Online Physiology 2130 – The Renal System

Introduction

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Thank you for opening this resource for Physiology 2130, and welcome. This resource has been created by the Education Team at WebStraw. The Education Team consists of students that have previously taken and/or students that are currently taking Physiology 2130.

Purpose

This resource focuses on key concepts that are important for students to understand to succeed within this course. This resource was created by students for other students. Our goal is to help students (1) further develop their understanding of course content and (2) achieve greater academic success. (3) Our resource is also open access meaning there are no financial or legal barriers to students who wish to access and use our resource.

Instructions

These study resources consists of several parts. The first part includes a condensed review of the major takeaways from each physiology module. This is followed by a series of questions and fill in the blank worksheets that should be completed after you have gone through the module and course material, in order to verify your understanding.

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We wish you the best of luck on your exams!
The WebStraw Team

Note to Instructors: If this resource has been created for your course and you would like to collaborate with us, please email us at team@webstraw.ca

Module 11 – The Renal System

Fluid Homeostasis

The kidneys help maintain fluid homeostasis by regulating the concentration of bodily fluids

- The kidneys remove waste products from metabolism in the form of urine

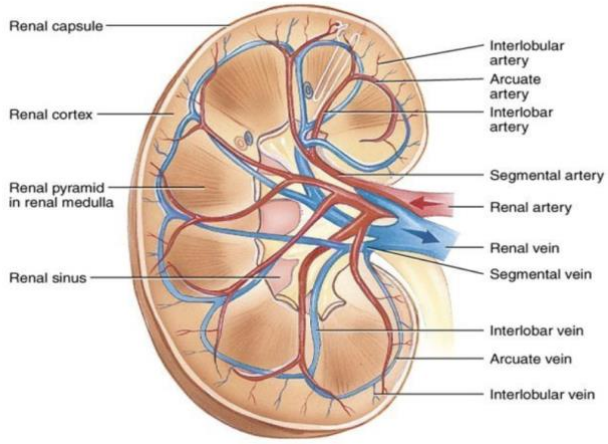
Ways the Kidneys Maintain Homeostasis:

1. Acid-base balance
2. Regulation of blood pressure
3. Secreting hormones
4. Concentration of electrolytes

Functions of the Kidney

1. Remove non-essential substances from the plasma
   - E.g. Waste metabolites, excess water and electrolytes
2. Recover any essential substances
   - E.g. Glucose
3. Regulation of water levels, concentration of bodily fluids, and the pH of the blood
4. Elimination of waste substances
   - E.g. Drugs and vitamins
5. Produce hormones
   - Erythropoietin, renin, vitamin D, and stanniocalcin

Fact: The kidneys do ***not*** produce water/electrolytes; they conserve them by limiting the amount excreted by the body.



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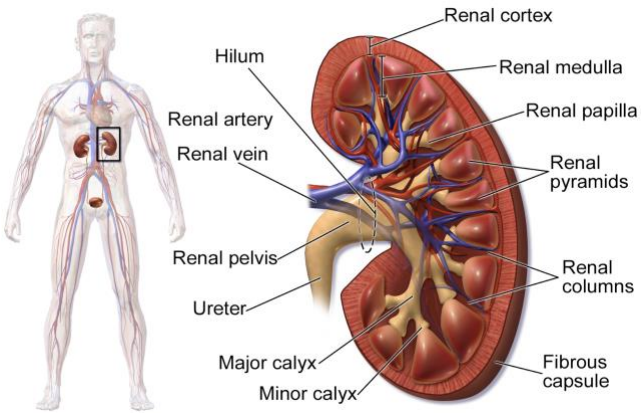
Anatomy of the Kidney



