Acid-base balance disorders – practical interpretation

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Learning outcomes

- Student will learn to detect the presence of acid-base balance disorder.
- Student will learn how to evaluate the compensation of acid-base balance disorder.
- Student will learn how to detect unmeasured anions of organic acids and to suggest differential diagnosis of the cause of metabolic acidosis.

Content of the lecture

- Basic terms and definitions
- Classification of acid-base balance disorders and it‘s evaluation
- Evaluation of compensation of acid-base balance disorders, Boston rules
- Calculation of anion gap
- Differential diagnosis of metabolic acidosis
- Practical examples

Basic terms and definitions

- Acid-base balance – the set of processes leading to the formation and disappearance of acids and bases in the internal environment

- Constant concentration of hydrogen cations H^+ (40 nmol/l)
- (norm 7,35 – 7,45)

- **Acid** – a substance that is capable of releasing H^+ → pH reduction
- **Base** – a substance that is capable of accepting H^+ → pH increasement

Basic terms and definitions

- **Acidemia** – increase in H^+ concentration – pH drop below 7,35
- **Acidosis** – processes in the internal environment that lead to the formation of acids or to the disappearance of bases and thus to a decrease in pH

- **Alkalemia** – decrease in H^+ concentration – pH increase above 7,45
- **Alkalosis** – processes that lead to the disappearance of acids or to the formation of bases and thus to a rise in pH

Basic terms and definitions

- Buffer - a solution containing a conjugated pair of a weak acid and its salt, maintaining a stable pH

$HA \rightarrow A^{-} + H^{+}$

Henderson-Haaselbalch equation:

Basic terms and definitions

pK of carbonic acid

CO_2 solubility coefficient

The change in pH is determined by the partial pressure of CO_2 ($PaCO_2$) and the concentration of bicarbonate (HCO_3^-).

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Classification of ABB disorders

Respiratory

- Caused by changes in $PaCO_2$ (norm $PaCO_2$ 4,6-6 kPa)
- Acidosis – insufficient CO_2 elimination, pCO_2 in extracellular fluid rises
- Alkalosis – alveolar ventilation higher than needed to maintain normal $PaCO_2$, pCO_2 decreases

Metabolic

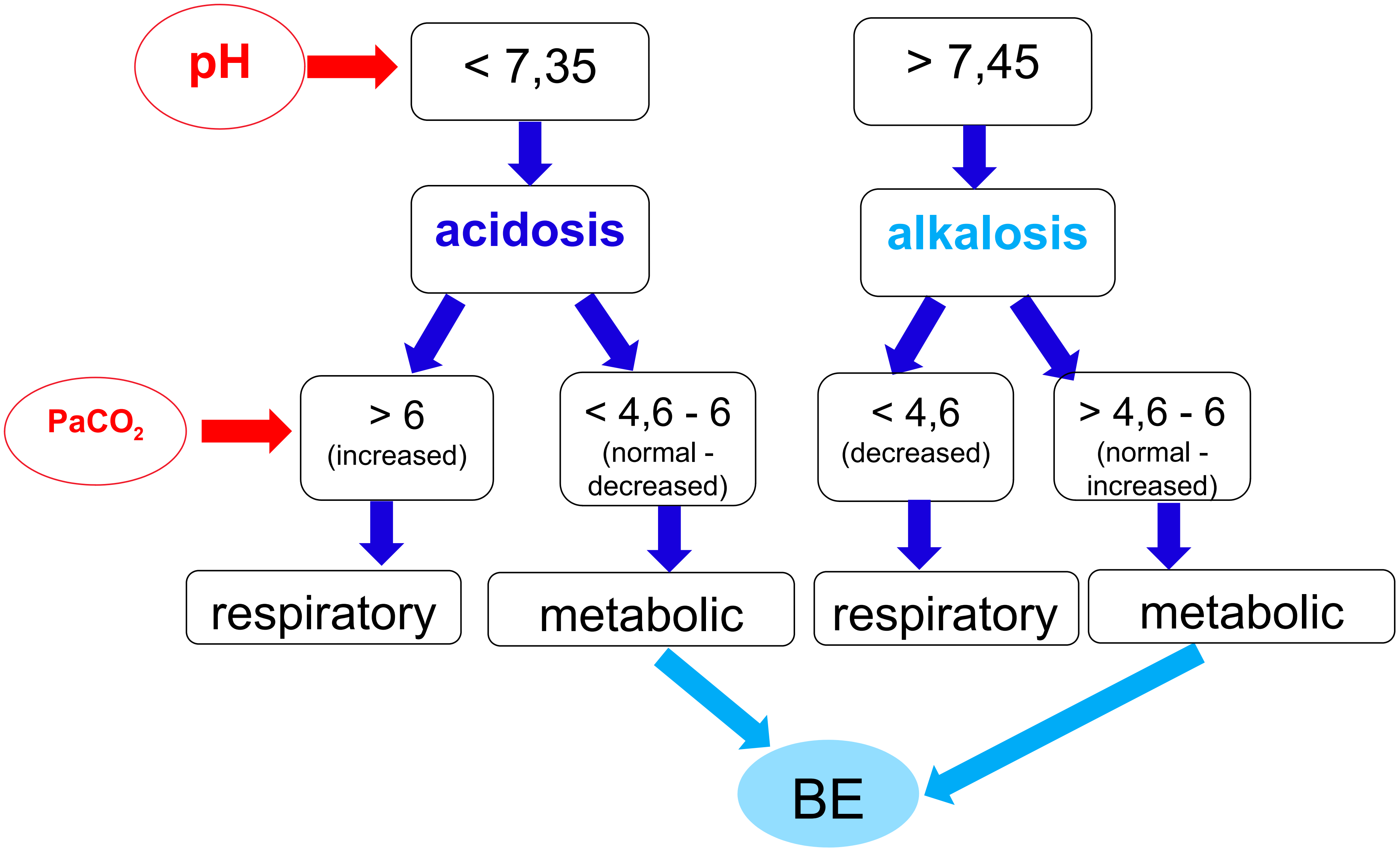
- Caused by changes in HCO_3 (norm 24 2 mmol/l), changes in the concentration of buffer bases (BB)

Excess of bases – Buffer Base (BB)

- Sum of base concentrations of all buffering systems
- Bicarbonate bases, non-bicarbonate bases (phosphates, albumin)

Base Excess (BE)

- The difference between the current BB value and the normal BB value
- The amount of acid or base that must be added to the plasma to achieve a normal pH of 7,4 under a constant of $PaCO_2$ 5 kPa
- Norm -2 – +2
- Metabolic acidosis: decrease in BE < -2 or decrease in HCO_3^- concentration
- Metabolic alkalosis: increase in BE > 2 or increase in HCO_3^- concentration


pH
< 7,35
> 7,45
acidosis
alkalosis
$PaCO_2$
> 6 (increased)
< 4,6 - 6 (normal - decreased)
< 4,6 (decreased)
> 4,6 - 6 (normal - increased)
respiratory
metabolic
respiratory
metabolic
BE

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Compensation of acid-base balance disorders

- If the $PaCO_2/HCO_3^-$ ratio is kept constant, the pH will be normal
- Primary ABB disturbance → reaction by opposing change to normalize pH → **compensation = secondary ABB disturbance**

- Respiratory system– $PaCO_2$ regulation
- Metabolic regulation - kidneys, liver

! Normal pH does not mean that an ABB disorder is not present
! ABB disturbance is present if there is an abnormal pH **or** $PaCO_2$

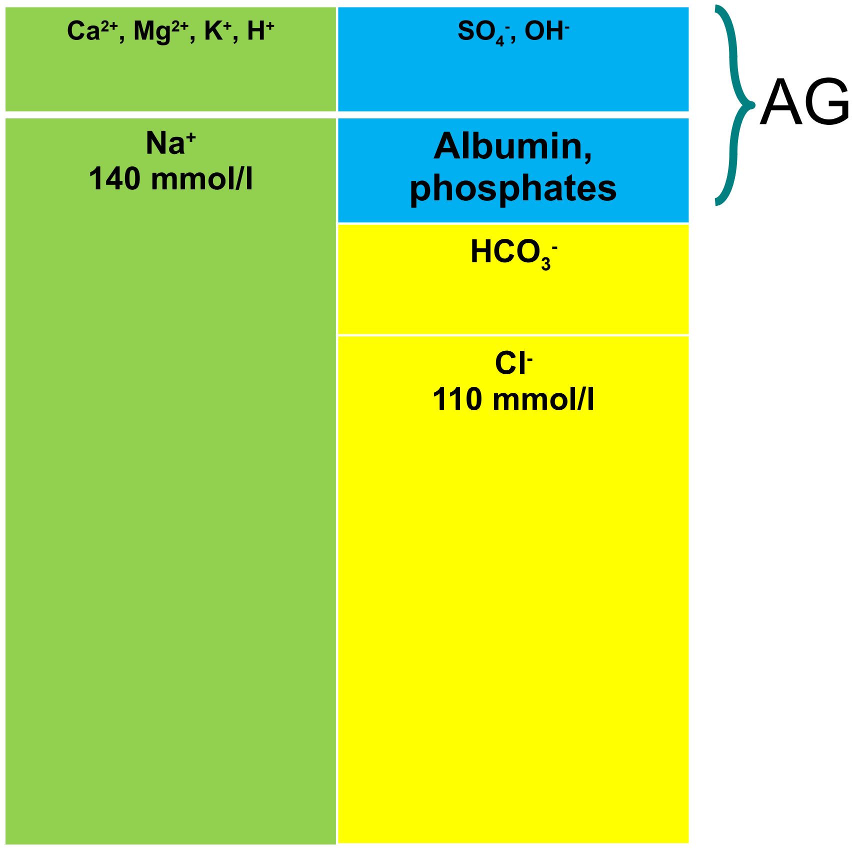
Degree of ABB disturbance compensation – Boston rules

Primary disorder	HCO_3^- concentration (mmol/l)	$PaCO_2$ (kPa)
Metabolic acidosis	< 22	$HCO_3^-/5 + 1$
Metabolic alkalosis	> 26	$HCO_3^-/10 + 2,6$
Acute respiratory acidosis	$(PaCO_2 – 5,3)$ x + 24 increased by per kPa	> 6
Chronic respiratory acidosis	$(PaCO_2 – 5,3)$ x 3 + 24 increased by 3 per kPa	> 6
Acute respiratory alkalosis	24 – 1,5 x $(5,3 – PaCO_2)$ decreased by 1,5 per kPa	< 4,7
Chronic respiratory alkalosis	24 – 4 x $(5,3 – PaCO_2)$ decreased by 4 per kPa	< 4,7

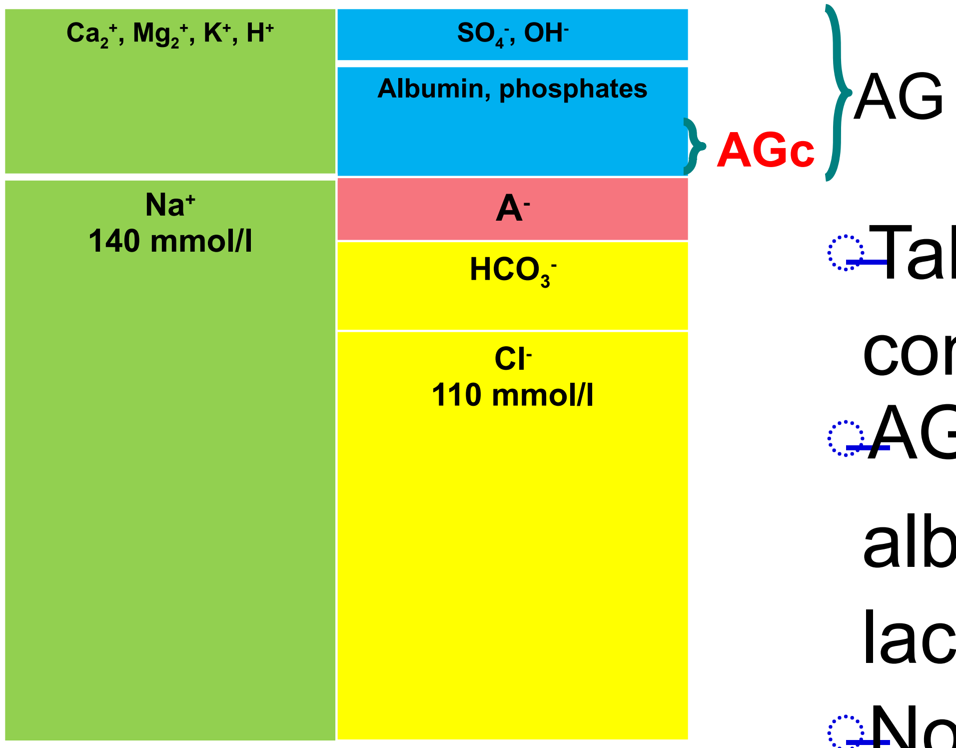
Anion Gap (AG)

- Detection of the presence of acid anions undetectable by conventional laboratory methods
- Law of conservation of electroneutrality - the sums of all positive and negative charges in the system are equal

- **$AG = (Na^{+} + K^{+}) – (Cl^{-} + HCO_3^{-})$**
- norm 12 4 mmol/l



Corrected anion gap – AGc



- Takes into account the current concentration of albumin and phosphate
- AGc = [(Na^+ + K^+) – (Cl^- + HCO_3^-)] – (0,2 x albumin (g/l) + 1,5[phosphate (mmol/l)]) – lactate
- Norm AGc = 0

→ MAC with a high AG (HAGMA)

→ MAC with a normal AG

Metabolic acidosis

With a high AG - HAGMA

- M — Methanol
- U — Uremia
- D — Diabetic/alcoholic ketoacidosis
- P — Propylene glycol
- I — Iron, isoniazid
- L — Lactate
- E — Ethylene glycol/ethanol
- S — Salicylates

With a normal AG - hyperchloremic

1. GIT secretion
2. Renal tubular acidosis
3. Iatrogenic

Pactical approach:
1. Identify the primary ABB disorder

- Is pH or $PaCO_2$ abnormal?
- If both pH and $PaCO_2$ are abnormal, compare the direcion of change
- If the change is in the same direction, the primary ABB disorder is metabolic
- If the change is in the opposite direction, the primary ABB disorder is respiratory
- If pH or $PaCO_2$ is normal, it is a combined disorder

1. Identify the primary ABB disorder

- Example 1: patient with pH 7,23 and $PaCO_2$ 3,0 kPa
- pH $PaCO_2$ → **primary metabolic acidosis**

- Example 2: patient with pH 7,23 and $PaCO_2$ 7,2 kPa
- pH $PaCO_2$ → **primary respiratory acidosis**

- Example 3: patient with pH 7,37 and $PaCO_2$ 7,5 kPa
- Normal pH$PaCO_2$ → **combined respiratory acidosis with metabolic alkalosis**

Practical approach:
2. evaluate the compensatory response

- Boston rules
- Metabolic acidosis: calculate the expected $PaCO_2$ (HCO_3^-/5 + 1)
- Metabolic alkalosis: calculate the expected $PaCO_2$ (HCO_3^-/10 + 2,6)
- Respiratory acidosis: calculate the expected HCO_3 :
  - acute ($PaCO_2$ – 5,3) x + 24
  - chronic ($PaCO_2$ – 5,3) x 3 + 24
- Respiratory alkalosis: calculate the expected HCO_3 :
  - acute 24 – 1,5 x (5,3 – $PaCO_2$)
  - chronic 24 – 4 x (5,3 – $PaCO_2$)

