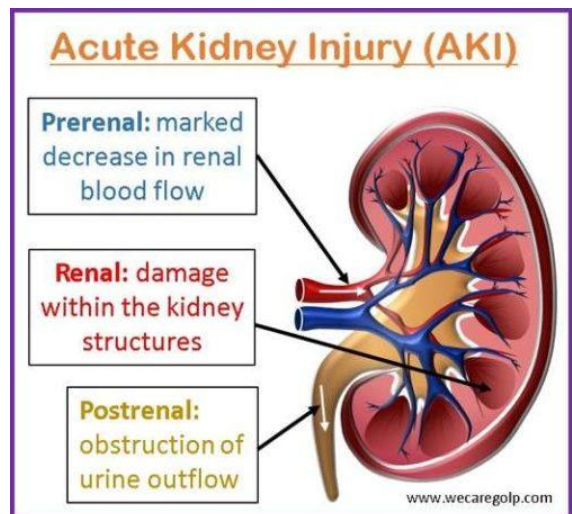
Nephrogenic DI

- ✓ ADH receptor/response defects
- Inherited receptor or aquaporin defects.
- Acquired: drugs (lithium, foscarnet, clozapine), infiltrating infections, Sickle cell, Hypercalcemia/hypokalemia, Pregnancy.

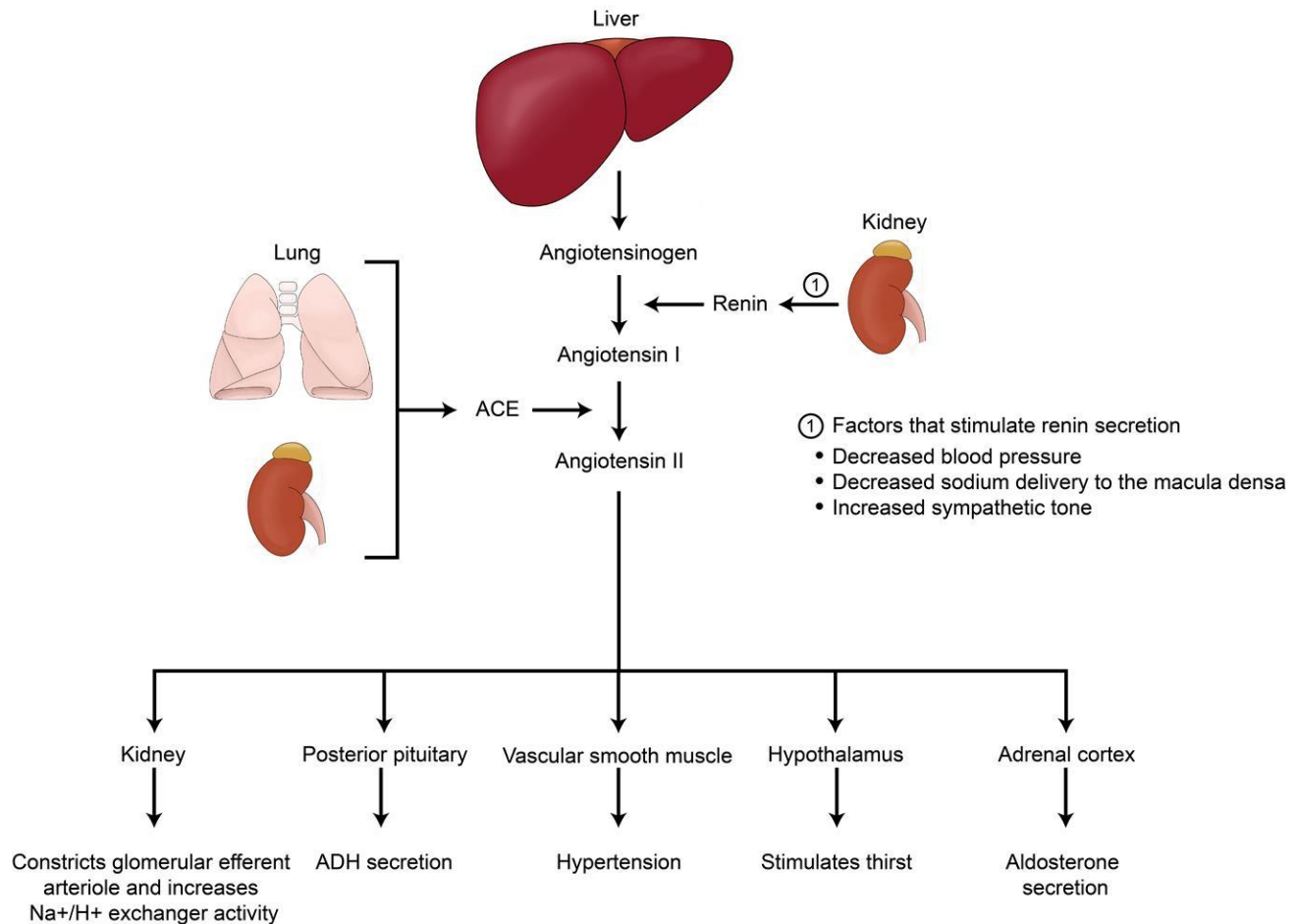


§ Desmopressin, Treat underlying cause.

- Hypovolemia
- Dehydration
- Weakness
- Fatigue
- Nocturia



Renin-Angiotensin-Aldosterone System



1. Kidney Detects a Problem

On the left, the kidney releases **Renin**.