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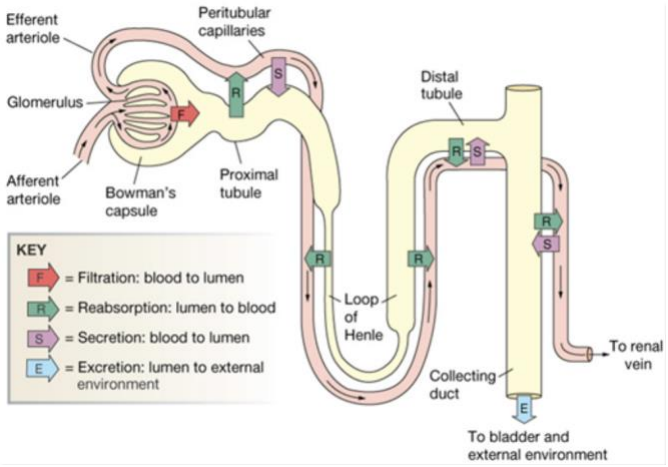
The Nephron



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Filtration

- Movement of a substance from the glomerular capillaries into the Bowman's capsule

Reabsorption

- Movement of a substance from the lumen of the nephron back into the blood

Secretion

- Movement of a substance from the blood into the lumen of the nephron

Excretion

- Removal of a substance from the body

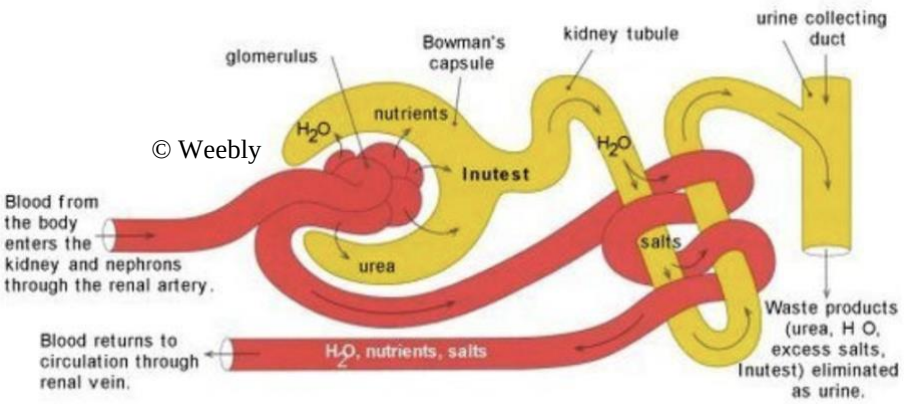
Excretion = Filtration + Secretion - Reabsorption

Blood Flow Through the Kidney:

Renal Artery → Segmental Arteries → Interlobular Arteries → Arcuate Arteries → Interlobular Arteries → Afferent Arterioles → Glomerular Capillaries → Efferent Arterioles → Peritubular Capillaries → Interlobular Veins → Arcuate Veins → Interlobular Veins → Segmental Veins → Renal Vein

Factors Affecting Glomerular Filtration:

1. Structural features increase filtration
   - Podocytes surrounding the capillaries have large filtration slits between pedicles
2. Extremely permeable capillaries
3. Starling forces



Starling Forces

- Movement of fluids across the capillaries is due to the combination of hydrostatic and colloid osmotic forces

Four Starling Forces:

1. **Blood Hydrostatic Pressure (BHP)**
   - Favours filtration of fluid into the glomerular capsule
2. **Colloid Osmotic Pressure of Plasma Proteins (COP)**
   - Favours reabsorption of fluid into the plasma
3. **Capsular Pressure (CP)**
   - Favours reabsorption of fluid into the plasma
4. **Colloid Osmotic Force of Glomerular Capsule**
   - Not present as very few proteins are filtered
   - 0 mmHg in healthy individuals

Net Filtration Pressure (NFP)

- Favours filtration of fluid into the glomerular capsule

Outward forces driving *filtration*

Inward forces driving *absorption*

NFP = BHP – (COP + CP)

Glomerular Filtration Rate

- Volume of fluid that is filtered by the glomerulus during a certain time period

Filtered Load

- The amount of substances filtered by the kidneys per day

Filtered Load = GFR X $[Substance]_{plasma}$

Amount Excreted = $[Substance]_{urine}$ X Amount of urine excreted per day (1.8 L/day)

