ACID-BASE BALANCE

(CHAPTER 9)

QUESTION 1

What is the normal pH of adult blood?

Normal blood pH is **7.35-7.45** (slightly basic/alkaline)

QUESTION 2

Death can occur when blood pH falls above ___ or below ___.

Above **7.8** (more alkaline) or below **6.9** (more acidic)

This is a very narrow range–roughly equivalent to seawater vs. distilled water!

QUESTION 3

Describe the normal values for P_aCO_2 and HCO_3^-.

P_aCO_2 (partial arterial pressure of CO_2): **36-44** mmHg

HCO_3^- (bicarbonate): **22-26** mEq/l

P_aCO_2, HCO_3^-, and serum pH are all part of a set of five tests known as ABGs—**arterial blood gases**.

The other tests are P_aO_2 and S_pO_2, but these have to do with oxygenation rather than acid-base balance.

QUESTION 4

Explain the three major mechanisms that regulate acid-base.

Three main categories:

- Buffer systems
- Respiration
- Renal system

Buffer systems are the **fastest-acting** of the three categories, and make small adjustments to pH by "soaking up" and "spitting out" H^+ ions as necessary.

One of the major pH buffers in the body is the **carbonic acid–bicarbonate buffer**.

We'll talk more about this in a second, but the important thing for now is **carbonic acid**—H_2CO_3

What's special about H_2CO_3?

$$H_2CO_3 \rightleftarrows H_2O + CO_2$$

Carbonic acid is just **carbon dioxide** plus **water**.

That brings us to our second system: **respiration**.

Carbonic acid is very easy to get rid of. Break it down, breathe out the CO_2, and we're left with just water.

Water is **neutral**—boom, acid gone.

pH balance through respiration is **slower** than buffer systems, but actually **removes** the acid from the body.

It also helps correct the ratio between carbonic acid and bicarbonate.

What's special about HCO_3^-?

$$HCO_3^- + H^+ \rightleftarrows H_2CO_3$$

Bicarbonate is **carbonic acid** minus **hydrogen**.

On to the third system of pH balance: the **kidneys**.

First and foremost, the kidneys are actually where (some) bicarbonate is **produced**.

Second, the kidneys can also **excrete** excess bicarbonate from the blood, or reabsorb it if needed.

Third, the kidneys can also excrete excess **hydrogen** to correct for **low pH**.

Kidneys produce **ammonia** (NH_3). Excess hydrogen bonds to it to form **ammonium** (NH_4^+).

Ammonium is excreted in the urine, taking the hydrogen ions with it.

(can handle any acid **except** H_2CO_3, which must be expelled as CO_2)

Too much acid?

reabsorb filtered bicarbonate

increase bicarbonate production

excrete hydrogen ions as NH_4^+

Too much base?

excrete bicarbonate in the urine

reduce bicarbonate production

reabsorb filtered metabolic acids

This is the **slowest** of the three mechanisms, but is also capable of making huge corrections fairly easily.

Buffers: nearly **instant**, but **limited** by HCO_3^- levels

Respiration: **slower**, but actually **removes** acid from the body in the form of CO_2

Renal system: the "big guns"—**slowest** of all, but capable of making the **most drastic** adjustments

QUESTION 5

What do these mechanisms reflect?

P_aCO_2 – **respiratory function**

HCO_3^- – **renal function**

Serum pH – **overall acid-base balance**

QUESTION 6

Describe the bicarbonate buffer system.

A quick word on **carbonic acid**: H_2CO_3 is a **weak acid**, meaning that it's usually perfectly content to stay in solution without shedding an H^+ ion.

The **stronger** an acid, the more its H^+ ion wants to "pop off" when given the opportunity.

We can quickly **reduce** the number of free H^+ by bonding them to **bicarbonate**, creating **carbonic acid**.

$$HCO_3^- + H^+ \rightarrow H_2CO_3$$

We can also **increase** the number of free H^+ by taking them from **carbonic acid**, creating **bicarbonate**.

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$

This is the **carbonic acid–bicarbonate buffer system**.

The body can respond to changes in pH **almost instantly** with just one chemical reaction.

Carbonic acid will stay in solution until…

If pH increases – turned back into bicarbonate

If pH remains low – broken down and exhaled as CO_2

Bicarbonate will stay in solution until…

If pH decreases – turned back into carbonic acid

If pH remains high – excreted by the kidneys

QUESTION 7

What is the ratio of bicarbonate ions to carbonic acid?

20 bicarbonate (HCO_3^-) to **1 carbonic acid** (H_2CO_3)

Kidneys and lungs will **try** to preserve this ratio if working properly.

QUESTION 8

What happens in the bicarbonate buffer system when there is too much acid? Too little acid?

Too much acid – bicarbonate bonds to free H^+, creating carbonic acid

Too little acid – carbonic acid sheds H^+, creating bicarbonate

QUESTION 9

What can the respiratory system contribute to pH regulation?

