CARBON DIOXIDE METABOLISM AND CAPNOGRAPHY
CARBON DIOXIDE METABOLISM

- Production
- Transportation
- Elimination
Carbon Dioxide production

- CO₂ is the metabolite produced by the utilization by cells of oxygen and energy substrates (glucose, lipids, proteins).
- The carbon dioxide daily production is 200ml/min
- CO₂ production (VCO₂) is correlated with O₂ consumption (VO₂). In an adult in basal conditions for a usual diet,
  - VO₂ = 250ml/min
  - VCO₂ = 200ml/min
RESPIRATORY QUOTIENT

- VCO$_2$/VO$_2$ ratio is called the respiratory quotient
- It is equal to 0.82
- Can be modified according to diet, anaerobic metabolism, excess of carbohydrates incomes
TRANSPORT OF CARBON DIOXIDE

- Bicarbonate ($\text{HCO}_3^-$) - 60% formed when $\text{CO}_2$ (released by cells making ATP) combines with $\text{H}_2\text{O}$ (due to the enzyme in the red blood cells called carbonic anhydrase)

- Carbaminohemoglobin - 30% - Formed when $\text{CO}_2$ combines with hemoglobin (Hemoglobin molecule that give up their oxygen)

- Dissolved in the plasma - 10% (1.2 mmol/l)


- Carbamino: 100%
  - Dissolved: 90%
  - Arterial Blood: 5%

- HCO₃⁻:
  - Arteriovenous Difference: 60%
  - Arterial Blood: 10%
**Gas Transport to the Tissue**

- **CO₂** moves from the capillary wall to the tissue.
- **H₂O** moves from the capillary wall to the tissue.
- **O₂** moves from the plasma to the tissue.
- **HCO₃⁻** moves from the capillary wall to the plasma.
- **Cl⁻** moves from the capillary wall to the plasma.
- **Na⁺** moves from the capillary wall to the plasma.
- **K⁺** moves from the capillary wall to the plasma.
- **HbO₂** moves from the red blood cell to the plasma.
- **CO₂** reacts with water to form **H₂CO₃**, which then dissociates into **HCO₃⁻** and **H⁺**.
- **HCO₃⁻** moves from the plasma to the red blood cell.
- **Cl⁻** moves from the plasma to the red blood cell.
- **Hb⁻** moves from the red blood cell to the plasma.
- **O₂** moves from the red blood cell to the tissue.

**Diagram Explanation:**
- The diagram illustrates the exchange of gases and ions across the capillary wall.
- CO₂ is transported from the capillary into the tissue, while O₂ moves in the opposite direction.
- H₂CO₃ and H⁺ are formed from the reaction of CO₂ with H₂O, which then dissociates into HCO₃⁻ and H⁺.
- HCO₃⁻ moves from the plasma to the red blood cell, while Cl⁻ moves in the opposite direction.
- Na⁺ and K⁺ ions also move between the plasma and the red blood cell.
- HbO₂, the oxygen-carrying form of hemoglobin, moves from the red blood cell to the plasma.
- O₂ is transferred from the red blood cell to the tissue, completing the transport cycle.
**BOHR AND HALDANE EFFECT**

- **Bohr Effect**: Increased CO$_2$ in the blood enhances the O$_2$ release by hemoglobin: Positive effect at the tissue level

  \[ \text{CO}_2 + \text{H}_2\text{O} + \text{HbO}_2 \rightarrow \text{HbH}^+ + \text{HCO}_3^- + \text{O}_2 \]

- **Haldane effect**: Increased O$_2$ in the blood enhances the CO$_2$ release by hemoglobin: Positive effect at the lung level

  \[ \text{O}_2 + \text{HCO}_3^- + \text{HbH}^+ \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{HbO}_2 \]
GAS EXCHANGE IN LUNGS

