LECTURE 4

ACID-BASE BALANCE

Introduction

Read Chapter 11 in the textbook to refresh your background chemistry on acids, bases, and pH. Pay particular attention to the roles of the renal and respiratory systems in pH regulation. Review also the buffer systems of the body, especially the bicarbonate and hemoglobin-oxyhemoglobin buffers. Notice how they work together in systemic and pulmonary capillary beds to help keep arterial and venous blood close in pH. Review the phosphate buffer system as well. **Disregard all discussion of anion gap measurements.**

Chemically speaking, pH is a number describing the relative acidity or alkalinity of a solution and ranging in value from nearly zero up to 14. A value of 7.0 represents neutral. Values below 7.0 are acidic with hydrogen ion excesses while values above 7.0 are alkaline with deficiencies of hydrogen ions. Thus, hydrogen ion concentration is the main determiner of pH values. The origin of pH values can be expressed with the following equation:

$$pH = -\log [H]$$

Notice that the pH value is represented by the negative log of hydrogen ion concentration. Being a negative log relationship, as hydrogen ion concentration goes up, pH values go down. Being a logarhithmic relationship, a solution with a pH of 1 does not just have twice the hydrogen ions as another with a pH of 2. Instead, there can be differences of many times the hydrogen ion concentration with only a numerical pH value change of 1 point.

A major difficulty many students have with human acid-base balance is the confusion resulting from the chemical definition of **neutral** and the physiological definition of **normal**. The two are not necessarily the same. Recall that normal body pH is in the range of 7.35-7.45 or about 7.4 on the average. Notice that normal body pH is not neutral, but is slightly alkaline. Consequently, a pH of 7.2 is alkaline chemically speaking since it is above 7.0. However, since it is on the acid side of normal, it is physiologically termed acidosis. So, a client could be in acidosis with an alkaline pH as long as the pH is below normal. In reality, acidic body pH's, below 7.0, are not usually compatible with life.

In order to understand acid-base balance, some knowledge of elementary chemistry is essential. **Specifically, the Bronstead-Lowery definition of acids and bases as proton (hydrogen ion) donors and acceptors, respectively, should be reviewed.** Also, the concept of buffers is necessary to understand how body pH is regulated. **Recall that buffers resist changes in pH by accepting or donating hydrogen ions when they are excessive or deficient, respectively**. Thus, buffers become the body's first line of defense against pH changes and are considered responsible for pH "**regulation**." By controlling levels of acidic carbon dioxide and alkaline bicarbonate ion, the respiratory and renal systems also contribute to pH regulation. However, these two organ systems are also of major importance in pH "**compensation**" when normal regulatory buffer mechanisms are overwhelmed.

PH Regulation

In normal individuals, pH is controlled by two major and related processes; **pH regulation and pH compensation.** Regulation is a function of the buffer systems of the body in combination with the respiratory and renal systems, whereas compensation requires further intervention of the respiratory and/or renal systems to restore normalcy.

Given that normal body pH is slightly alkaline and that normal metabolism produces acidic waste products such as carbonic acid (carbon dioxide reacted with water) and lactic acid, body pH is constantly threatened with shifts toward acidity. This is where buffers play a normal vital role by guarding against this shift toward acidosis and helping keep blood and body pH in the normal range regardless of its arterial or venous source. Recall that systemic venous blood is high in acidic carbon dioxide and should be low in pH. Similarly, systemic venous blood is low in carbon dioxide and should be alkaline. In fact, the two are strikingly similar in pH primarily due to buffers.

REVIEW QUESTIONS:

1. What are the physiological reasons why a client who has been in cardiac and respiratory arrest for longer than expected be given an I.V. bolus of sodium bicarbonate?

2. Explain the physiological impact of chronic vomiting on body pH.

3. Explain the physiological impact of chronic diarrhea on body pH.

4. Compare the carbon dioxide content of systemic and pulmonic arterial and venous blood and explain why their pH's are similar.

The two metabolic acids mentioned above, carbonic and lactic, are chemically different in an important way. Carbonic acid is described as a **volatile acid** since it has a vapor phase. The vapor phase exists because it can be converted into carbon dioxide and water vapor, both of which are volatile (gaseous) and can be removed across the lungs. Since carbon dioxide is a common waste product, this is a valuable process in both pH regulation and compensation. The kidneys participate in normal pH regulation by the secretion of hydrogen ions into the urine as blood is processed by nephrons.

$$\underset{\text{Volatile}}{CO_2 + H_2O} \Leftrightarrow \underset{\text{carbonic acid Intermediate}}{H_2CO_3} \Leftrightarrow \underset{\text{nonvolatile}}{H^+ + HCO_3^-}$$

