

Acid-Base Physiology

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What is a blood gas assessment?

- ▶ We get it from an arterial sample (a.radialis, a. brachialis, a. femoralis)
- ▶ Invasive technique
- ▶ If the patient is on anticoagulants, you have to be cautious
- ▶ A blood gas assessment is suitable for diagnosing oxigenation problems, respiratory failure, acid-base disturbance in the patient and is *essential* in all these problems

$$\text{pH} = -\log[\text{H}^+]$$

- ▶ Constant H^+ concentration of bodyfluids is crucially important in vital cellfunction
- ▶ Outside the acceptable range of pH, proteins are denatured and digested, enzymes lose their ability to function

- ▶ ECF normal pH=7.4
- ▶ ICF normal pH=7.1

- ▶ Alkalosis or alkalemia - arterial blood pH rises above 7.45
- ▶ Acidosis or acidemia - arterial pH drops below 7.35

Acid-base disturbance

Main definitions

- ▶ **ACIDEMIA**: a lower than normal arterial pH
- ▶ **ALKALEMIA**: a higher than normal arterial pH
- ▶ **ACIDOSIS**: a process leading to acidemia. Can be of metabolic or respiratory origin, or the result of compensation
- ▶ **ALKALOSIS**: a process leading to alkalemia.
Can be of metabolic or respiratory origin, or the result of compensation

Alterations in the acid-base balance

- ▶ The function of the organs will be affected as the following:

Acidotic state (low pH)

The contractility of the myocardium is decreased; the response of the vascular bed to catecholamines is decreased; lessens the production of several mediators

Alkalotic state (high pH)

Disturbs the oxygenation of tissues and the normal neurologic and muscle function.

A significant change in the pH (higher than 7,8 or lower than 6,8) without compensation or therapy will lead to death

Buffer systems

- ▶ Concentration of hydrogen ions is regulated sequentially by:
 - 1) **Chemical buffer systems** - act within seconds
 - 2) **Physiological buffer systems**
 - ▶ The respiratory center in the brain stem - acts within 1-3 minutes
 - ▶ Renal mechanisms - require hours to days to effect pH changes

1) Chemical buffering agents

▶ ECF:

- ▶ Bicarbonate
- ▶ Haemoglobin
- ▶ Phosphate
- ▶ Plasmaproteins

▶ ICF:

- ▶ Phosphate
- ▶ Cellproteins
- ▶ Bicarbonate

▶ BONE

- ▶ Ca carbonate (hours - in chronic metabolic acidosis)

▶ URINE

- ▶ Phosphate
- ▶ Ammonia

2) Physiological buffer systems

Respiratory regulation

- ▶ There is a reversible equilibrium between:
 - ▶ Dissolved carbon dioxide and water
 - ▶ Carbonic acid and the hydrogen and bicarbonate ions
- ▶ **Carbonic acid dissociation reaction**
 - ▶ $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$
- ▶ When hypercapnia or rising plasma H^+ occurs:
 - ▶ Deeper and more rapid breathing expels more carbon dioxide
 - ▶ Hydrogen ion concentration is reduced
- ▶ Alkalosis causes slower, more shallow breathing, causing H^+ to increase

2) Physiological buffer systems

Renal Mechanisms of Acid-Base Balance

- ▶ Chemical buffers can tie up excess acids or bases, but they cannot eliminate them from the body
- ▶ The lungs can eliminate carbonic acid by eliminating carbon dioxide
- ▶ Only the kidneys can get rid the body of metabolic acids (phosphoric, uric, and lactic acids and ketones) and prevent metabolic acidosis
- ▶ The most important renal mechanisms for regulating acid-base balance are:
 - ▶ Conserving (reabsorbing) or generating new bicarbonate ions
 - ▶ Excreting bicarbonate ions

'Maximal compensation' versus 'full compensation'?

- ▶ **Maximal compensation** refers to the actual maximal amount of compensation that is typically seen in a patient with a simple acid-base disorder.
- ▶ **Full compensation** refers to the amount of compensation that would correct the pH all the way back to within the normal range.
- ▶ The general rule for all acid-base disorders is that the body's compensatory response is almost never sufficient to return the plasma pH to normal. If the pH is normal then it suggests that a second, compensating acid-base disorder is present.

Respiratory Acidosis

- ▶ Main causes:
 - ▶ Hypoventilation (chest/lung disease, CNS disease /drug, trauma/)
 - ▶ Acute hypercatabolic disorders (Malignant hypertermia)
 - ▶ Increased Intake of Carbon Dioxide
- ▶ **CO₂ rapidly and easily crosses lipid barriers, a respiratory acidosis has rapid & generally depressing effects on intracellular metabolism.**
- ▶ Acutely the acidosis will cause a right shift of the oxygen dissociation curve
- ▶ Note that 'hypercapnia' and 'respiratory acidosis' are not synonymous as, for example, a patient with a severe metabolic acidosis and a concomitant respiratory acidosis could have an arterial pCO₂ less than 40mmHg.