Amount Reabsorbed = Filtered Load – Amount Excreted

Fraction Excreted = (Amount Excreted/Filtered Load) X 100%

Nephron Anatomy

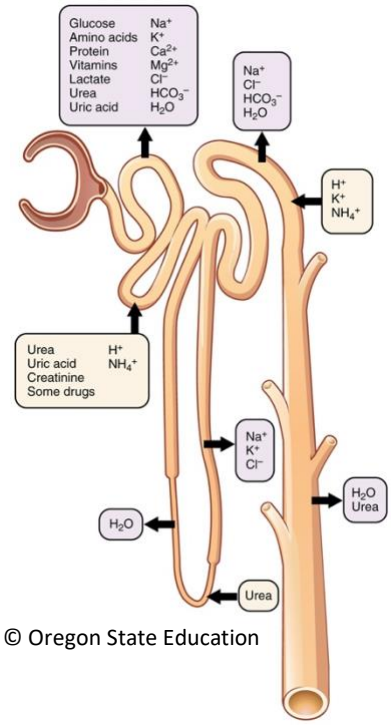
Proximal Convoluted Tubule

Reabsorbs roughly 66% of total filtrate

- **Na^+ reabsorption** → Na^+/glucose co-transporte Na^+/amino acid co-transporter, Na^+/H^+ exchanger, diffusion
- **H^+ secretion** → Na^+/H^+ exchanger
- **Glucose and amino acid reabsorption** → Na^+/glucose co-transporter, Na^+/amino acid co-transporter
  - Only happens in this region
- **Water reabsorption** → moves into the cell and interstitial space ***after*** solute reabsorption through ***osmosis***
- **K^+ and Cl^- reabsorption**: 65% reabsorbed in PCT
  - **Solvent drag** – movement of solute along with movement of solvent (water)
  - **Simple diffusion** – after osmosis of water, solute concentration increases in filtrate and can diffuse into interstitial space
  - **Transcellular transport** – only Cl^-

Diabetes Mellitus and PCT

- Affects pancreas' ability to produce ***insulin***
  - Increase in glucose concentration in the blood
- Large quantity of glucose → Na^+/glucose co-transporter cannot reabsorb all of it
  - Symptom: ***glucose in urine*** as Na^+/glucose co-transporter in PCT is saturated



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Descending Loop of Henle

- Very permeable to water, not very permeable to ions
- Osmolarity gradient increases as you go further down the medulla (up to 1200 mOsm)
- Large osmolarity gradient allows water to be reabsorbed by ***osmosis*** down its concentration gradient
- Osmolarity of filtrate matches the osmolarity of the interstitial space at ***1200 mOsm***

Ascending Loop of Henle

25% of all filtered ions reabsorbed in ascending loop

- Very permeable to ions (Na^+/K^+/Cl^-) and NOT permeable to water
- Na^+/K^+ pumps create a concentration gradient for Na^+ to move into tubule cells
  - Drives a co-transporter that carries Na^+/K^+/Cl^- at the same time
  - Na^+/H^+ exchanger is also used for Na^+ reabsorption
- Filtrate concentration drops from 1200 mOsm to ***100 mOsm*** by the time it reaches the top of the loop

Distal convoluted tubule

12% of filtered Na^+ reabsorbed here

- **Water reabsorption –** controlled by *ADH (vasopressin)* and hydration level
  - 0-15% reabsorbed here
- **Na^+ reabsorption** – early segments are uncontrolled while later segments depend on ***aldosterone***
- **K^+ secretion** – K^+ secreted into lumen of nephron in response to aldosterone

Collecting duct

10% of filtered Na^+ reabsorbed here (regulated mechanisms only)

- Collects filtrate from many nephrons and is the final region for processing the filtrate into urine
- Reabsorption is controlled by ***aldosterone*** and ***ADH***
  - K^+ secretion is also promoted by aldosterone

Hormonal Regulation

Release of ADH

- Osmolarity outside the osmoreceptor cell is high causing water to move out and cell ***shrinks***
- Shrinking of cell (in ***hypothalamus***) occurs, sending signals to ***posterior pituitary*** to release ***ADH***
- Volume and baroreceptors send info to hypothalamus to cause ADH release when dehydrated and low blood volume

Antidiuretic hormone (ADH)