The kidney releases renin when:

- Blood pressure drops
- Blood volume is low
- Sodium levels are low
- Sympathetic nervous system is activated

Renin = **starter enzyme** of the whole system.

2. Renin Converts Angiotensinogen → Angiotensin I

Renin acts on a liver protein called **angiotensinogen** and turns it into **Angiotensin I**.

This step isn't shown directly, but it's understood.

3. ACE Converts Angiotensin I → Angiotensin II

The image shows **ACE** written in green.

ACE = **Angiotensin Converting Enzyme**

Found mostly in the lungs.

ACE turns **Angiotensin I** → **Angiotensin II (All)**

Angiotensin II is the **main "action" hormone**.

4. Angiotensin II (All) Effects

The diagram shows arrows from All pointing to:

✓ Adrenal Cortex

All tells the adrenal glands to release **Aldosterone (Aldo)**.

✓ Brain

All tells the brain to release **ADH** and also increases thirst.

✓ Direct effects on blood vessels

Angiotensin II **constricts blood vessels**, raising blood pressure.

So All does 3 big things:

1. **Constricts blood vessels** (↑ BP)
2. **Triggers Aldosterone** release (saves sodium & water)
3. **Triggers ADH** release (saves water)

5. Aldosterone (Aldo) Actions — From Adrenal Cortex

Aldosterone (in red in the top of the diagram) acts on the kidney to:

- **Increase sodium reabsorption**
- **Increase water reabsorption** (water follows sodium)
- **Increase potassium secretion**

Overall:

👉 **Raises blood volume and Raises blood pressure**

6. ADH Actions — From Brain

ADH (in red) acts on the **collecting duct** of the kidney.

ADH:

- Inserts **aquaporin channels**
- Makes kidneys reabsorb **water only**
- Concentrates urine
- Raises blood volume

Overall:

👉 **Raises BP by saving water**

Topic 20: Introduction to kidney study guide (preppages.com) questions

- Which of the following lists the correct three layers of the glomerular filtration membrane in order from blood → filtrate?
 - Podocyte slit diaphragm → basement membrane → endothelium
 - Endothelium (fenestrated) → basement membrane → podocyte slit diaphragm
 - Endothelium → podocytes → basement membrane
 - Fenestrations → podocytes → glycocalyx
- What structure contains fenestrations that allow plasma to filter but block blood cells?
 - Podocytes
 - Glomerular basement membrane
 - Glomerular capillary endothelium
 - Mesangial cells
- Which Starling force favors filtration in the kidney?
 - Bowman's space hydrostatic pressure
 - Glomerular oncotic pressure
 - Glomerular hydrostatic pressure
 - Bowman's space oncotic pressure
- Which transporter reabsorbs most glucose in the early proximal tubule?
 - GLUT2
 - GLUT1
 - SGLT1
 - SGLT2
- Which part of the nephron is permeable to water but not solutes?
 - Thick ascending limb
 - Distal convoluted tubule
 - Descending limb of Loop of Henle
 - Collecting duct principal cells
- Which part of the nephron uses the NKCC2 transporter?
 - Proximal tubule
 - Thick ascending limb
 - Distal convoluted tubule
 - Collecting duct
- Vasopressin (ADH) acts on which receptor in the collecting duct?
 - V1 receptor
 - V2 receptor
 - M3 receptor
 - AT1 receptor
- ADH causes which change?
 - Removal of aquaporin-1
 - Insertion of aquaporin-2 channels
 - Increased Na^+ reabsorption only
 - Decreased water reabsorption
- Which hormone increases ENaC channels in the collecting duct?
 - ADH
 - Aldosterone
 - PTH
 - ANP
- What is the main function of the juxtamedullary nephrons?
 - Glucose reabsorption
 - Forming dilute urine
 - Concentrating urine
 - Secreting drugs
- Afferent arteriole dilation causes which change?
 - Decreased GFR
 - Increased GFR
 - No effect on GFR
 - Increased urine pH
- Which best describes the myogenic mechanism?
 - Hormonal control of filtration
 - Macula densa sensing NaCl
 - Afferent arteriole constriction when stretched
 - Efferent arteriole dilation
- Which triggers renin release?
 - High NaCl at macula densa
 - Increased blood pressure
 - Sympathetic β_1 activation
 - High blood volume
- Angiotensin II primarily causes which effect?
 - Efferent arteriole dilation
 - Increased GFR by constricting efferent arteriole
 - Decreased aldosterone release
 - Decreased thirst
- Which correctly describes a major effect of PTH in the kidney?
 - Increase phosphate reabsorption
 - Increase calcium reabsorption in the distal tubule
 - Decrease calcium reabsorption
 - Inhibit activation of vitamin D
- What is the primary intracellular cation?
 - Na^+
 - Ca^{2+}
 - K^+
 - Mg^{2+}
- In acidosis, what happens to potassium movement?
 - K^+ shifts into cells
 - K^+ shifts out of cells
 - No change
 - K^+ is completely excreted
- What is the main function of the vasa recta?
 - Filtration
 - Create medullary gradient
 - Preserve the medullary osmotic gradient
 - Secrete renin
- What is the role of bicarbonate reabsorption in the proximal tubule?
 - Acidifies the blood
 - Converts HCO_3^- directly to ammonium
 - Helps maintain blood pH by reclaiming filtered bicarbonate
 - Occurs without carbonic anhydrase
- Urea recycling is important because it:
 - Dilutes the medulla
 - Helps maintain the medullary osmotic gradient
 - Blocks ADH
 - Prevents proteinuria

Fill in the missing parts:

