Evolution of Blood Gas Analysis - Acid-Base Balance and the Practical Applications of the Acid-Base Chart

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Agenda

Part 1 (Today)

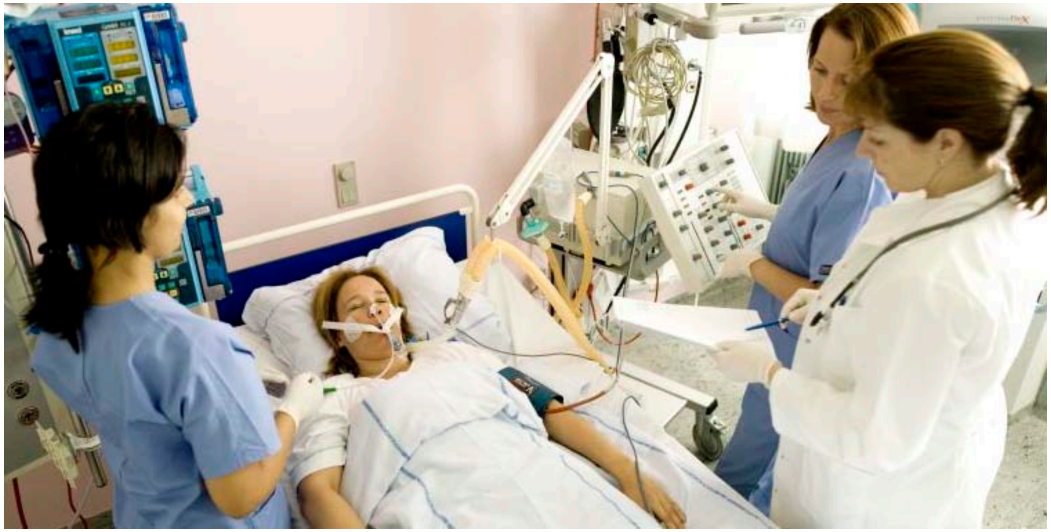
- Why measure blood gases
- Overview of acid-base disturbances
- Use of the Acid-Base Chart

Part 2

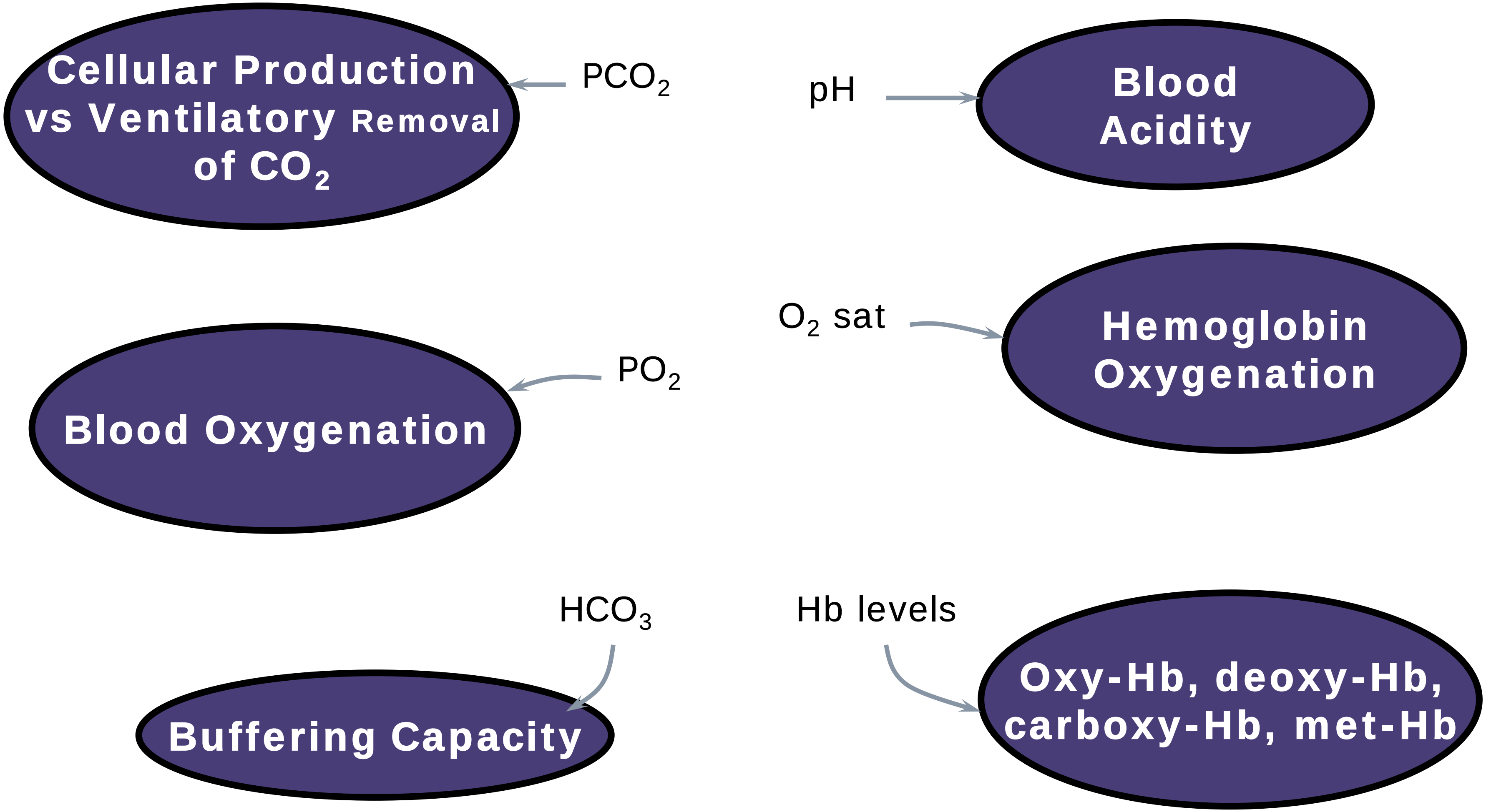
- Full value of the pO_2 assessment via
  - Oxygen uptake, Oxygen transport, Oxygen release
- Why a measured saturation is the best
- Assessment of tissue perfusion - Lactate

What is ABG?

