Protocol in General Pathological Physiology

Acid-base disorders

Introduction

Maintaining the homeostasis of the inner milieu and the acid-base equilibrium is an important prerequisite for the proper metabolic processes in the body. Each day the cells produce approximately 20 mol of "volatile" acids (carbonic acid) and about 40 – 80 mmol of fixed or "non-volatile" acids (acetoacetic acid, lactic acid and others). Fluctuations in the balance between acids and bases produced during the metabolism are constantly regulated and the acid-base balance is maintained by cooperation among several regulatory mechanisms: intracellular and extracellular buffer systems (bicarbonate, phosphate, protein, hemoglobin), lungs (excretion of CO_2) and kidneys (excretion of H^+, retention of bicarbonate HCO_3^-), but also other organs (liver, gastrointestinal system, bone).

Acid-base disorders are divided into four basic forms (tab. 1): **metabolic acidosis (MAC), metabolic alkalosis (MAL), respiratory acidosis (RAC)** and **respiratory alkalosis (RAL)**. These may occur as simple disorders, or as combined acid-base disorders, i.e. combination of two or more acid-base disorders. The combined acid-base disorder may be consequence of one disease (e.g.: in an obstructive lung disease a RAC may develop together with a lactic MAC), but also two or more different diseases (e.g.: patient with chronic obstructive pulmonary disease combined with severe vomiting can have combined RAC, MAC and MAL disorder).

Any acid-base disorder, acidosis or alkalosis, induces the *compensatory response* of the organism, which tries to restore the pH to normal. Metabolic disorders are compensated by respiratory system (hyper- or hypoventilation) and kidneys compensate respiratory disorders (by increased or decreased retention of bicarbonate) (Tab. 1).

Tab. 1.	**Acid-base disorders classification**		
Acid-base disorder	**Laboratory findings**	**Causes**	**Compensation**
MAC	pH < 7,36 HCO_3^- < 22 mmol/l	Ketoacidosis (diabetes mellitus), lactic acidosis (cardio-pulmonal disorders, shock), intoxication with substances in the metabolism of which acids are formed (ethanol $\rightarrow$ acetic acid), renal insufficiency, renal tubular acidosis type I and II...	Increased excretion of CO_2 by lungs - hyperventilation
MAL	pH > 7,44 HCO_3^- > 26 mmol/l	Excessive loss of HCl by vomiting, antacids overdose, excessive loss of chlorides (diarrhoea), loss of potassium (hyperaldosteronism)...	Decreased excretion of CO_2 by lungs - hypoventilation
RAC	pH < 7,36 pCO_2 > 5,8 kPa	Disorders of ventilation (hypoventilation) due to inhibition of the respiratory centre (sedatives, hypnotics), damage of muscles or nerves (muscular dystrophy), respiratory diseases (chronic lung obstruction), inappropriate artificial ventilation...	Decreased excretion (increased retention) of HCO_3^- by kidneys
RAL	pH > 7,44 pCO_2 < 4,8 kPa	Hyperventilation - fear, hysteria, fever, sepsis, anemia, altitude disease...	Increased excretion of HCO_3^- by kidneys

Assessment of acid-base disorders

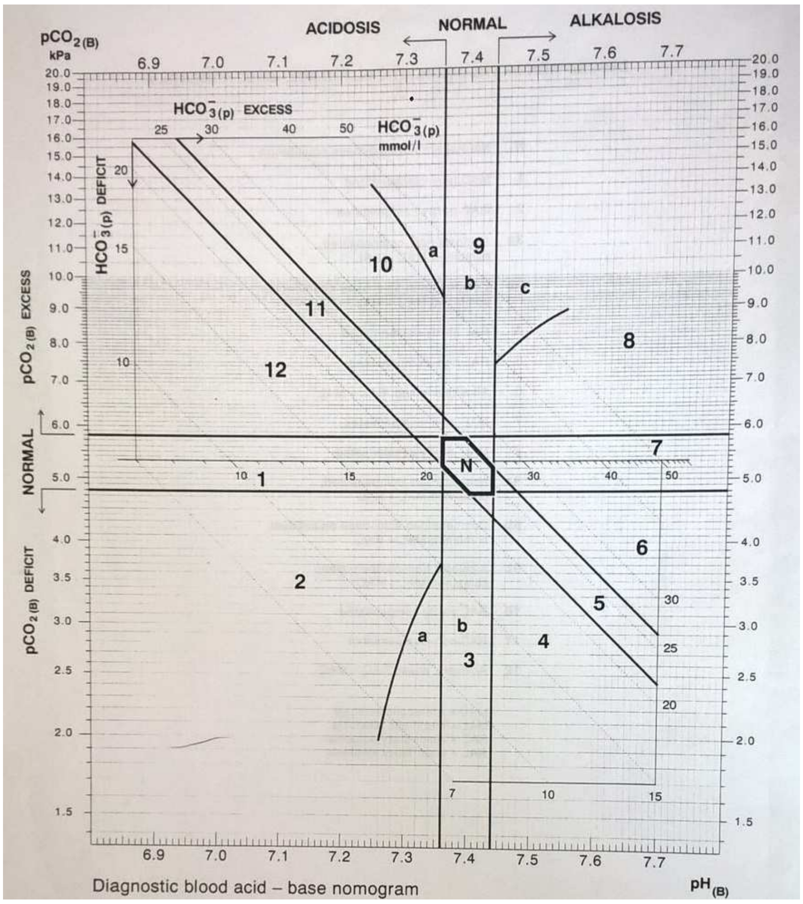
Acid-base parameters are determined from the capillary (ear, tip of finger) or from the artery (a. radialis) blood sample.