Expired gas

Inspired gas

Right heart

Alveoli

Left heart

Veins

Artery

Tissues

O₂ 116
CO₂ 32
H₂O 47
N₂ 565

O₂ 158
CO₂ 0.3
H₂O 5.7
N₂ 596

O₂ 100
CO₂ 40
H₂O 47
N₂ 573

O₂ 40
CO₂ 46
H₂O 47
N₂ 573

O₂ 40
CO₂ 46
H₂O 47
N₂ 573

O₂ 95
CO₂ 40
H₂O 47
N₂ 573
CARBON DIOXIDE DISSOCIATION CURVE

CARBOXYHEMOGLOBIN AND OXYHEMOGLOBIN DISSOCIATION CURVES

FIGURE 7-4
Carboxyhemoglobin and oxyhemoglobin dissociation curves. An increase in the partial pressure of oxygen above a certain level (50 mm Hg) does not result in a greater increase in the oxygen content of the blood. However, a linear relationship is seen between the partial pressure of carbon dioxide and carbon dioxide blood content. (Adapted from Dartsker MD, David R: Pulmonary gas exchange. In Bone R, ed: Pulmonary and Critical Care Medicine. St. Louis, Mosby, 1987.)
CO2 Elimination
GAS EXCHANGE IN LUNGS

Inspired gas

O₂ 158
CO₂ 0.3
H₂O 5.7
N₂ 596

Expired gas

O₂ 116
CO₂ 32
H₂O 47
N₂ 565

Right heart

O₂ 40
CO₂ 46
H₂O 47
N₂ 573

Veins

O₂ 40
CO₂ 46
H₂O 47
N₂ 573

Tissues

Artery

O₂ 95
CO₂ 40
H₂O 47
N₂ 573

Alveoli

O₂ 100
CO₂ 40
H₂O 47
N₂ 573

Left heart
HYPERCAPNIA

- Increase in $\text{Paco}_2 > 45\text{mmHg}$
- $\text{PH} < 7.35$
- $\text{Paco}_2 = \text{VCO}_2 / \text{VA}$
- Any increase in $\text{VCO}_2$ or decrease in $\text{VA}$ results in hypercapnia.
CAUSES (ACUTE)

Airway obstruction
- Emesis with aspiration
- Bronchospasm
- Laryngospasm

Respiratory center depression
- GA
- Sedative overdose or narcotic overdose
- Head injury

Circulatory collapse
- Cardiac arrest
- Pulmonary edema

Neurogenic causes
- Cervical spine injury
- Gullen barre Syndrome
- Mysthenic crisis

Restrictive defects
- ARDS
- Flail chest
- Hemothorax or pneumothorax
Mechanism during anesthesia

- Hypoventilation
- Increased dead space ventilation
- Increased CO$_2$ production
- Low ventilator settings
- Circuit disconnection
- Ventilator Failure
HYPOVENTILATION

- Abnormal surgical position
- Increased airway resistance (ETT obstruction)
- Decreased compliance
- Decreased respiratory drive due to Anesthetics
INCREASED CO$_2$ PRODUCTION

- Hyperthermia
- Shivering
- Catecholamine release during light anesthesia
- Hypertension
- Thyroid storm
RESPIRATORY EFFECTS

- Maximal effect attained by Paco$_2$ of 100mmHg
- Higher Paco$_2$ respiration ceases altogether.
- Co$_2$ narcosis at Paco$_2$ to more than 90 to 120mmHg.
- Bronchodilation.
- Pao$_2$ and PAO$_2$ may decrease
HYPOCAPNIA

- PH >7.45
- $\text{Paco}_2$ less than 35mmHg
DIAGNOSIS

- Symptoms and signs
- ABGs
- Capnograph
- Other investigations
Capnography

Capnometry
Methods of measurement

- **Mass spectrometry**
  - Expensive, voluminous, time consuming, difficult to use.

- **Laser spectrometry**
  - Raman’s principal, may measure gas & vapours, portable but voluminous.