- Binds to membrane-bound receptors on distal tubular/collecting duct cells
- Stimulates cells to make ***aquaporins*** in luminal membrane
- Water flows down the concentration gradient into cells and then into peritubular capillaries
- Hence, less water excreted in urine

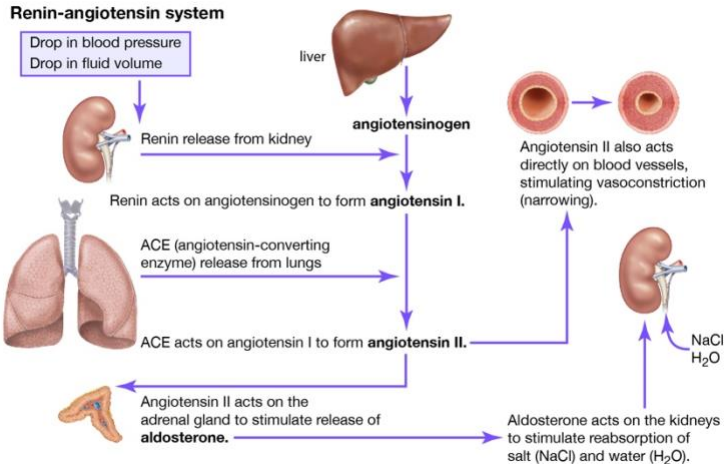
Alcohol inhibits ADH release causing more urination

Aldosterone

- Secreted when Na^+ levels are low or blood K^+ levels are high
- Secreted in response to ***angiotensin II*** and ***adrenocorticotropic hormone (ACTH)***
- **Causes *Na^+ reabsorption*** and ***K^+ secretion***
- Causes cells to make more Na^+ and K^+ channels on the luminal membrane
  - Na^+ enters the cell and K^+ leaves, both down their concentration gradients
- Also increases the activity of the Na^+/K^+ pump

Angiotensin II

- One of the most potent vasoconstrictors in the body
- Stimulates the sensation of "thirst" in the brain
- Stimulates the release of ***aldosterone***
- Causes absorption of water and Na+ from the digestive tract



Renin

- Produced by the ***juxtaglomerular cells*** which are located in the walls of the afferent and efferent arterioles before and after the glomerular capsule

Review Questions

1. Which of the following is/are associated with the role of the kidneys?
    a. Release of Renin
    b. Activation of Vitamin D
    c. Release of Erythropoietin
    d. Removal of Electrolytes
    e. All of the above

2. Which of the following does NOT occur due to the release of Angiotensin II?
        1. Decreased glomerular hydrostatic pressure
        2. Increased synthesis of vitamin E
        3. Increased release of erythropoietin
        4. Increased filtration rate

    a. 1, 2, and 3 only
    b. 1 and 3 only
    c. 2 and 4 only
    d. 4 only

3. The majority of reabsorption and secretion occurs in which of the following parts of the nephron?
    a. Collecting Ducts
    b. Proximal Convoluted Tubule
    c. Descending Loop of Henle
    d. Ascending Loop of Henle
    e. Distal Convoluted Tubule

4. A patient is found to have abnormally high levels of glucose in his urine. Which of the following parts of the nephron is most likely the cause of this excess glucose?
        1. Ascending Loop of Henle
        2. Distal Convoluted Tubule
        3. Descending Loop of Henle
        4. Proximal Convoluted Tubule

    a. 1, 2 and 3 only
    b. 1 and 3 only
    c. 2 and 4 only
    d. 4 only

5. Reabsorption of which of the following ions is increased in the presence of aldosterone?
    a. Potassium
    b. Sodium
    c. Calcium
    d. Both A and B are correct

6. You are examining the filtrate as it travels up the ascending loop of Henle. What observation would you make?
    a. The filtrate becomes more concentrated because of high ion permeability
    b. The filtrate becomes less concentrated because of high ion permeability
    c. The filtrate becomes more concentrated because of high water permeability
    d. The filtrate becomes less concentrated because of high water permeability