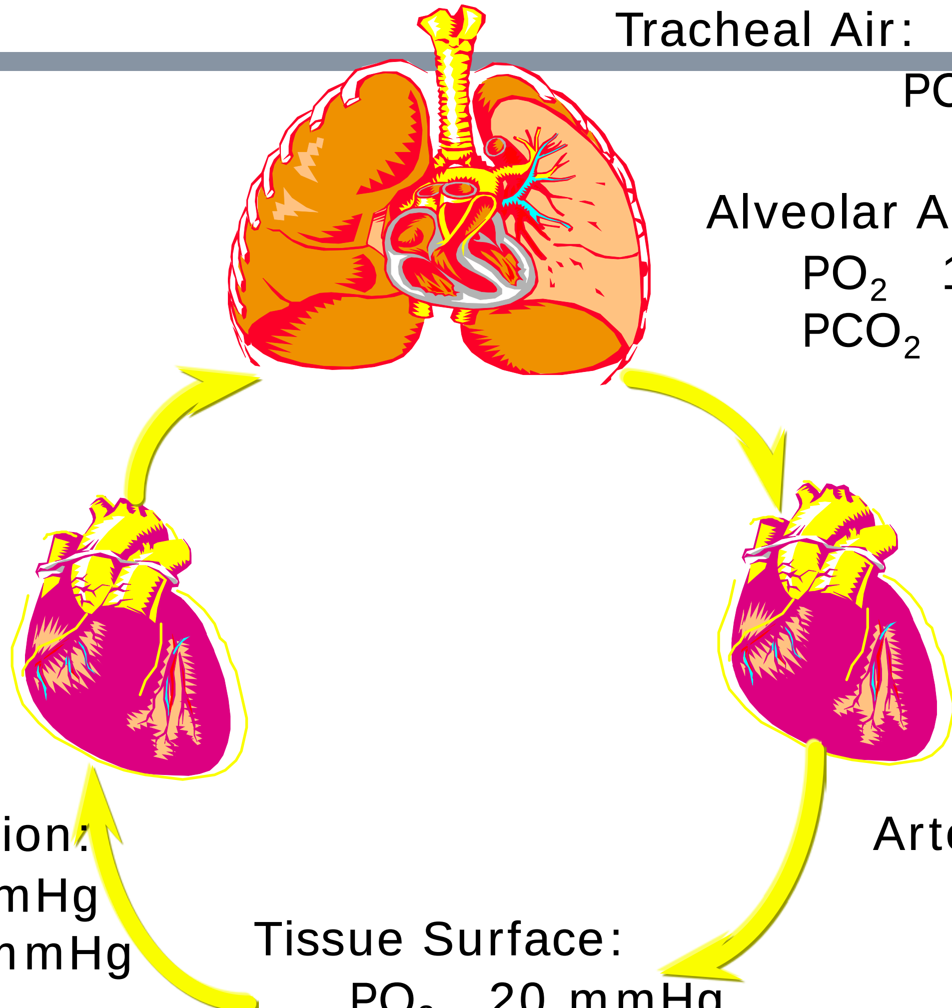
- Arterial Blood Gas - ABG:
  - pH, pO_2 and pCO_2
- An ABG is routinely used in the diagnosis and monitoring of predominantly **critically / acutely** ill patients
- Additionally, ABG is useful in delivery of clinical care to some patients with **acute and chronic respiratory** disease



Information Provided by Blood Gas and CO-oximeter Data



Gas Pressures in the Pulmonary and Systemic Circulation



Examples of reference intervals

- pH
  - Children and adults: 7.35 - 7.45 (7.3 – 7.5)*
- pCO_2
  - Male: 35 – 48 mmHg (4.7 - 6.4 kPa) (30 – 50 mmHg)*
  - Female: 32 - 45 mmHg (4.3 - 6.0 kPa)
- pO_2
  - 2 days - 60 years: 83 – 108 mmHg (11.0 - 14.4 kPa) (>80)*

