7.4.4

Acid Base Disturbances

So far, we have alluded to the fact that acid-base imbalances can have devastating effects on the body. Since all proteins, particularly enzymes, are very sensitive to changes in pH, normal body functions can be altered by small changes in pH. For example, the activity of the enzyme phosphofructokinase, an important enzyme in glycolysis, can be reduced by as much as 90% by a change in pH as small as 0.1 pH units. The general effect of acidosis is depression of the central nervous system. This can lead to disorientation, coma and even death. Conversely, the main problem associated with alkalosis is hyper excitability of the nervous system. This can lead to muscle spasms, tetany and death due to paralysis of the respiratory muscles. Fortunately, the mechanisms discussed above do an admirable job of maintaining blood pH within the normal range under most conditions. As we examine acid-base imbalances there are two factors to which we must pay close attention, the concentrations of carbon dioxide and HCO_3^- in the arterial blood. Recall that these are both components of the bicarbonate buffer system.

Normally we don't measure the concentration of CO_2 in the blood but express it in terms of its partial pressure, normal arterial PCO_2=40 mm Hg. To determine the actual CO_2 concentration, we can multiply the PCO_2 by its solubility coefficient which is 0.03. Therefore, the concentration of CO_2 in arterial blood is 1.2 mmol/Liter (40 X 0.03). The normal concentration of HCO_3^- in arterial blood is 24 mmol/liter (24 mM). The pH of the blood is determined by the ratio of these two factors. Under normal conditions this ratio would equal 20, (24/1.2=20). It can be shown that as long as this ratio is 20 the pH of the arterial blood will be 7.4. Based on this reasoning, if the HCO_3^- concentration were to decrease to 20 due to the addition of some non-volatile acid, normal pH could be maintained if the CO_2 concentration decreased to 1.0. (20/1 = 20). Even though both the HCO_3^- and the CO_2 concentrations are lower than their "normal" levels, arterial pH would be maintained at 7.4. [For those curious as to why this is so, we must employ the Henderson-Hasselbalch equation. This is an important equation used to define buffer systems. The general equation can be written pH = pKa + log ([conjugate base]/[acid]). For the bicarbonate buffer system, the equation would look like this: pH = 6.1 + log $[HCO_3^-]/[CO_2]$, where the $[CO_2] = PCO_2$ X 0.03. Since the log of 20 = 1.3, as long as $[HCO_3^-]/[CO_2]$ is 20 the pH will be 7.4.]

Acid-base disturbances can be classified according to the underlying cause of the problem. If the disturbance is due to a problem with respiration we classify the problem as either respiratory acidosis or respiratory alkalosis. Respiratory disturbances would manifest as changes in PCO_2. Respiratory acidosis would be caused by anything that depresses the respiration, such as damage to the respiratory centers of the brain or, more commonly, COPD, and would result in a PCO_2 greater than 40. Respiratory alkalosis would be caused by any activity that causes an abnormal increase in respiration. Although less common, it can also be caused by hyperventilation associated with heightened anxiety. Clinically, respiratory alkalosis can be the result of over ventilation of a patient who is on a ventilator. Respiratory alkalosis would be manifest by a PCO_2 that is less than 40. Acid-base imbalances that are not due to altered respiration are classified as metabolic imbalances and are manifest by changes in HCO_3^-. Metabolic acidosis can be caused by renal failure, excessive diarrhea, ingestion of acids not normally found in foods such as aspirin or methanol, or by excessive production of ketoacids (diabetic ketoacidosis) or lactic acid (circulatory shock). Metabolic acidosis would be manifest by a HCO_3^- of less than 24. Metabolic alkalosis can be caused by vomiting, ingestion of alkaline drugs (sodium bicarbonate), certain diuretics or excessive secretion of aldosterone. Metabolic alkalosis would be manifest by a HCO_3^- of greater than 24.

As described above, as long as the HCO_3^- / PCO_2 ratio is 20, arterial pH will be normal. Because of this, if there is a respiratory disturbance that causes the pH to drop (respiratory acidosis, PCO_2 greater than 40), it can be compensated by an increase in the HCO_3^-. In other words, the respiratory acidosis is being compensated by a metabolic alkalosis. On the other hand, if a person is suffering from metabolic acidosis (HCO_3^- less than 24) it can be compensated for by a respiratory alkalosis (PCO_2 less than 40). These mechanisms allow the body to maintain pH within the safe range until the underlying problem is remedied, either by the body healing itself or by medical intervention. When it comes to medical intervention, it is important to treat the underlying problem and not the compensatory mechanism. If you treat the compensatory mechanism, you could kill your patient. Let's look at an example and see if we can determine what the underlying problem is so that proper treatment can be administered. A patient presents at your clinic because she has been experiencing nausea for several days. As you perform your initial evaluation you note that her hands are shaking. She also explains that she feels light-headed and has experienced some periods of confusion. You run some routine labs and observe the following values. Red blood cell count and hemoglobin concentrations are within the normal ranges. Differential blood cell count reveals that white blood cells are also within normal ranges. Blood tests reveal the following values: HCO_3^- = 35 mmol/Liter; PCO_2 = 47 mmHg; Arterial pH = 7.49. What is your diagnosis?

If you look at the HCO_3^- it suggests a metabolic alkalosis while the PCO_2 suggests a respiratory acidosis. The question is which is the underlying cause? If we look at the pH we note that it is greater than 7.45, suggesting a state of alkalosis. Your diagnosis should therefore be that the patient is suffering from a metabolic alkalosis that is being compensated by a respiratory acidosis. Your next step is to determine the cause and treat metabolic alkalosis.