Answers
1. E 2. A 3. B 4. D 5. B 6. B

Conceptual Questions

1. After an intense workout causing excessive sweating, which of the following would you EXCEPT?
   Hint: sweat is a hypotonic solution
   1. Increased ADH release from the posterior pituitary
   2. Increased aldosterone release from the kidney
   3. Increased renin release from the kidney
   4. Increased K^+ reabsorption in the collecting duct

a) 1, 2, and 3 only
b) 1 and 3 only
c) 2 and 4 only
d) 4 only
e) All of the above

2. Syndrome of inappropriate ADH (SIADH) releases more ADH than needed. This would result in:
   1. Increased urine production
   2. Increased ADH receptor expression
   3. Increased aquaporins in proximal tubule cells
   4. Low serum Na^+ concentration

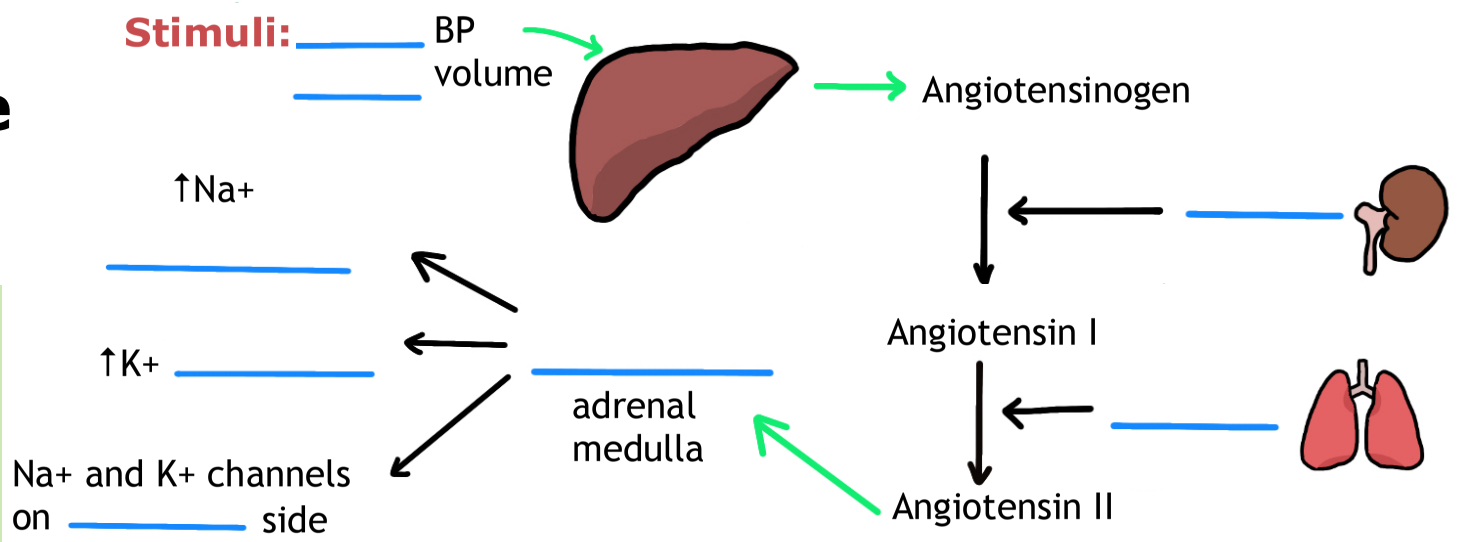
a) 1, 2, and 3 only
b) 1 and 3 only
c) 2 and 4 only
d) 4 only
e) All of the above

3. Loop diuretics are drugs that act on the ascending loop of Henle that result in increased urine production. Which of the following combinations is a possible mechanism of action and outcome?

a) Inhibit NKCC transporter; decreased blood pressure
b) Inhibit NKCC transporter; increased blood pressure
c) Promote NKCC transporter activity; increased plasma osmolarity
d) Promote NKCC activity; decreased plasma osmolarity