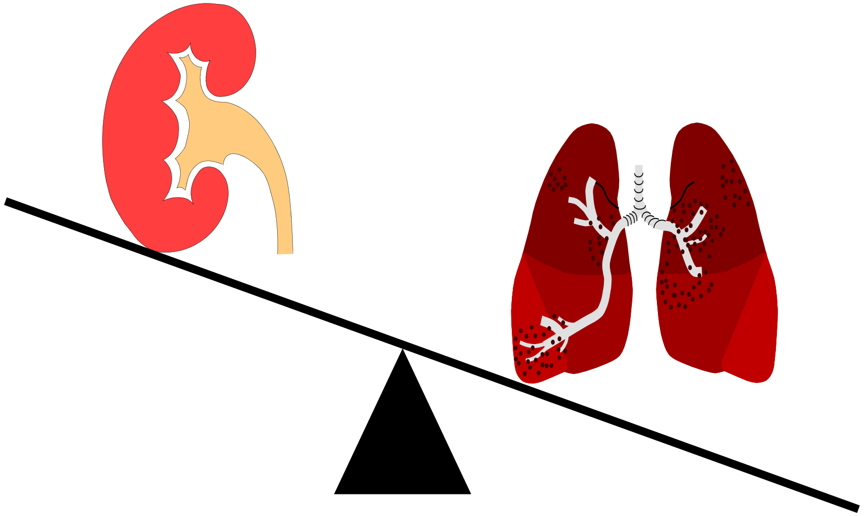
*Clinically acceptable values

ABG

- ABG allows assessment of
  - Pulmonary gas exchange: facility of the lungs to simultaneously add oxygen and remove carbon dioxide
  - Acid-base balance: ability of the body to maintain the pH of blood within narrow healthy limits
- But there is much more information that can be obtained from a BG sample
  - Oxygen transport, energy supply, kidney function, intoxication and a lot more

Acid-base

- The organism is depending on the acid-base balance to maintain a pH around 7.4 by excreting
  - CO_2 in the lungs
  - Non-carbonic acid or base via the kidneys
- An acid-base imbalance may be caused by
  - Respiratory regulation
  - Metabolic regulation
  - Mixture of both

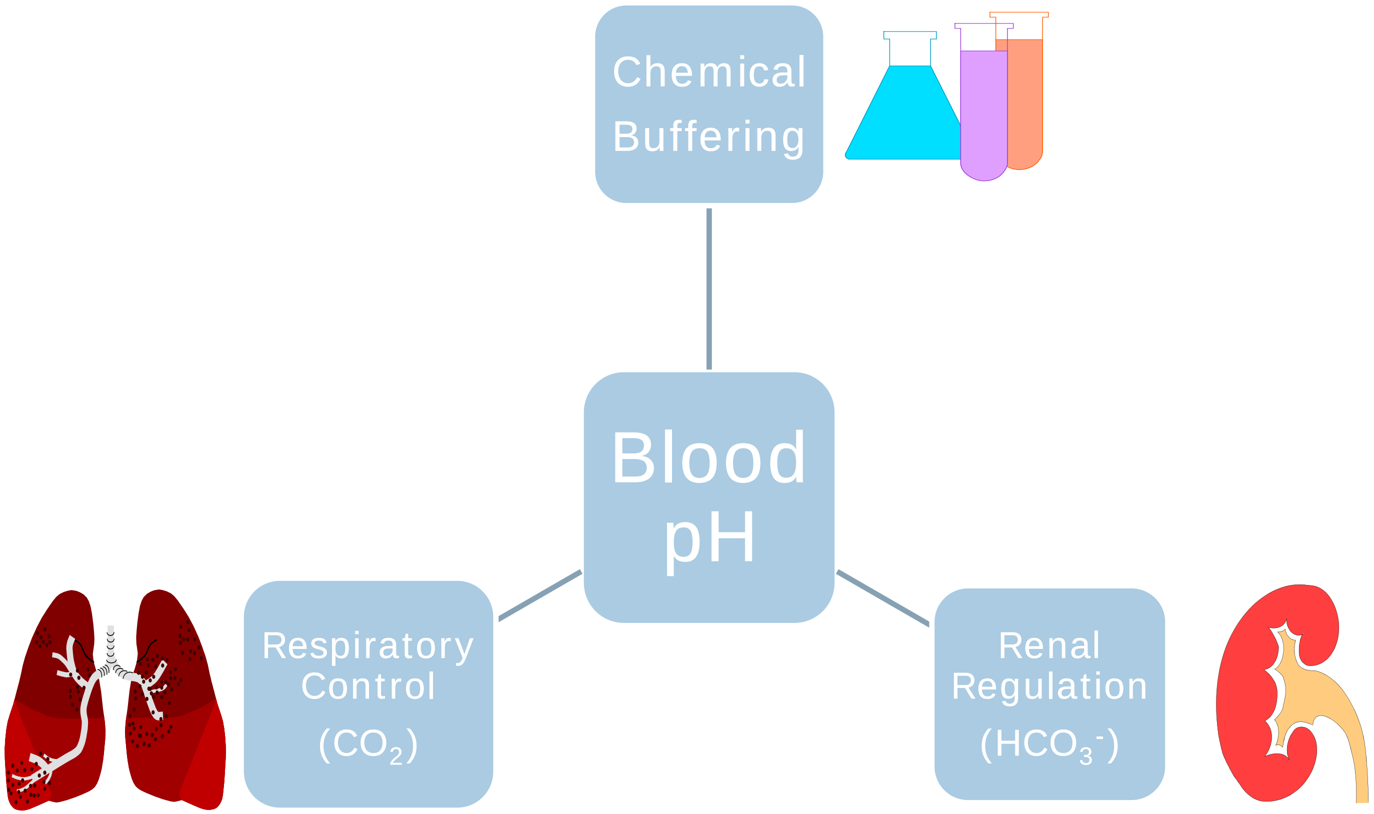


Acid-base disturbances – main causes

- Disease of, damage to, **one of the three organs** whose function is necessary to maintain pH within normal interval:
  - Lungs
  - Kidney
  - Brain
- Disease, or condition that results in **increased production** of metabolic acids - like lactic acid and keto acids - such that mechanisms for maintenance of normal pH are overwhelmed
- **Medical intervention** (ventilation or drugs)

Acid-Base Balance

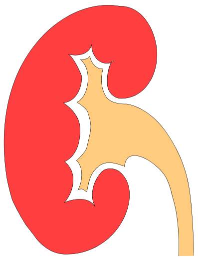
- Normally, acid-base balance is maintained by 3 primary functions:

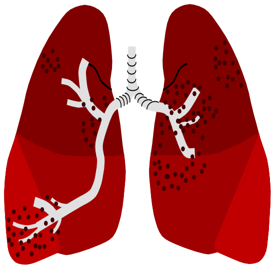


The synergistic role of lungs and kidney

- pH is primarily regulated by the factors in the Henderson-Hasselbalch equation

$$pH = pK + \log \frac{[HCO_3^-]}{\alpha \times pCO_2}$$

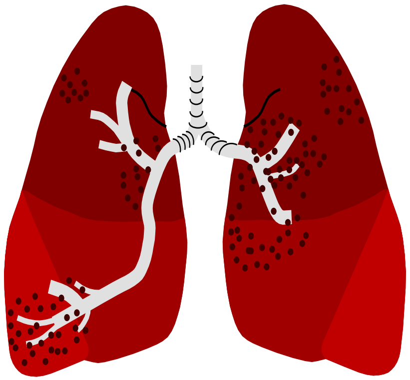




- Bicarbonate:pCO_2 ratio must be preserved to maintain pH within the normal range
- If pH goes up, pCO_2 goes down and vise- versa

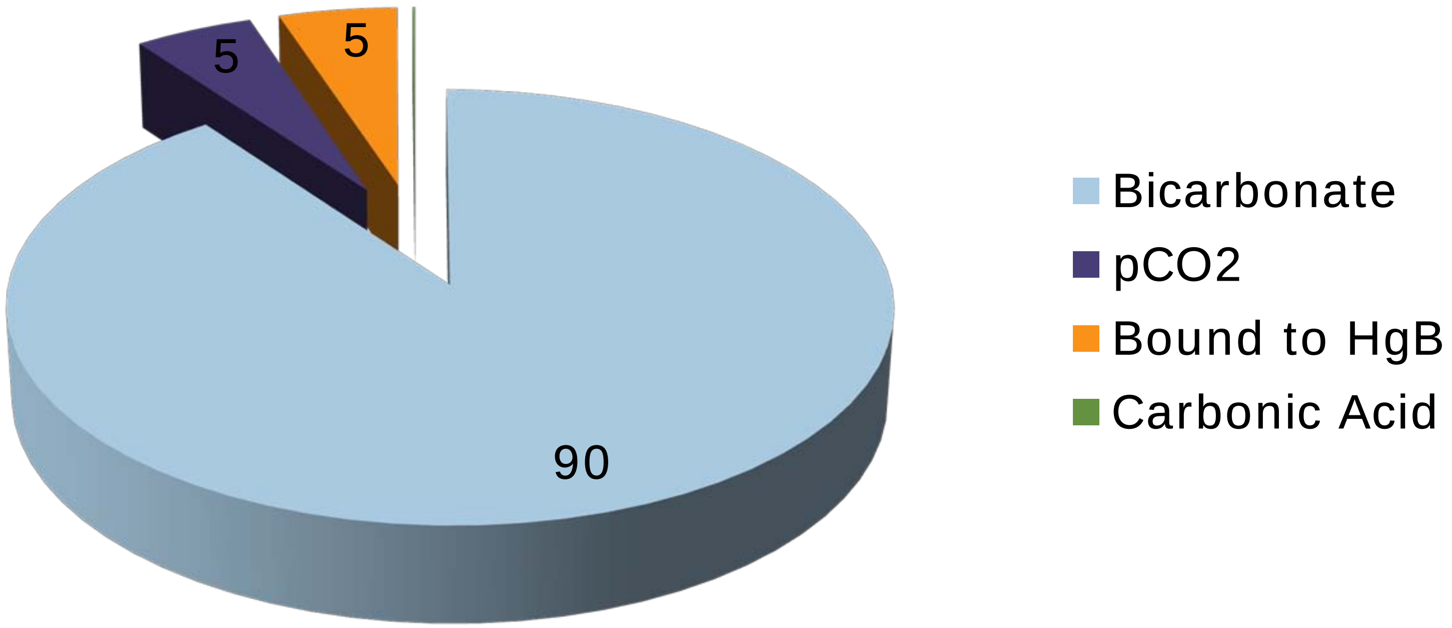
Regulation of pCO_2

- If pCO_2 -↑ then ventilation of the lungs will increase
- If pCO_2 ↓ then ventilation of the lungs will decrease



- The regulation of pCO_2 takes place within minutes
- pCO_2 reflects how well the lungs are functioning

CO_2 transport



Diseases or conditions that effect Acid-Base Balance

respiratory failure/distress
caused by COPD
pneumonia
pulmonary edema
pulmonary embolism
asthma
acute respiratory distress
syndrome
Guillain Barre syndrome
traumatic chest injury
acute/chronic renal failure
diabetic ketoacidosis
circulatory failure (shock) due to
severe hemorrhage

burns
sepsis
cardiac arrest
liver failure
fetal distress
traumatic brain injury
cerebral edema
brain tumor
drug overdose/toxic poisoning
(e.g. salicylate, antacids,
opiates, barbiturates,
diuretics, methanol,
ethanol and ethylene glycol)
mechanical ventilation etc.

