Chapter 27 - Fluid, Electrolyte and Acid-Base Homeostasis

Objectives

1. List the fluid compartments of the body and their relative volumes.

2. Review the processes and effects of filtration, reabsorption, diffusion and osmosis as they affect the volumes in fluid compartments.

3. Define metabolic water. List the sites/mechanisms and relative volumes of water gained and lost each day.

4. Review the mechanisms of the hypothalamic thirst center, and the hormones involved in the body's response to dehydration or fluid overload (water intoxication).

5. List the principal electrolytes found in body fluids, and compare their relative amounts in different fluid compartments. Describe the general functions of the cations: Na^+, K^+, Ca^{++}, Mg^{++}, and anions: Cl^-, HCO_3^-. phosphate$^{(-)}$, sulfate$^{=}$, and proteins$^{(-)}$.

6. Describe the action of a pH buffer, and list some examples found in the body (proteins including hemoglobin, bicarbonate and carbonic acid, phosphate).

7. Review how the red blood cells assist in carrying CO_2. Define volatile and non-volatile metabolic acids. Define acidosis and alkalosis, and describe how the body responds to those conditions (compensates).

8. Distinguish the two basic causes of acidosis (respiratory and metabolic) and the two basic causes of alkalosis (respiratory and metabolic).

I. Fluid Compartments

A. ~60% of body is water

fig 27.1

1. ~ 2/3 of body water is inside cells (intracellular)
remaining 1/3 (extracellular) is divided between

80% between cells (interstitial)
20% inside vessels (plasma)

minor volumes of lymph fluid, csf, synovial fluid, aqueous humor, fluids in serous cavities

2. water movement between plasma and interstitial fluid is driven by hydrostatic pressure (filtration)

only filters across capillaries

water movement between intracellular and interstitial fluid is driven by osmosis

when dissolved substance passes through membrane, it takes along its associated "water of hydration" = transfer of H_2O too

most dissolved substances that traverse cell membrane are electrolytes

electrolytes = ionized atoms (ex: Na^+., K^+, Cl^-, HCO_3^-)

note: since electrolytes carry charges, balance between pos and neg charges must also be maintained

B. Water constitutes body mass other than:
lipid
protein (including muscles and fibers)
insoluble bones
dissolved substances (ex: electrolytes, glucose, urea, metabolic waste)

1. males have larger bones & more muscles but less fat → ~ 60% H_2O
2. females have more fat (breasts, hips, abdomen) → ~ 55% H_2O

C. Daily input of H_2O must equal daily output; i.e. water balance

fig 27.2

1. sources:	drink liquid	1600 mL
	eat soggy food	700 mL
	metabolic H_2O	200 mL
		2500 mL input per day
2. loss:	urine	1500 mL
	perspiration	600 mL
	breath	300 mL
	normal feces	100 mL
		2500 mL output per day

D. Regulation of water balance depends on hormones and hormones respond to osmolarity of body fluids

osmolarity = collective concentration of all dissolved substances

Therefore ↑ osmolarity can be either ↑ substances or ↓ H_2O

1. vasopressin (= ADH) from posterior pituitary directly controls volume of water excreted by kidneys

↑ plasma osmolarity → stimulates thirst centers in hypothalamus → voluntary ↑ in ingested liquid

↑ plasma osmolarity → ↑ secretion of ADH → ↑ number of H_2O-transport pores in renal collecting ducts → ↑ reabsorption of H_2O and highly concentrated urine

2. other mechanisms can directly affect water excretion:

a: major changes in blood pressure → corresponding changes in blood flow to the kidneys → altered volume of urine
b. fever → ↑ evaporation through breath
c. vomiting or diarrhea → ↑ loss from GI tract

3. Na^+ and Cl^- concentrations are the largest contributors to plasma osmolarity.

↑ osmolarity of plasma/interstitial fluid pulls H_2O out of cells by osmotic pressure → ↑ blood volume

Na^+ and Cl^- concentrations are regulated by
renin-angiotensin-aldosterone
atrial natriuretic peptide (ANP)

a. ↑ blood volume →
↑ blood flow to JGA of nephron →
↓ secretion of enzyme renin →
↓ conversion of plasma angiotensinogen I into angiotensin