Answers
1. B 2. D 3. A

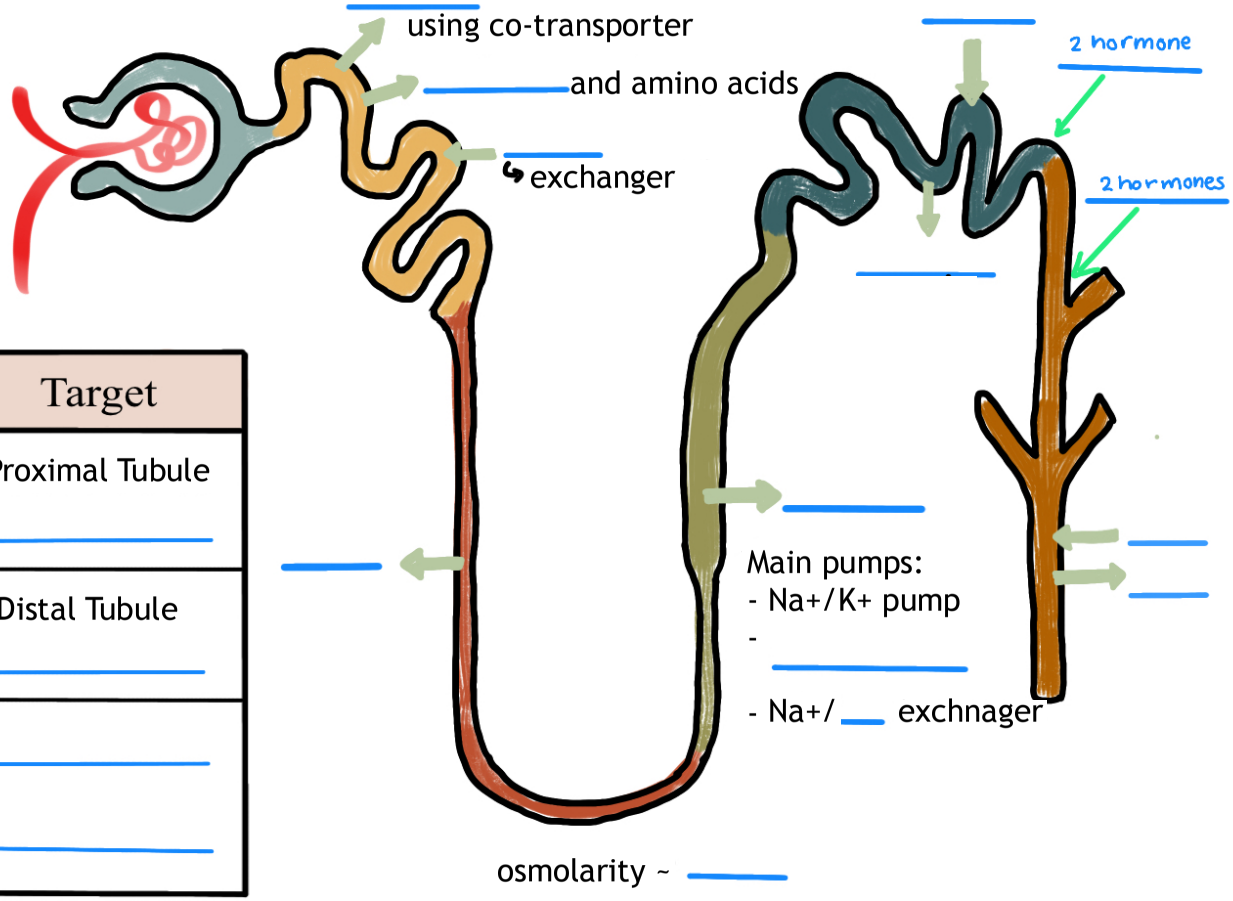
Module 11: The Renal System



Think about this:
Diabetes Mellitus can cause increased glucose concentration in the filtrate causing increased urine production or osmotic diuresis

Factors Affecting Glomerular Filtration

1. _____ surronding capillaries have slits between _____
2. Extremely _____ capillaries
3. _____ Forces



Name	Stimuli	Effect	Target
Angiotensin II	_____ Na+	vasoconstriction Na+ _____	Proximal Tubule _____
Aldosterone	_____ Na+ _____ K+	_____ _____	Distal Tubule _____
ADH	low _____ _____ ECF volume	increased _____ on luminal side H2O _____	_____ _____