Signs and symptoms of Acid-Base disturbance

coma/reduced consciousness
drowsiness, confusion
convulsions/seizures
combativeness
lethargy
headache
reduced blood pressure
breathlessness/shortness of breath/difficulty breathing
wheezing/chronic cough
reduced or increased respiratory rate
cardiac arrhythmia
anuria/polyuria,
muscle spasm/tetany
electrolyte disturbance

Bicarbonate - HCO_3^-

- Bicarbonate is the principal buffer in blood plasma
  - 90 % of CO_2 is transported as bicarbonate
- The kidneys are vital for a well-regulated pH
- The concentration of bicarbonate indicates the buffering capacity of blood
  - Low bicarbonate indicates that a larger pH change will occur for a given amount of acid or base produced
- Bicarbonate is classified as the metabolic component of acid-base balance

Bicarbonate - HCO_3^-

- In the blood gas analyzer bicarbonate is calculated from the measurement of pH and pCO_2 via the Henderson-Hasselbalch equation:

$$\mathrm{pH} = \mathrm{pK} + \log \frac{[HCO_3^-]}{\alpha \times pCO_2}$$

- This is the actual bicarbonate, and the standard bicarbonate is corrected from deviation from normal of the respiratory component of acid-base balance (pCO_2 = 40 mmHg, pO_2 = 100 mmHg and at 37°C)

Actual or standard bicarbonate?

- Standard HCO_3^-
    - More precise measure of metabolic (non-respiratory) component
    - Eliminates effect of respiratory component on HCO_3^-

Wettstein R Wilkins R Interpretation of Blood Gases (Chapter 8) In: Clinical Assessment in Respiratory Care (6th ed) Mosby: St Louis Missouri 2010

Bicarbonate - HCO_3^-

1. Consumption of HCO_3^- in buffering excessive acid production
2. Loss of HCO_3^- from the body
3. Failure to regenerate HCO_3^-

1. Increased generation of HCO_3^- consequent of excessive loss of hydrogen ions and/or chloride ions
2. Excessive administration/ingestion of HCO_3^-

Some terms for acid base disorders

Acidosis

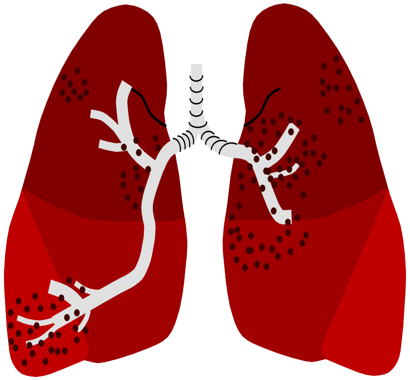
- Clinical term for the process that gives rise to acidemia, typically associated with pH < 7.35 initially.

Alkalosis

- Clinical term for the process that gives rise to alkalemia, typically associated with pH > 7.45 initially.

Respiratory acidosis	Acid-base disturbance that results from primary increase in pCO_2. Associated with reduced pH (in the absence of metabolic compensation).
Respiratory alkalosis	Acid-base disturbance that results from primary decrease in pCO_2. Associated with increased pH (in the absence of metabolic compensation).
Metabolic acidosis	Acid-base disturbance that results from primary reduction in HCO_3^-. It is associated with reduced pH.
Metabolic alkalosis	Acid-base disturbance that results from primary increase in HCO_3^-. It is associated with increased pH.

Respiratory disorders



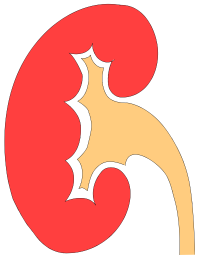
Respiratory acidosis
pH ↓ pCO_2 ↑

Emphysema, COPD, Pneumonia, depression of respiratory center

Respiratory alkalosis
pH ↑ pCO_2 ↓

Hyper-ventilation, Anxiety attacks, stimulation of brain respiratory center

Metabolic disorders



Metabolic acidosis

pH ↓ HCO_3^- ↓

Metabolic alkalosis

pH ↑ HCO_3^- ↑

Renal failure,
diabetic
ketoacidosis,
circulatory failure

Bicarbonate
administration,
potassium depletion

Acid-base disturbances and its compensation

	Respiratory acidosis	**Respiratory alkalosis**	**Metabolic acidosis**	**Metabolic alkalosis**
Primary issue	Primary increase in *p*CO2	Primary decrease in *p*CO2	Primary decrease in bicarb.	Primary increase in bicarb.
Some common causes	Emphysema, COPD, pneumonia, depression of respiratory center	Hyper-ventilation, anxiety attacks, stimulation of brain respiratory center	Renal failure, diabetic ketoacidosis, circulatory failure	Bicarbonate administration, Potassium depletion
Initial blood gas results - uncompensated	pH decreased pCO_2 increased Bicarbonate normal	pH increased pCO_2 decreased Bicarbonate normal	pH decreased pCO_2 normal Bicarbonate decreased	pH increased pCO_2 normal Bicarbonate increased
Compensatory mechanism	RENAL: increase bicarbonate	RENAL: decrease bicarbonate	RESPIRATORY: decrease pCO_2	RESPIRATORY: increase pCO_2 but limited compensation in metabolic alkalosis
Blood gas results after partial compensation	pH decreased but closer to normal pCO_2 increased Bicarbonate increased	pH increased but closer to normal pCO_2 decreased Bicarbonate marginally decreased	pH decreased but closer to normal pCO_2 marginally decreased Bicarbonate decreased	Limited compensation in metabolic alkalosis
Blood gas results after full compensation	pH normal pCO_2 increased Bicarbonate increased	pH normal pCO_2 decreased Bicarbonate decreased	pH normal pCO_2 decreased Bicarbonate decreased	Limited compensation in metabolic alkalosis

BE - Base Excess

- Reflects only non-respiratory (metabolic) component of acid-base disturbances
- Invented by Ole Siggaard-Andersen (more about him later)
- Several types of BE available on a blood gas analyzer....
  - Base(B) = base excess in whole blood
  - Base(Ecf) = base excess in extracellular fluid
- Base(Ecf) is independent from changes on pCO_2 and the recommended BE to use
- Base(Ecf) is also called
  - ”in-vivo base excess”
  - ”standard base excess” (SBE)

Kofstad J. All about base excess – to BE or not to BE. www.acutecaretesting.org. Jul 2003

BE – Base Excess

- BE predicts quantity of acid or alkali to return the plasma in vivo to a normal pH under standard conditions [1]
- BE may help determine whether an acid/base disturbance is a respiratory, metabolic for mixed metabolic/respiratory problem [1]
- Examples of reference intervals (mmol/L)
  - Adult Female: -2.3 to 2.7 [3]
  - Adult Male: -3.2 to 1.8 [3]
  - Newborn: -10 to -2 [4]
  - Infant: -7 to -1 [4]
  - Child: -4.0 to 2.0 [4]

[1] Tofaletti JG. Blood gases and electrolytes. AACC press 2009, 2nd edition. Washington DC, USA
[2] ACTH BE section
[3] Siggaard-Andersen O. Textbook on acid-base and oxygen status of the blood. http://www.siggaard-andersen.dk/OsaTextbook.htm
[4] Soldin SJ, Wong EC, Brugnara C et al. Pediatric reference intervals. 7th edition. AACC Press Washington DC 2011

Interpretation of BE

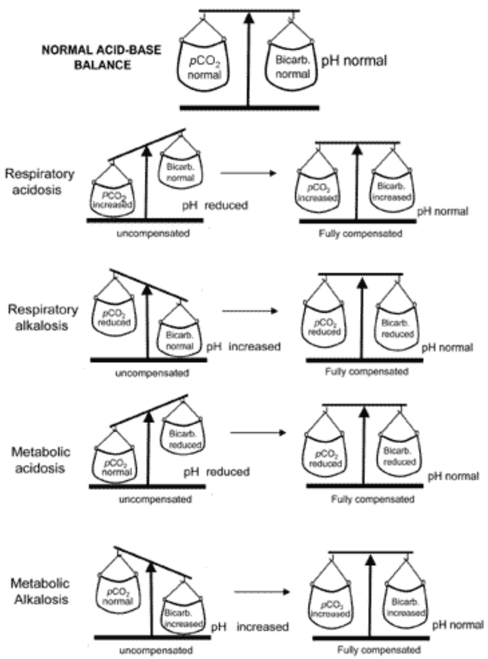
- Abnormal negative value (base deficit)
    - Indicates decreased base (principally HCO_3^-) or relatively increased non-carbonic and a diagnosis of metabolic acidosis
- Abnormal positive value
    - Indicates increased base (principally HCO_3^-) or decreased non-carbonic and a diagnosis of metabolic alkalosis
- BE is normal in uncompensated respiratory acidosis and respiratory alkalosis
    - Abnormal BE in these cases indicates a renal compensation
- BE may be normal in complex acid-base disturbances involving both alkalosis and acidosis

BE and/or HCO_3^-

- Essentially provides the same information
- BE takes into account all carbonic and non-carbonic acids and buffers that may affect the metabolic component
- BE should be a more satisfactory parameter for assessment of the metabolic component that HCO_3^-

How to get an overview of acid-base disturbances.......

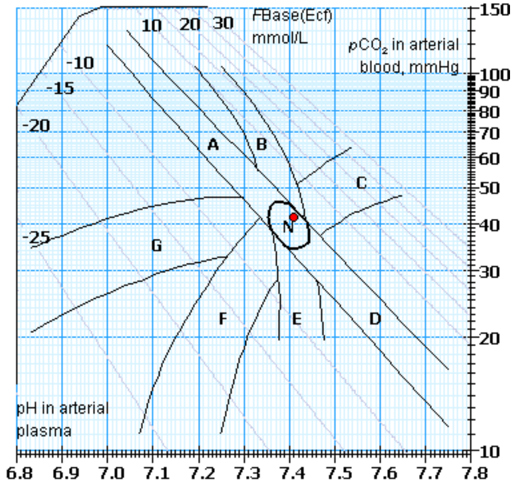
- Various tools can be found in textbooks, the internet etc.