Respiratory Acidosis - Compensation

- ▶ The acute physicochemical change and consequent buffering esp by intracellular protein. (Immediate onset - as occurs with an acute respiratory acidosis.)
 - ▶ In acute respiratory acidosis the $[\text{HCO}_3^-]$ rises by 1 mmol/l for every 10mmHg increase in pCO_2 above its reference value of 40mmHg.
- ▶ The renal retention of bicarbonate as renal function is altered by the elevated arterial pCO_2 and additional bicarbonate is added to the blood passing through the kidney. (Slow onset: hours-days)
 - ▶ In chronic respiratory acidosis an average 4 mmol/l increase in $[\text{HCO}_3^-]$ occurs for every 10mmHg increase in pCO_2 from the reference value of 40mmHg.

Anion gap (AG)

$$AG = ([Na^+] + [K^+]) - ([Cl^-] + [HCO_3^-]) = 10-20 \text{ mEq/l}$$

$$AG = [Na^+] - ([Cl^-] + [HCO_3^-]) = 8-16 \text{ mEq/l}$$

- ▶ The negatively charged proteins account for about 10% of plasma anions and make up the majority of the unmeasured anion represented by the anion gap under normal circumstances.
- ▶ Relevance of AG:
 - ▶ To signal the presence of a metabolic acidosis
 - ▶ Help differentiate between causes of a metabolic acidosis (Organic/Inorganic)
 - ▶ To assist in assessing the biochemical severity of the acidosis and follow the response to treatment

The Anion Gap can be Misleading :

- ▶ The error with an AG is quite high (3 other measured ions)
- ▶ If the AG is greater than 30 mmol/l, than it invariably means that a metabolic acidosis is present.
- ▶ If the AG is in the range 20 to 29 mmol/l, than about one third of these patients will not have a metabolic acidosis.

Key Fact: Hypoalbuminaemia causes a low anion gap

- ▶ Every 10 g/l decrease in albumin will decrease anion gap by 2.5 to 3 mmoles.

Metabolic Acidosis

- ▶ A decrease in plasma bicarbonate can be caused by two mechanisms:
 - ▶ A gain of strong acid
 - ▶ A loss of base
- ▶ **Classified by Anion Gap**
 - ▶ High Anion-Gap Acidosis (eg:DKA, Lactic Acidosis, Renal Failure, Toxins)
 - ▶ Normal Anion-Gap Acidosis (eg: RTA, Carbonic anhydrase inhibitors, severe diarrhoea, Addition of HCl, NH₄Cl)

Metabolic Acidosis - Compensation

- ▶ Compensation for a metabolic acidosis is **hyperventilation** to decrease the arterial pCO₂.
- ▶ Maximal compensation takes 12 to 24 hours
- ▶ The expected pCO₂ at maximal compensation can be calculated from a simple formula
 - ▶ Expected pCO₂ = 1.5 (Actual [HCO₃]) + 8 mmHg
- ▶ If a patient with a severe metabolic acidosis requires intubation and controlled ventilation in hospital, the acidosis can markedly worsen unless the hyperventilation is maintained. The ventilation should be set to mimic the compensatory hyperventilation to keep the pCO₂ low.

Respiratory Alkalosis

- ▶ Hyperventilation (ie increased alveolar ventilation) is the mechanism responsible for the lowered arterial pCO₂ in ALL cases of respiratory alkalosis.
- ▶ Hyperventilation (emotionel, fever, salicilate intoxic, iatrogen)

Respiratory Alkalosis - Compensation

▶ Compensation in an ACUTE Respiratory Alkalosis

- ▶ The buffering is predominantly by protein and occurs intracellularly
- ▶ There is a drop in HCO_3^- by 2 mmol/l for every 10mmHg decrease in pCO_2 from the reference value of 40mmHg.
- ▶ The lower limit of 'compensation' for this process is 18mmol/l - so bicarbonate levels below that in an acute respiratory alkalosis indicate a co-existing metabolic acidosis

▶ Compensation in a CHRONIC Respiratory Alkalosis

- ▶ Renal loss of bicarbonate causes a further fall in plasma bicarbonate
- ▶ Average 5 mmol/l decrease in $[\text{HCO}_3^-]$ per 10mmHg decrease in pCO_2 from the reference value of 40mmHg. This maximal response takes 2 to 3 days to reach.
- ▶ The limit of compensation is a $[\text{HCO}_3^-]$ of 12 to 15 mmol/l.