↓ angiotensin →
↓ blood pressure →
↓ renal filtration & ↓ reabsorption of Na^+ and Cl^- from renal filtrate

also ↓ angiotensin →
↓ secretion of aldosterone from adrenal cortex →
↓ reabsorption of Na^+ (in exchange for K^+ and/or H^+) in renal DCT

either way, ↓ reabsorption of electrolytes →
↓ reabsorption of "water of hydration" = ↑ loss of water

b. ↑ blood volume →
stretches cardiac atria →
↑ secretion of ANP →
↓ reabsorption of Na^+ from renal filtrate →
↓ reabsorption of "water of hydration" = ↑ loss of water in urine

(note: in hospital labs, the type of ANP that is measured is the beta type, therefore it is called BNP beta natriuretic peptide)

fig 27.3 Dehydration

fig 27.4 Increased osmolarity

fig 27.5 H_2O intoxication

II. Electrolyte Balance

Book says milliequivalents are here to stay -- HOG WASH!

The modern unit for electrolyte concentration is millimoles per liter (mmol/L)

A. In each fluid compartment, cumulative concentration of positive ions = cumulative concentration of negative ions
However, each compartment has its own unique complement of ions

fig 27.6

major cations (positive): Na^+ in extracellular (interstitial & plasma)
K^+ and Mg^{++} in intracellular

(recall membrane voltages mechanisms in muscles and nerves that are established by Na^+ and K^+ pores and pumps)

major anions (negative) Cl^- in extracellular
phosphate ($HPO_4^=$) and protein in intracellular

B. Specific regulation and functions (i.e., besides their contribution to osmolarity) of electrolytes

1. Na^+ contributes almost ½ of plasma osmotic pressure
normal concentration in plasma 140 ± 5 mmol/L

controlled by angiotensin, aldosterone, ANP

crosses cell membranes when muscle or nerve is stimulated to contract or conduct

2. Cl^- contributes almost 1/3 of plasma osmotic pressure

normal concentration in plasma 100 ± 10 mmol/L

no specific control mechanism

most cells have lots of Cl^- channel proteins

Cl^- crosses membrane to achieve charge balance

ex: when red blood cell accumulates HCO_3^- ion during O_2 transport, Cl^- moves opposite to HCO_3^- to maintain electrical neutrality

note: lack of Cl^- channel causes cystic fibrosis

3. K^+ leakage channels are major cause of negative voltage on membranes of muscles and neurons

normal concentration in plasma 4.5 ± 0.5 mmol/L

aldosterone controls K^+ by exchange for Na^+ in renal tubules; also K^+ is exchanged for H^+ at cell membranes for pH control

4. HCO_3^- the major plasma buffer because it is the mechanism for carrying most CO_2 from peripheral cells to lungs for excretion

normal plasma concentration 24 ± 2 mmol/L (arterial)
and 25 ± 2 mmol/L (venous)

also able to buffer metabolic acids which prevents them from changing blood pH

$HCO_3^- + H^+$ from metabolic acid $\rightarrow H_2CO_3 \rightarrow H_2O + CO_2$

5. Ca^{++} almost all is stored in bones and teeth; also required for muscle contraction and blood coagulation

normal concentration in plasma 2.6 ± 0.3 mmol/L

main controlling hormone is parathyroid hormone which uses negative feedback

6. phosphate most is stored in bones and teeth; also part of energy metabolism (ex: ATP), and buffer against metabolic acids

$HPO_4^{=} + H^+ \rightarrow H_2PO_4^-$
either form of phosphate is excreted in urine

urinary excretion is enhanced by parathyroid hormone

normal concentration in plasma 1.15 ± 0.3 mmol/L

7. Mg^{++} significant amount is stored in bones; also major intracellular ion where it acts as enzyme activator

no specific hormonal control

normal concentration in plasma is 0.85 ± 0.20 mmol/L

III. Acid Base Balance

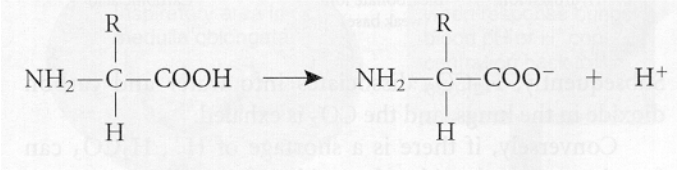
A. Buffer = any compound that has two forms: one form binds H^+ and the other form releases H^+
in "chemist talk": a weak acid and its conjugate base