The classic method of evaluating the acid-base balance is based on the Henderson-Hasselbalch equation for the bicarbonate buffer system and is based on an assessment of three basic laboratory parameters: pH, pCO_2 and HCO_3^- concentration.

Henderson-Hasselbalch equation:

$$pH = pK + \log \frac{[HCO_3^-]}{[H_2CO_3]}$$

Tab. 2.	Overview and interpretation of acid-base parameters	
Parameter	**Physiological value**	**Interpretation**
pH	7,4 ± 0,04	pH of blood below 7.36 is **acidemia**, pH higher than 7.44 is **alkalemia**. The range of blood pH values compatible with life is from 6.8 to 7.7.
pCO_2	5,3 ± 0,5 kPa	pCO_2 below 4,8 kPa is **hypocapnia**, pCO_2 higher than 5,8 kPa is **hypercapnia.**
HCO_3^-	24,0 ± 2,0 mmol/l	The so-called actual bicarbonates are calculated from the measured pH and pCO_2 values according to the Henderson-Hasselbalchic equation. The concentration of HCO_3^- in the blood below 22 mmol/l is **hypobasemia**, a concentration higher than 26 mmol/l is **hyperbasemia**.
pO_2	10,0 ± 13,3 kPa	Decreased partial pressure of oxygen in the blood is **hypoxemia**, increased partial pressure of oxygen in the blood is **hyperoxemia.**
BE	0 ± 2,0 mmol/l	The base excess refers to an excess (+BE) or a deficit in the amount of base present in the blood (-BE).
AG	15,2 ± 1,6 mmol/l	Anion gap represents the concentration of all the unmeasured anions in the plasma (lactate, keto acids, sulphates, phosphates). AG is calculated from the following formula: $AG = (Na^+ + K^+) - (Cl^- + HCO_3^-)$.
BB	42 ± 2 mmol/l	Buffer base is the sum of all "strong" bases in the blood.



Acid-base normogram

N	Normal area of acid-base equilibrium
1	MAC non-compensated
2	MAC partly compensated
3a	Acidosis non-compensated combined MAC + RAL
3b	Compensated acid-base equilibrium combined MAC + RAL
4	RAL partly compensated
5	RAL non compensated
6	Alkalosis mixed, RAL + MAL
7	MAL non compensated
8	MAL partly compensated
9a	Acidosis non-compensated combined MAL + RAC
9b	Compensated acid-base equilibrium combined MAL + RAC
9c	Alcalosis non-compensated combined MAL + RAC
10	RAC partly compensated
11	RAC non compensated
12	Acidosis, mixed RAC + MAC

Empirical calculations of acid-base disorders:

Metabolic acidosis:
$\Delta\ pCO_2 = 0{,}16 \times \Delta[HCO_3^-] \pm 0{,}2$
Δ = deviation of the measured value from the average

Metabolic alkalosis:
$\Delta\ pCO_2 = 0{,}093 \times \Delta[HCO_3^-] \pm 0{,}2$
Δ = Deviation of the measured value from the average

Metabolic disorders:
The pH and $[HCO_3^-]$ relationship expresses the equation:
$[HCO_3^-] + 15$ = the last two numbers of pH

Respiratory acidosis:
$\Delta[HCO_3^-] = 2{,}63 \times \Delta\ pCO_2 \pm 2{,}0$
Δ = deviation of the measured value from the average

Respiratory alkalosis:
$\Delta[HCO_3^-] = 3{,}76 \times \Delta\ pCO_2 \pm 2{,}0$
Δ = deviation of the measured value from the average

Respiratory disorders:
Estimation of pH fluctuations in respiratory disorders
$pH = 0{,}056 \times \Delta\ pCO_2 \pm 0{,}02$
Δ = deviation of the measured value from the average