Respiratory rate and depth control how much **carbon dioxide** is blown off, affecting **carbonic acid** levels.

Breathe **faster** or **deeper** → **decreases** H_2CO_3

Breathe **slower** or **shallower** → **increases** H_2CO_3

QUESTION 10

What is the body's volatile acid? Give examples of metabolic acids?

volatile acid – carbonic acid

metabolic acids – lactic, pyruvic, acetic, etc.

And now for something completely different…

An **excess** of acid in the blood is called **acidosis**.

A **deficit** of acid in the blood is called **alkalosis**.

In addition, pH imbalances are named after their **source**...

Where is the problem coming from?

From the lungs – respiratory

From anywhere else – metabolic

This means there are **four categories** of pH imbalance:

metabolic acidosis

metabolic alkalosis

respiratory acidosis

respiratory alkalosis

Let's go over some examples...

(These are meant to be **hard** and really get you thinking.)

A patient has a history of **end-stage renal disease**.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

A patient is experiencing an acute exacerbation of **chronic obstructive pulmonary disease**.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

A patient is experiencing intractable **vomiting**.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

A patient is on a high-dose IV **morphine** drip for pain.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

A patient is experiencing intractable **diarrhea**.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

A patient is experiencing an acute **panic attack**.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

respiratory alkalosis

Okay, on to the next question...

QUESTION 11

Compensation for an excess of metabolic acid is ___.

Need to get rid of acid and the kidneys aren't doing it...

Convert to **carbonic acid** and **breathe it out**!

(compensation for **metabolic acidosis** – **faster**, **deeper** breathing)

QUESTION 12

Compensation for a deficit of any acid except carbonic acid is ___.

Now we need **more** acid, and the kidneys aren't correcting...

Hold on to carbonic acid and keep that H^+!

(compensation for **metabolic alkalosis** – **slower**, **shallower** breathing)

QUESTION 13

The kidneys' response to changes in pH includes ___.

Too much acid?

reabsorb filtered bicarbonate

increase bicarbonate production

excrete hydrogen ions as NH_4^+

Too much base?

excrete bicarbonate in the urine

reduce bicarbonate production

reabsorb filtered metabolic acids

QUESTION 14

What does HCO_3^- in the plasma reflect?

Serum **bicarbonate** reflects both kidney function and the amount of metabolic acids in the blood.

If HCO_3^- is low, either not enough is being produced by the kidneys, or a lot is being converted to H_2CO_4.

QUESTION 15

What is renal compensation for an increase or decrease in carbonic acid?

respiratory acidosis – produce more bicarbonate, excrete H^+ as ammonium

respiratory alkalosis – excrete bicarbonate, reabsorb metabolic acids

QUESTION 16

What is starvation ketoacidosis? How does it affect pH?

When they lack available glucose, cells will use triglycerides as an alternate energy source.

Acidic ketones such as **acetoacetate** are produced as a byproduct of fatty acid catabolism.

Ketone production results in **decrease** of pH, a form of **metabolic acidosis**.

When caused by malnutrition, we call this **starvation ketoacidosis**.

When caused by a lack of insulin, we call this **diabetic ketoacidosis** (DKA.)

QUESTION 17

What are some examples of excess removal or decrease in base?

Most commonly, an excessive loss of **pancreatic** bicarbonate due to loss of intestinal contents, such as **diarrhea**.

Can also be caused by type 2 **renal tubular acidosis**, where HCO_3^- is not properly reabsorbed in the PCT.

QUESTION 18

Which tissues of the body are most affected by pH disturbances?

Acidosis can have a severe **negative inotropic** effect on the heart (decreases force of contraction, lowering cardiac output.)

Many tissues affected by pH due to effects of acid environment on various proteins. For example, muscle contraction is impaired by excessive acid.

QUESTION 19

How do we think about compensation versus correction when thinking about acid-base disturbances?

Correction – fixing the imbalance **at the source**

Compensation – **opposite** system counteracts

Compensation for **metabolic** imbalances is **respiratory**.

Compensation for **respiratory** imbalances is **metabolic**.

QUESTION 20

Describe some conditions that could cause respiratory acidosis.

Anything that **slows** breathing or **impairs gas exchange**.

- Resiratory depression (e.g. opioids)
- Airway obstruction (COPD, asthma)
- Reduced effective lung volume (pneumonia, atelectasis)

QUESTION 21

How can base increase?

Not too many ways.

- Ingesting bicarbonate or other bases (e.g. antacids)
- Transfusion of blood preserved with citrate (conjugate base of citric acid)
- Fluid volume loss (contraction alkalosis)

QUESTION 22

How can metabolic acid decrease?

More ways.

- Emesis or gastric suction (losing stomach acid)
- Hyperaldosteronism ($\uparrow Na^+$, $\downarrow H^+$)
- Hypokalemia ($\uparrow K^+$, $\downarrow H^+$)
- Again, fluid volume loss (contraction alkalosis)