1. both intracellular and extracellular <u>proteins</u> act as temporary buffers

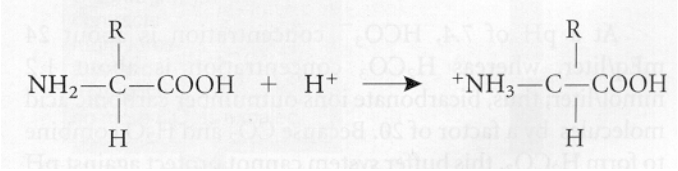
a. temporary because after combining with (or releasing) H^+ then they must be restored to their original form in order to perform their intended function

proteins have two chemical groups capable of being a buffer

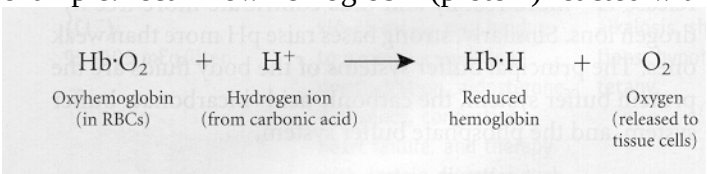
the carboxyl group can add or release H^+



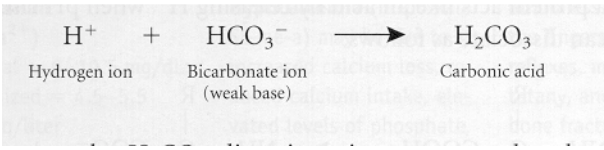
the amino group can add or release H^+

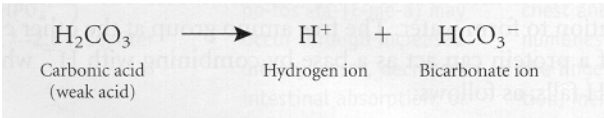


example: recall how hemoglobin (protein) reacted with H^+ as it carried O_2

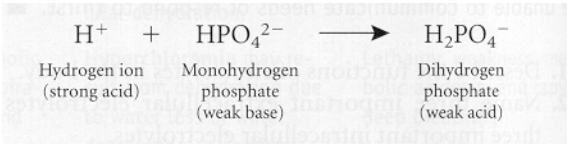


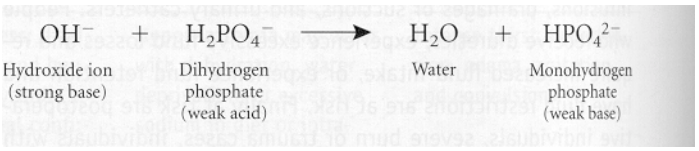
2. HCO_3^- is an important buffer (see above)





3. phosphate can buffer excess H^+ (see above) or lack of H^+ (same as extra OH^-)





B. lungs and kidneys are the ultimate excretors of metabolic acids

lungs excrete CO_2 (which was H_2CO_3 carbonic acid in the blood)

kidneys excrete phosphate (as well as other H^+ traps like ammonia)

C. when blood pH varies from normal, then "compensation" mechanisms restore it

table 27.3

normal blood pH 7.37 ± .02 (arterial)
7.35 ± .02 (venous)

normal blood pH reflects the relative concentrations of H_2CO_3 (acid from dissolved CO_2) and HCO_3^-

kidneys compensate for lung disease, and breathing compensates for kidney (or metabolic) disease

definitions: acidosis = any condition that causes ↓ blood pH
alkalosis = any condition that causes ↑ blood pH

ex: ↓ excretion of CO_2 → ↑ H_2CO_3 in blood → respiratory acidosis
(emphysema, pneumonia, etc)

compensation: kidneys make and reabsorb more HCO_3^- to balance the H_2CO_3 → restores normal blood pH

ex: ↑ production metabolic acids → ↓ HCO_3^- which gets used up buffering the H^+ → metabolic acidosis
(renal failure, diabetic ketoacidosis, etc)

compensation: lungs breathe faster → ↓ H_2CO_3 to balance the HCO_3^- → restores normal blood pH

ex: ↑ excretion of CO_2 → ↓ H_2CO_3 in blood → respiratory alkalosis
(hysterical breathing, fever, aspirin poisoning, etc)

compensation: kidneys excrete more HCO_3^- to balance the H_2CO_3 → restores normal blood pH