Case studies
Simple acid-base disorders

Case study 1

A 19 year old pregnant patient was admitted with a history of polyuria and thirst. She felt ill and was presented to hospital.
Biochemistry: Na^+ = 136 mmol/l, K^+ = 4.8 mmol/l, glucose = 19.0 mmol/l,
Arterial blood gases: pH 7.26, pCO_2 3.13 kPa, pO_2 17 kPa, HCO_3 9.1 mmol/l.
Characterize this acid-base balance disorder. What kind of breathing pattern is typical for these states? What is the presumable disease patent is suffering from?
Acid-base balance disorder:
Breathing pattern:
Diagnosis:

Case study 2

The patient with the duodenal peptic ulcer disease was uncontrollable treated by $NaHCO_3$. During control his laboratory parameters were as follows: pH = 7.50, pCO_2 = 6.13 kPa, HCO_3^- = 36.0 mmol/l.
Characterize this acid-base balance disorder. What is the presumable cause of the patient´s problems?
Acid-base balance disorder:
Explanation:

Case study 3

The middle-aged obese man was admitted following a motor vehicle crash. His major injury was chest trauma with a small right pneumothorax and at least five fractured ribs on the right. There was no head or neck injury.
Biochemistry: Na^+ = 138 mmol/l, K^+ = 3.9 mmol/l, Cl^- = 103 mmol/l, glucose = 4.89 mmo/l.
Arterial blood gases: pH = 7.18, pCO_2 = 9.73 kPa, pO_2 = 9.3 kPa, HCO_3 = 27mmol/l.
Characterize this acid-base balance disorder. What organ (organs) typically compensate this ABB disorder?
Acid-base balance disorder:
Compensation by:

Case study 4

A 20 year old man presented with sudden onset of muscle weakness in arms and legs. There were no other neurological abnormalities, in particular his level of consciousness was normal. There were no sensory abnormalities. Mild constipation was present.
Biochemistry: Na^+ = 143 mmol/l, K^+ = 2.0 mmol/l, Cl^- = 101 mmol/l, glucose = 4.89 mmo/l.
Arterial blood gases: pH = 7.49, pCO_2 = 6.9 kPa, pO_2= 13 kPa, HCO_3 = 39mmol/l.
Characterize this acid-base balance disorder. How this ABB disorder is typically compensated? Which from mentioned parameters could cause muscle weakness?
Acid-base balance disorder:
Compensation:
Cause of muscle weakness:

Case study 5

A 65 year old lady with a history of chronic obstructive lung disease and bronchiectasis presented with a 2 hours history of worsening dyspnoea. Bilateral wheezing was present. She was alert, orientated, haemodynamically stable and pupil size was normal.
Biochemistry: Na^+ = 135mmol/l, K^+ = 4.1mmol/l, Cl^- = 94mmol/l, glucose =5.8mmo/l.
Arterial blood gases: pH = 7.28, pCO_2 = 8.94 kPa, pO_2 = 7.03 kPa, HCO_3 = 34mmol/l.
Characterize this acid-base balance disorder. What organ (organs) typically compensate this ABB disorder?
Acid-base balance disorder:
Compensation by:

Combined acid-base disorders

Case study 1

A woman, 68 years old, with chronic obstructive pulmonary disease was transported to the hospital. Two days before she had epigastric pain with repeated strong vomiting. During hospitalization, severe dyspnoea is present.
Laboratory parameters: pH = 7.38, pCO_2 = 9.3 kPa, HCO_3^- = 43 mmol/l,pO_2 = 6.8 kPa, BE = + 19 mmol/l, Na^+ = 136 mmol/l, K^+ = 2.8 mmol/l, Cl^- = 71 mmol/l
What acid-base balance disorder(s) the patient suffer from?
Explain, why do you anticipate this acid-base disorder(s)?
Calculate anion gap (AG). What information does this result provide?

Case study 2

A young man, aged 15, was transported into hospital in comatous state. His breath smells like fruits. Patient's condition is further complicated due to severe pneumonia.
Laboratory values: pH = 7.10, pCO_2 = 7.7 kPa, HCO_3^- = 17.5 mmol/l, BE = - 13.5 mmol/l, glycemia = 19.6 mmol/l, ketone bodies in urine = +++.
What type of acid-base balance disorder is present in this case?
Explain why you suppose this disorder(s)?
What is the primal diagnosis (not the complicating one)?

Case study 3

Woman, aged 43, was hospitalised at the surgery clinic with diagnosis of acute pancreatitis, status post colica biliaris bilat. Repeated episodes of vomiting recorded. Significant anorexia is present, the patient has not eaten for longer time. Chest X-ray shows bilateral disseminated shadowing over the lungs, patient is dyspnoic.
Laboratory values: pH = 7,43, pCO_2 = 4,9 kPa, pO_2 = 8,9 kPa, HCO_3^- = 24,5 mmol/l, BE = + 0,5 mmol/l
Are acid-base balance values out of reference range? Is acid-base disorder present in this patient?
If yes, please specify:
Explain why you suppose this disorder(s):