2. evaluate the compensatory response: example

Patient with COPD exacerbation, dyspnoic, soporous
pH 7,15, $PaCO_2$ 16,3 kPa, PaO_2 10,3 kPa, HCO_3 42 mmol/l,
BE 7,9 mmol/l, SaO_2 90%

- Compare the direcion of change:
  pH $PaCO_2$ → primary respiratory acidosis
- Calculate the expected $HCO_3 = (PaCO_2 - 5{,}3) \times 3 + 24$
  $HCO_3 = (16{,}3 - 5{,}3) \times 3 + 24 = 57$
- Compare the actual and calculated HCO_3

→ Primary respiratory acidosis with insufficient compensatory metabolic alkalosis

3. Detection of unmeasurable anions - AG

- Example: a patient with a history of chronic alcohol abuse, admitted to hospital in a coma, Kussmaul breathing.

pH 7,31	Na 144 mmol/l
$PaCO_2$ 2,9 kPa	K 4,3 mmol/l
HCO_3^- 10,6 mmol/l	Cl 106 mmol/l
BE -13,4	Ca^{2+} 1,12 mmol/l
Albumin 27,8 g/l	Mg 0,81 mmol/l
Lactate 2,4	P 1 mmol/l

1. What is the primary disorder?

pH $PaCO_2$

HCO_3^- significantly negative

Primary metabolic acidosis

pH 7,31	Na 144 mmol/l
$PaCO_2$ 2,9 kPa	K 4,3 mmol/l
HCO_3^- 10,6 mmol/l	Cl 106 mmol/l
BE -13,4	Ca^{2+} 1,12 mmol/l
Albumin 27,8 g/l	Mg 0,81 mmol/l
Lactate 2,4	P 1 mmol/l

2. What is the compensatory response?

- Calculate the expected $PaCO_2$ in case of full compensation
- $PaCO_2 = HCO_3^-/5 + 1$
- $PaCO_2 = 10,6/5 + 1 = 3,12$
- Compare the actual and calculated $PaCO_2$

- **Fully compensated respiratory metabolic acidosis**

(no superimposed disorder present)

pH 7,31	Na 144 mmol/l
$PaCO_2$ 2,9 kPa	K 4,3 mmol/l
HCO_3^- 10,6 mmol/l	Cl 106 mmol/l
BE -13,4	Ca^{2+} 1,12 mmol/l
Albumin 27,8 g/l	Mg 0,81 mmol/l
Lactate 2,4	P 1 mmol/l

3. Detection of unmeasured anions with AGc

AGc = [(Na^+ + K^+) – (Cl^- + HCO_3^-)] – (0,2 x albumin (g/l) + 1,5[phosphate (mmol/l)]) – lactate

AGc = [(140 + 4,3) – (106 + 10,6)] – (0,2 x 27,8) + 1,5x1) – 2,4

AGc = 18,24

- Metabolic acidosis with a high AG → dif. dg.: MUDPILES

- Fully compensated respiratory metabolic acidosis with a high AG
- Probable cause: alkoholic ketoacidosis or intoxication by toxic alcohols

Take home message

- ABB disturbance is present when there is abnormal pH or $PaCO_2$.
- When evaluating ABB disorders, first determine what the primary disorder is, then evaluate the compensatory response.
- BE is a more reliable parameter to diagnose metabolic acidosis than bicarbonate concentration.
- The anion gap (AG) calculation is used to detect unmeasurable anions that cause metabolic acidosis.

Source literature

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- McNamara J, Worthley, LIG. Acid-base balance: part I. Physiology. Critical care and resuscitation. 2001;3:181-187.
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