Acid–Base Balance

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Introduction

Virtually all cellular, tissue, and organ systems are sensitive to changes in the hydrogen ion (H^+) concentration in the body. They function best at an extracellular fluid H^+ concentration of 35–45 nmol l^{-1} (each nmol l^{-1} equals 10^{-6} mmol l^{-1}). This concentration is extremely low compared with other ions; sodium (Na^+), for example, has a 3 million times greater concentration. Therefore, H^+ concentration is commonly expressed as pH, a negative logarithm of H^+ concentration. Maintenance of acid–base balance in the body is important because H^+ binds avidly to proteins and changes their shape and function. Many essential metabolic, enzymatic, and transmembrane transport processes can be jeopardized because of alterations of the protein structure and function, resulting in severe organ dysfunction and clinical consequences. With an increase in body H^+ concentration, a patient may experience hypotension, depressed myocardial contractility, and sensorium. With decreased body H^+ concentration, the patient may develop coronary spasm, cardiac arrhythmias, hyperreflexia, muscle spasm, and seizure (Table 1).

In normal conditions, H^+ varies little from the normal value of approximately 40 nmol l^{-1}, even though acids and bases are continually being added to the extracellular fluid. This can be achieved by three homeostatic mechanisms: (1) intracellular and extracellular buffers; (2) changing partial pressure of carbon dioxide in the blood by altering the ventilation rate; and (3) renal H^+ excretion. The basic principles of acid–base physiology and the role of the kidneys and lungs in acid–base balance will be discussed in this article.

General Concepts

An acid is defined as a compound capable of donating an H^+, and a base is a compound that is capable of accepting an H^+. Examples of acids in the body include H_2CO_3, HCl, NH_4^+ and $H_2PO_4^-$, and examples of bases in the body are HCO_3^-, Cl^-, NH_3 and HPO_4^{2-}.

Food and cellular metabolism produces more acid than base. Base is lost in the feces daily. The net effect is the addition of acid to the body fluids. To maintain acid–base balance, acid must be excreted from the body at a rate equivalent to its addition. Acidosis (a disease process that tends to decrease the pH) results if acid addition exceeds excretion. Conversely, alkalosis (a disease process that tends to increase the pH) results if acid excretion exceeds addition. Systemic pH can still be maintained within a normal range at acidosis or alkalosis because of compensatory mechanisms, which are discussed in the section below. If these conditions or processes are left unopposed, the pH will increase or decrease from the normal range, and result in acidemia (pH < 7.35) or alkalemia (pH > 7.45). Metabolic acidosis results from a primary reduction in plasma bicarbonate concentration and respiratory acidosis results from a primary increase in CO_2 partial pressure (P_{CO_2}). Metabolic alkalosis is a result of a primary decrease in plasma bicarbonate concentration and respiratory alkalosis is a result of a primary decrease in P_{CO_2}. An increase in P_{CO_2} secondary to compensation for metabolic alkalosis is not called respiratory acidosis; a secondary decrease in P_{CO_2} in response to metabolic acidosis is not called respiratory alkalosis.

Acid and Alkali Generation

The major constituents of the human diet are carbohydrates, fats, and proteins. In normal conditions, 15 000 mmol CO_2 is generated from the metabolism of carbohydrates and fats. Although not an acid, this CO_2 will combine with H_2O to form H_2CO_3; therefore, it is termed a volatile acid, reflecting the fact that it has the potential to generate H^+ after hydration with H_2O. An accumulation of this endogenously produced CO_2 will result in respiratory acidosis (Table 2). Fortunately, this large quantity of CO_2 is eliminated by alveolar ventilation, and acid–base balance is maintained.

However, nonvolatile acids (mostly sulfuric acid) are primarily generated from the metabolism of proteins. For example, oxidation of the sulfur-containing amino acids cysteine and methionine yields sulfuric acid (H_2SO_4), whereas metabolism of lysine, arginine, and histidine generates hydrochloric acid (HCl).

Table 1 Clinical manifestations of an acid–base imbalance

Increased acidity (pH < 7.20)	*Increased alkalinity (pH > 7.55)*
Hypotension	Perioral and extremity paresthesias
Depressed myocardial contractility	Muscle spasms
	Hyperreflexia
Mental confusion	Seizures
	Coronary spasm
	Cardiac arrhythmias