Acid-base physiology and interpreting blood gas results

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Abstract

Each day there is a production of acid by the body's metabolic processes. To maintain balance, these acids need to be excreted or metabolised. Normally, the body can respond very effectively to changes in acid production.

Multiple homeostatic mechanisms interact to ensure a stable concentration of hydrogen ions [H^+] exists so that enzymes can function efficiently. Pathological derangement of pH will slow reactions or even permanently denature proteins.

The most useful investigation into acid-base balance in the acute setting is a blood gas. A blood gas can help with diagnosis, assessing physiological state, reviewing response to treatment, and prognosis in resuscitation. Having a structured approach to reviewing blood gases can be invaluable in paediatric practice and having a knowledge of how acid-base turnover, buffering, compensation, respiratory and renal excretion co-exist will help you understand what is going on particularly in situations where there is a critically ill child.

This review aims to revise acid-base physiology and provide a structure to interpreting a blood gas, with particular emphasis on metabolic conditions.

Keywords alkalosis; anion gap; blood gas; metabolic acidosis; strong ion difference

Introduction

It is Friday at 5pm. A 4 day old male is brought in by his parents with poor feeding and decreased responsiveness. He is breathing fast with oxygen saturations of 97% in air. He has a tachycardia and poor perfusion. He looks unwell. His parents are consanguineous. A venous blood gas is performed as a cannula is inserted. This is the first result available to direct further management.

Result:
pH 7.19
pCO_2 2.8
HCO_3 18.1
K^+ 8.2
Na^+ 118
Cl^- 94
Glucose 6.1
BE -6
Anion gap 11mmol/l
Lactate 3.1

At first glance, this result provides some simple information about the underlying acid-base situation. However, with further inspection there is enough in this result to narrow the differential diagnosis and to guide initial therapy as well as ongoing treatment over the weekend before definitive laboratory tests will be available.

Ions, acids, and bases

Ions

An ion is a particle which is not electrically neutral, i.e. it has lost or gained an electron. Cations (positively charged) and anions (negatively charged) will attract each other. They will only "ionise" or dissociate in solution (where they will be in constant flux of association and dissociation) or if an electrical current is applied to attract the ions to a stronger electrical target.

Pure water itself will ionise to a small degree (Figure 1), but will ionise more with other particles in solution and under different conditions.

[NB. For those like the Editor in Chief who struggle to remember which ions are cations and which are anions, *CAT*ions are *PUSS*itive and *AN*ions *A*re *N*egative.]

Acids

An acid is defined as a proton donor (i.e. a hydrogen ion donor).

A strong acid is one which dissociates (ionises in solution) fully from its conjugate base. Examples include: Hydrochloric acid (HCl), sulphuric acid (H_2SO_4), phosphoric acid (H_3PO_4), and nitric acid (HNO_3).

Weak acids are only partially ionised in solution. Examples include: lactic acid, carbonic acid, ammonium ion and dihydrogen phosphate.

In human physiology, convention classifies acids into the "volatile acid" - carbonic acid (H_2CO_3) which is excreted in the lungs as CO_2 - and the "fixed acids" - excreted in the kidney. Fixed acids and volatile acids are produced during incomplete metabolism of carbohydrates (e.g. lactate), fats (e.g. ketones) and protein (e.g. sulphate, phosphate) See Figure 2.

Respiratory (volatile) acid: although not an acid itself, CO_2 can combine with water to produce an equal quantity of carbonic acid. This reaction is catalysed by the enzyme carbonic anhydrase which is found in a number of areas within the body including the kidney, red blood cells and the pulmonary endothelium. Carbonic acid is called a volatile acid because it can be readily excreted as a gas by the lungs as CO_2.

$$CO_2+H_2O \leftarrow\rightarrow H_2CO_3 \leftarrow\rightarrow HCO_3^-+H^+ \qquad (1)$$

If the concentration of CO_2 decreases (due to increased respiratory rate) then the hydrogen ions are pulled into the left hand side of this equation to compensate. Thus the hydrogen ion concentration decreases. This is the basis of the Hendersen–Hasselbach equation, which is simplified below:

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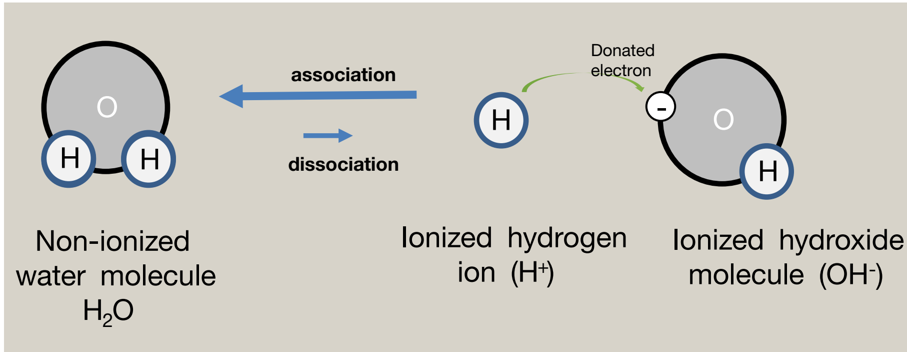

Figure 1 Ionisation of pure water.