Metabolic Alkalosis

- ▶ Without a second mechanism acting to maintain it, the alkalosis would be only transitory.
 - ▶ **Why?** This is because the kidney normally has a large capacity to excrete bicarbonate and return the plasma level to normal.
- ▶ **What are these abnormal 'maintenance factors'?**
 - ▶ Chloride Depletion (Loss of acidic gastric juice, diuretics, post-hypercapnia)
 - ▶ Potassium Depletion (Kaliuretic diuretics, steroids!)
 - ▶ Reduced glomerular filtration rate (GFR)
 - ▶ ECF volume depletion
 - ▶ Excessive NaHCO_3 intake
 - ▶ Severe hypoalbuminaemia

Metabolic Alkalosis - Compensation

- ▶ The compensatory response is **hypoventilation**
- ▶ Peripheral oxygen unloading may be impaired because of the alkalotic shift of the haemoglobin oxygen dissociation curve to the left.
- ▶ Risk of Hypoxaemia → GIVE OXIGEN!

- ▶ For patients that you intubate and ventilate: It is easy to render ventilated patients hypocapnic and this respiratory alkalosis can greatly worsen the alkalemia.
- ▶ Expected $p\text{CO}_2 = 0.7 [\text{HCO}_3] + 20 \text{ mmHg}$ (range: +/- 5)

The Six Steps of Systematic Acid-Base Evaluation

- ▶ **1. pH:** Assess the net deviation of pH from normal
- ▶ **2. Pattern:** Check the pattern of bicarbonate & pCO₂ results
- ▶ **3. Clues:** Check for additional clues in other investigations
- ▶ **4. Compensation:** Assess the appropriateness of the compensatory response
- ▶ **5. Formulation:** Bring the information together and make the acid base diagnosis
- ▶ **6. Confirmation:** Consider if any additional tests to check or support the diagnosis are necessary or available & revise the diagnosis if necessary

1. pH: Check arterial pH

▶ **NO OVERCOMPENSATION!**

- ▶ IF an acidaemia is present THEN an acidosis must be present
- ▶ IF an alkalaemia is present THEN an alkalosis must be present

▶ IF pH is normal pH THEN

- ▶ Either (no acid-base disorder is present) *or*
- ▶ Compensating disorders are present ie a mixed disorder with an acidosis and an alkalosis
- ▶ The body's compensatory response is **almost never sufficient for full compensation**

2. Look for suggestive pattern in pCO₂ & [HCO₃]

- ▶ IF Both [HCO₃] & pCO₂ are low THEN Suggests presence of either a Metabolic Acidosis or a Respiratory Alkalosis (but a mixed disorder cannot be excluded)
- ▶ IF Both [HCO₃] & pCO₂ are high THEN Suggests presence of either a Metabolic Alkalosis or a Respiratory Acidosis (but a mixed disorder cannot be excluded)
- ▶ IF [HCO₃] & pCO₂ move in opposite directions THEN a mixed disorder MUST be present

3. Check for additional clues in other investigations

High anion gap	<i>Always</i> strongly suggests a metabolic acidosis.
Hyperglycaemia	If ketones also present in urine -> diabetic ketoacidosis
Hypokalaemia and/or hypochloraemia	Suggests metabolic alkalosis
Hyperchloraemia	Common with normal anion gap acidosis
Elevated creatinine and urea	Suggests uraemic acidosis or hypovolaemia (prerenal renal failure)
Elevated creatinine	Consider ketoacidosis: ketones interfere in the laboratory method

4. Bedside Rules for Assessment of Compensation

- ▶ The $[\text{HCO}_3^-]$ will increase by 1 mmol/l for every 10 mmHg elevation in pCO_2 above 40 mmHg in **Acute Respiratory Acidosis**
- ▶ The $[\text{HCO}_3^-]$ will increase by 4 mmol/l for every 10 mmHg elevation in pCO_2 above 40mmHg in **Chronic Respiratory Acidosis**
- ▶ The $[\text{HCO}_3^-]$ will decrease by 2 mmol/l for every 10 mmHg decrease in pCO_2 below 40 mmHg in **Acute Respiratory Alkalosis**
- ▶ The $[\text{HCO}_3^-]$ will decrease by 5 mmol/l for every 10 mmHg decrease in pCO_2 below 40 mmHg in **Chronic Respiratory Alkalosis**
- ▶ **Rule - for a Metabolic Acidosis: Expected $\text{pCO}_2 = 1.5 \times [\text{HCO}_3^-] + 8$ (range: +/- 2)**
 - ▶ Maximal compensation may take 12-24 hours to reach
 - ▶ The limit of compensation is a pCO_2 of about 10 mmHg
- ▶ **Rule - for a Metabolic Alkalosis: Expected $\text{pCO}_2 = 0.7 [\text{HCO}_3^-] + 20$ (range: +/- 5)**