In contrast, lactic acid is nonvolatile and must be eliminated via the kidneys. Importantly, most of the carbon dioxide transported in circulating blood is carried as the bicarbonate ion as a result of the bicarbonate buffer system. This ion is in itself alkaline since it can accept a hydrogen ion to become carbonic acid and contributes to a normal base excess in the body. In fact, there is about 20 times as much bicarbonate as carbon dioxide in blood of a normal human, and this “excess” keeps body pH at the normal alkaline level of about 7.4. Loss of this base excess occurs as the buffer systems become overwhelmed by excess hydrogen ions and serves as a good index of body buffer status. Bicarbonate ion is also nonvolatile, and must be eliminated or retained by the kidneys as pH changes dictate. When a bicarbonate ion is formed in blood or body fluid from carbonic acid, a free hydrogen ion is generated which must be taken up by hemoglobin to prevent pH shifts toward the acid side of the scale (review the hemoglobin/oxyhemoglobin buffer).

PH Compensation

Once hydrogen ion concentration becomes excessive (acidosis) or deficient (alkalosis) as a result of failure of the buffer systems, mechanisms of compensation must take over. Given that the respiratory and renal systems are essential for pH regulation and compensation, they are often the causes of serious pH imbalances. For example, poor lung ventilation can cause carbon dioxide to accumulate in blood and generate excess hydrogen ions driving the pH toward acidosis. If the lungs are imparied sufficiently to cause a pH imbalance, it is not likely that they will be very helpful in correcting the situation. In this case, the kidneys must intervene to compensate for a respiratory problem. Generally, a failure in one organ system results in the other assuming the compensatory role.

REVIEW QUESTIONS:

1. How would the respiratory system compensate for acidosis? Alkalosis?

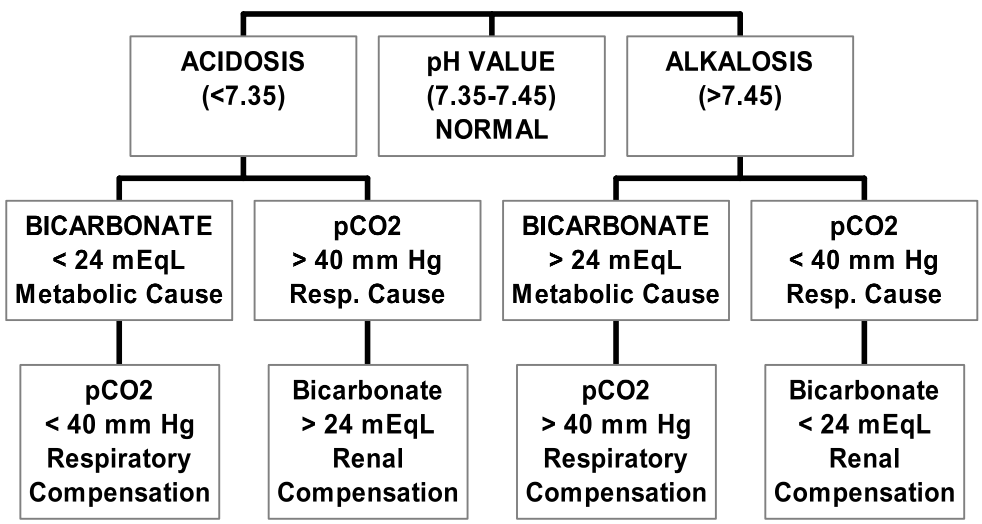
2. How would the renal system compensate for acidosis? Alkalosis?

3. In time and under what conditions would the kidneys reabsorb bicarbonate ions?

Interpreting Arterial Blood Gas Disorders

Since the respiratory and renal systems can be both the cause and the "cure" for pH imbalances, assessing pH abnormalities from lab values can be somewhat tricky. However, by concentrating on carbon dioxide levels and bicarbonate levels in arterial blood gas reports, some of the confusion can be eliminated. Keep in mind all along that the lungs control carbon dioxide levels and the kidneys control bicarbonate levels. Then, look at carbon dioxide and bicarbonate levels after examining the pH value to help work through the assessment.

ACID-BASE IMBALANCES



Examine the flow chart above for a summary of blood chemistry values under different pathophysiological pH imbalances.

Practice Assessment Exercises: (Post your work to the "Patho Discussion group").

From the flow charts on text pages 221-223 concerning causes and clinical manifestations of various pH disorders, select one example from each of the categories below and explain the physiological disruptions characteristic of each. Try to avoid repeating the topics used by other classmates. Include physiological explanations of both causes and clinical manifestations.

(1) Acidosis (respiratory)
(2) Acidosis (metabolic)
(3) Alkalosis (respiratory)
(4) Alkalosis (metabolic)

Be sure to respond to the work of your classmates!!