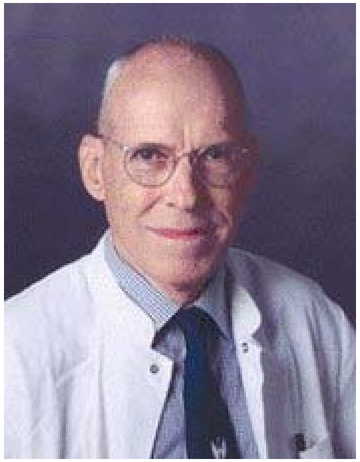


	Primary disturbance			
	Respiratory acidosis primary increase in *p*CO_2	**Repiratory alkalosis primary decrease in *p*CO_2**	**Metabolic acidosis primary decrease in bicarb.**	**Metabolic alkalosis primary increase in bicarb.**
Some common causes	Emphysema COPD Pneumonia Depression of repiratory center	Hyper-ventilation Anxiety attacks Stimulation of brain respiratory center	Renal failure Diabetic ketoacidosis Circulatory failure - clinical shock (lactic acidosis)	Bicarbonate admini-stration Potassium depletion
Compen-satory mechanism	RENAL increase bicarbonate	RENAL decrease bicarbonate	RESPIRA-TORY decrease *p*CO_2	RESPIRA-TORY increase *p*CO_2 but limited compen-sation in metabolic alkalosis
Initial blood gas results (uncompen-sated)	**pH decreased** *p*CO_2 increased Bicarbonate normal	**pH increased** *p*CO_2 decreased Bicarbonate normal	**pH decreased** *p*CO_2 normal Bicarbonate decreased	**pH increased** *p*CO_2 normal Bicarbonate increased
Blood gas results after partial compen-sation	pH decreased but closer to normal *p*CO_2 inreased Bicarbonate increased	pH increased but closer to normal *p*CO_2 decreased Bicarbonate marginally decreased	pH decreased but closer to normal *p*CO_2 marginally decreased Bicarbonate decreased	Limited compen-sation in metabolic alkalosis
Blood gas results after full compen-sation	**pH normal** *p*CO_2 increased Bicarbonate increased	**pH normal** *p*CO_2 decreased Bicarbonate decreased	**pH normal** *p*CO_2 decreased Bicarbonate decreased	Limited compen-sation in metabolic alkalosis

Higgins, C. An introduction to acid-base balance in health and disease. www.acutecaretesting.org Jun 2004
Acutecaretesting Handbook 2013 – Radiometer Medical - in press

The Acid-Base Chart

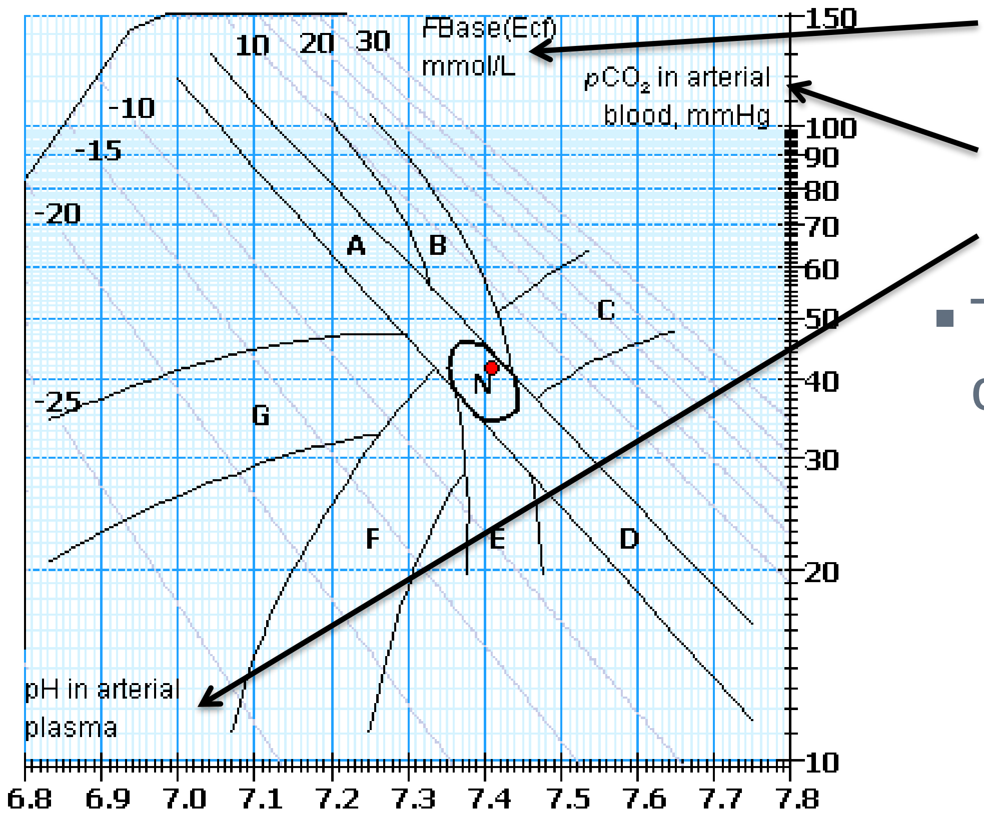




- Invented by Ole Siggaard-Andersen to ease acid-base interpretation.
- Ole Siggaard-Andersen, MD, PhD and professor of clinical biochemistry at the University of Copenhagen in Denmark.
- Pioneer within blood gas: 1963 doctoral thesis was entitled “The Acid-Base Status of the Blood” , and has appeared in five editions and five languages

Siggaard-Andersen O. The Acid-Base Status of the Blood”. 4. revised edition. Munksgaard, Copenhagen 1976