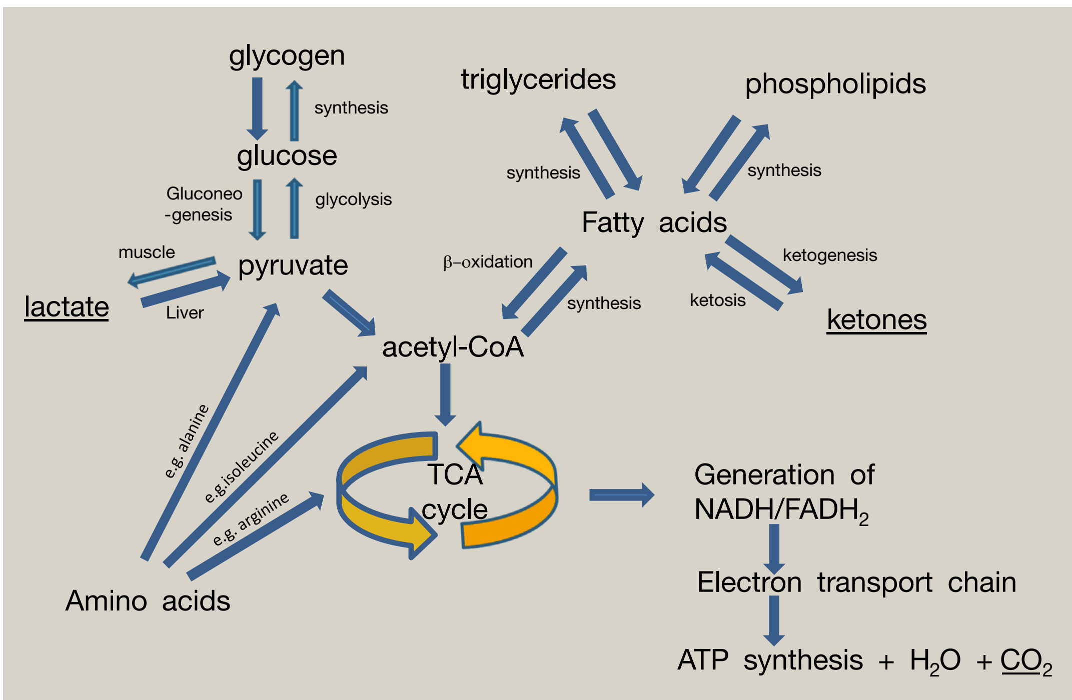

Figure 2 Overview of carbohydrate, fat and protein metabolism (TCA = tricyclic acid cycle).

$$[\mathrm{H}+] \text{ is proportional to } \frac{p\mathrm{CO_2}}{[\mathrm{HCO_3^-}]} \qquad (2)$$

Metabolic (fixed) acids: "fixed" (metabolic) acids are formed naturally by several metabolic processes and must be excreted by the kidneys. CO_2 is also generated as a consequence of normal metabolism through the oxidation of carbohydrates and fatty acids. CO_2 is the 'dominant partner' in the acid production; in an adult 12,000 mmol of CO_2 is produced each day. As a comparison, the net production of fixed acids is just 100mmol per day. The kidney has a smaller capacity than the lungs for controlling or restoring acid-base balance, particularly over short periods of time.

Other acids: lactate is not included in this 100mmol/day since it is metabolised by the liver and therefore does not need to be excreted by the kidneys.

Bases

A base will accept a proton from any proton donor. These include bicarbonate (HCO_3^-), chloride (Cl^-), ammonium (NH_3^-), phosphate (PO_3^-), ketones.

pH

The concentration of hydrogen ions $[H^+]$ within a solution determines the acidity of that solution. By convention, the $[H^+]$ is expressed using a negative logarithmic scale called pH (See Figure 3). The reason for using the pH scale is because the range of $[H^+]$ varies hugely within the human body. The concentration of H^+ in the stomach is 150,000,000 nmol/L whereas in the plasma its concentration is only 40 nmol/L. Expressed using the pH scale the stomach has a pH of 0.8 whereas in the plasma it is 7.40. Although the numbers are much more manageable to consider, it is more difficult to understand the magnitude of a change in $[H^+]$ using the logarithmic pH scale. It may help to

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