- **Infra red spectrometry**
  - Selective absorption by CO2 of selective infra red wavelength of 4.3um
  - Measure is made by reference to a calibrated cell containing a determined CO2 concentration (mmHg, or percentage)

- **Photo acoustic spectrography**
  - Uses an acoustic method instead of an optic technique, efficient, reliable and less need for calibration and maintenance.
Types of Capnographs

- **Main stream Capnographs**
  - Heavy, adds a dead space, adapted to high resp. frequencies >20

- **Side stream Capnographs**
  - Risk of under estimation, loss of ventilatory volume, can measure several gas simultaneously.
Normal Capnogram

CONSTITUTED OF 4 PHASES
Phase -1

- Basal level near at zero mmHg corresponding to the mechanic and anatomic dead space
Phase-11

- The curve is increasing rapidly corresponding to the increasing concentration in CO2 due to the CO2 expiration in the mixture of alveolar and dead space.
Phase -3

- Alveolar Plateau, slightly ascending to reach at the end the value of 40 mmHg corresponding to the EtCo2.
Inspiration starting just after the EtCo2 and producing a sharp decrease of Co2 concentration to reach the basal level.
Capnograph disturbances

1- Etco2 value
2- Morphology of the wave
3- The level of the base line
4- Modification of the respiratory rate
5- Trends- Etco2 decrease
6- Etco2 increase
CAPNOGRAPHIC ALTERATIONS WITH EQUIPMENT

High $\text{ETCO}_2$

- Increased apparatus dead space
- Rebreathing with circle system
- Rebreathing with Mapleson system
- Rebreathing due to malfunctioning non-rebreathing valve

Low $\text{ETCO}_2$

- Blockage of sampling line (absent)
- Leakage in sampling line
- Inadequate seal around tracheal device
Clinical applications

- 1-proof of adequate tracheal intubation
- 3- Apnea monitoring
- 4- Ventilation monitoring to:
  - Assess ventilation efficiency
  - Adapt ventilation parameters in neurosurgery, treatment of bronchospasm and acute asthma.
  - Adjust the best PEEP
  - Wean controlled ventilation.
  - Control metabolic modifications
  - Measure dead space, intrinsic PEEP.
Baseline elevated

- Incompetent expiratory valve
- Exhausted CO₂ absorbent
- Insufficient fresh gas flow to mapleson system
Elevated ETCO2

Time

Normal
A sudden rise in baseline

Causes

- Exhausted CO₂ absorber
- Calibration error
- Stuck valve in circle absorber system

Sudden increase in CO₂

Causes

- Release of a tourniquit
- Unclamping of major vessel

Gradual increase in CO₂

Causes

- Hypoventilation
- Rapidly rising body temp
- Absorption of CO₂ from peritoneal cavity
MECHANISM of LOW EtCo2 DURING ANAESTHESIA

- Hyperventilation (spontaneous or controlled ventilation)
- Decreased VD ventilation
- Decreased CO₂ production
Low ETCO$_2$
Slow decrease in CO$_2$

Causes
- Hyperventilation
- Fall in body temp

Sudden drop of ETCO2 to zero

Causes
- Esophageal intubation
- Complete breathing system disconnection
- Ventilator malfunction
- Totally obstructed tracheal tube
A sudden drop of ETCO$_2$ to non zero value

**Causes**
- Poorly fitting tracheal tube
- A leak or partial disconnection in breathing system
- Partial obstruction of tracheal tube

An exponential decrease in CO$_2$

**Causes**
- Sudden hypotension
- Pulmonary embolism
- Circulatory arrest
Cardiac output

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Factors affecting EtCo2

Production -- Metabolic
Transportation -- Circulatory
Elimination -- Ventilatory
New applications of CO2 measurement

- 1- Volumetric capnography
- 2- Cardiac output measurement based on Fick’s principal
- 3- Gastric tonometry
- 4- Sublingual capnography (PslCO2)
Conclusions

- Capnography is a sensitive and non invasive method which measures rapidly, easily and continuously expired Co2 at the bed side of the patient in clinical practice.
- Several clinical applications bring additional security.
- New derived techniques, such as tonometry, (both Gastric & sublingual) seem of interest.