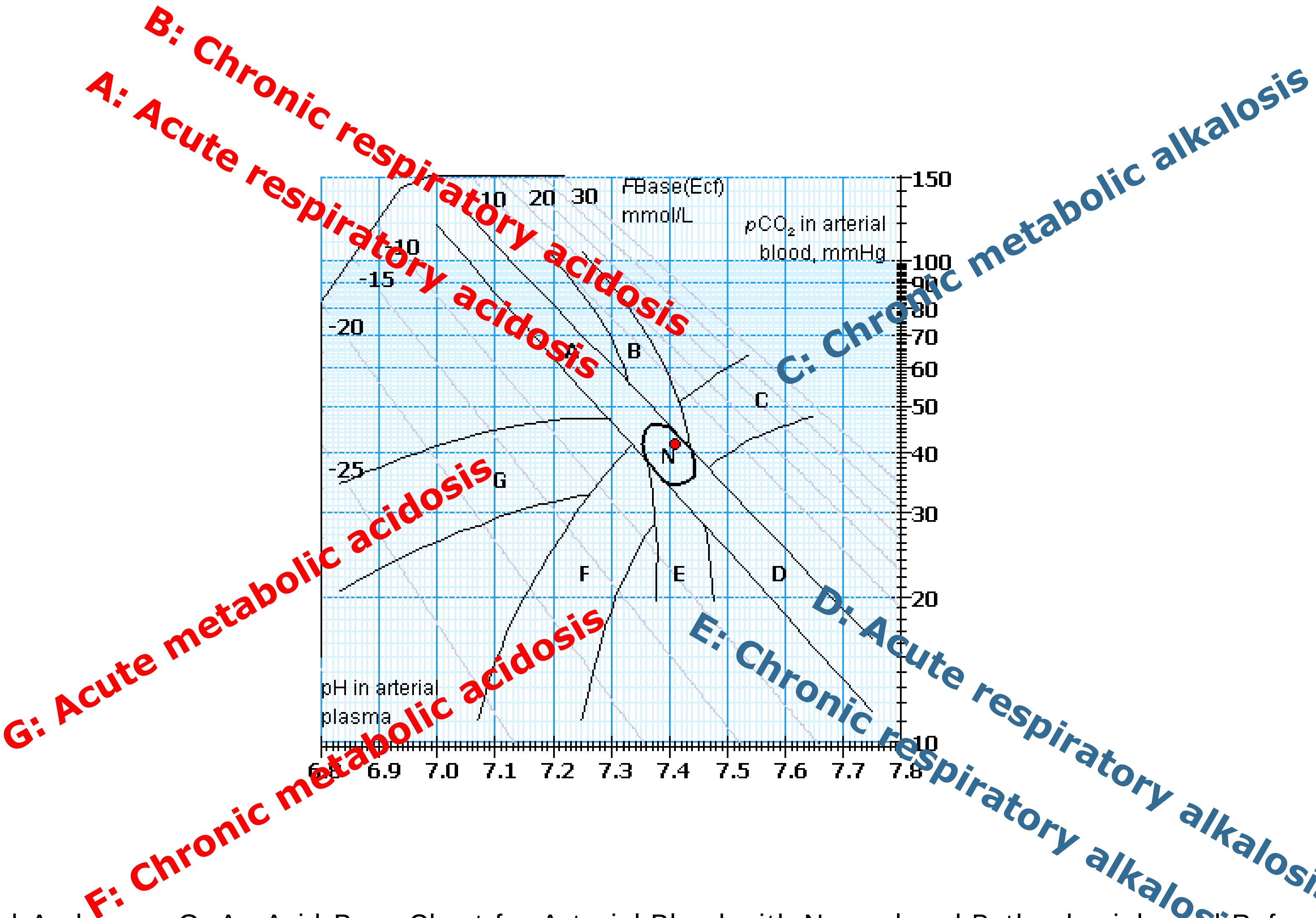
The Siggaard-Andersen Acid-Base Chart



- Illustrating
  - Standard base excess: *c*Base(ecf)
  - pCO_2
  - pH
- Tool for fast interpretation of acid-base status
  - Illustrates metabolic and respiratory conditions
  - Differentiates between acute and chronic cases
  - Gives a reading of Standard Base Excess

Siggaard-Andersen, O. An Acid-Base Chart for Arterial Blood with Normal and Pathophysiological Reference Areas. Scand. J. clin. Lab. Invest. 1971; 27: 239-245.

About the acid-base chart



Siggaard-Andersen, O. An Acid-Base Chart for Arterial Blood with Normal and Pathophysiological Reference Areas. Scand. J. clin. Lab. Invest. 1971; 27: 239-245.

Summary of acid-base

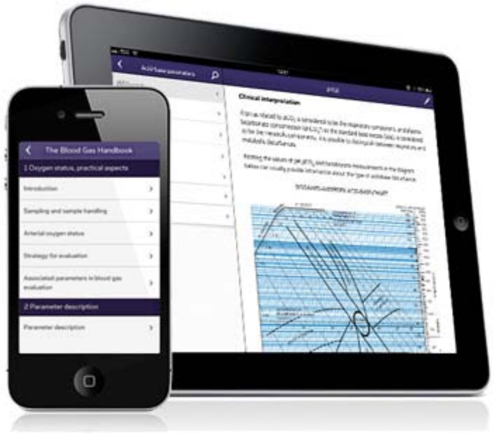
- Somewhat complex
- Different ways and models to look at acid-base disturbances
- Measurement of pH, pCO_2 and HCO_3^- is the cornerstone
- Consider using tools available on some BG analyzer, e.g., Acid-base chart

Read more

- Sources for Scientific knowledge about acute care testing

acutecaretesting.org

Your knowledge site



Blood gas app
- for smartphones and tablets

Avoid preanalytical errors app
- for smartphones