CAPNOGRAPHY

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Educational objectives

What you need to know

- what is capnography
- what are the normal values of capnography
- how the capnograph works
- types of capnographs
- stages of capnography
- capnography indications in intubated patients
- capnography indications in spontaneously breathing patients

Definition

Capnography (end-Tidal CO_2, $PETCO_2$ and $ETCO_2$) is a non-invasive monitoring means of the partial pressure of carbon dioxide in the exhaled air.

Values may be plotted against time (CO2 concentration in time) and against volume (CO2 volume concentration), the latter being difficult to carry out in non-intubated patients. The maximum level of carbon dioxide at the end of each exhaled breath is the end-Tidal CO_2 pressure. The shape changes illustrated in the diagram serve as diagnosis for certain conditions, whereas end-Tidal CO_2 changes are used for establishing severeness and treatment response.

Normal PETCO2 values fall within the range 24-45 mm Hg.

Figure 1. Capnograph: monitoring ETCO2 (39 mmHg, graph with exhalation plateau; pulse oximetry with RR 8, SpO_2 100%)

The role of capnography is to indicate data about each respiratory cycle in terms of:

- ventilation, i.e. the efficiency of carbon dioxide elimination from the airways
- perfusion, i.e. the efficiency of carbon dioxide transport through the respiratory system
- metabolism, i.e. the efficiency of carbon dioxide production

by cell metabolism.

Technology

Capnographs use infra-red radiations. Carbon dioxide molecules absorb infra-red radiations with wavelengths proportional with carbon dioxide concentration levels. For recording carbon dioxide levels, 2 configurations are used:

- mainstream – used only with intubated patients having a sensor inserted directly within the airways, in the intubation cannula region extending beyond the vocal chords
- sidestream, which determines carbon dioxide concentration in the exhaled air through the tube and sensor incorporated in the monitor. The latter is used both with intubated patients and non-intubated patients (by means of nasal or oral cannulas).

Figure 2. Mainstream capnograph

Figure 3. Sidestream capnograph

Physiology

Capnography is made up of 4 phases:

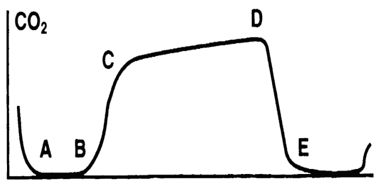

Figure 4. Capnography: AB – phase 1, BC – phase 2, CD – phase 3, DE – phase 4

Phase 1: ventilation of anatomical dead space – coincides with the start of the exhalation when the air from the dead space is expelled to the upper airways.

Phase 2: the ascending phase – coincides with the rapid growth of carbon dioxide concentration during respiration, upon reaching the upper airways.

Phase 3: the concentration of the carbon dioxide reaches a uniform level throughout the entire respiratory flow (from the alveoli to the upper airways) and coincides with a maximum carbon dioxide pressure point (which is the value shown on the monitor).

Phase 4: is the inhalation cycle during which the carbon dioxide level is 0, when oxygenated air reaches the airway.

Capnography indications in intubated patients:

1. Checking the position of the endotracheal tube
2. Continuous monitoring of the tube position during patient transport
3. Assessing the success of the resuscitation manoeuvre and the prognosis during cardiac arrest
4. Titration of $PETCO_2$ values in patients suspected of increased intra-cranial pressure
5. Predicts the prognosis of trauma patients
6. Assessing the ventilation quality

1. Checking the correct position of the endotracheal tube

- A waveform with all the 4 capnography phases appears following a correct intubation.
- A linear waveform following intubation indicates the protrusion of the tube in the oesophagus. There are certain situations which trigger a linear waveform even when the tube is inserted in the trachea:
  - the obstruction of the tube in the endotracheal section
  - the complete obstruction of the airway distal to the tube
  - improper pulmonary blood flow (due to improper compression during resuscitation)
  - prolonged cardiac arrest without carbon dioxide flow due to the interruption of cell metabolism.

2. Continuous monitoring of the tube position during patient transport

- Failing to acknowledge the correct position of the tube either due to its incorrect introduction or to its dislocation during transport may have catastrophic consequences.
- Continuous monitoring of the tube position during transport is essential for the patient's safety.
- $PETCO_2$ confirmation upon initial positioning of the tube and during transport is a widely accepted norm by the American Society of Anesthesiologists.

3. Assessing the effectiveness of cardiopulmonary resuscitation

- During cardiac arrest, $PETCO_2$ reflects the degree of pulmonary vascularization.
- In the mean time, it may be used as a quality standard for thoracic compressions. Effective cardiac compressions lead to an increase of cardiac flow and subsequently to the increase of perfusion, which contributes to the increase of $PETCO_2$ from the baseline.

4. Cardiac arrest recovery indicator

- The level of carbon dioxide reflects the recovery of the heart rate and of the pulmonary blood flow. Carbon dioxide is carried through the venous system towards the right half of the heart and then is pumped towards the lungs by the right ventricle.
- A $PETCO_2$ peak is an early sign of resuscitation success and may occur before palpation or assessment of hemodynamical signs (pulse, blood pressure). AHA guidelines recommend continuing chest compressions until the rhythm is restored on the monitor. Capnographic monitoring is always useful because it prevents the stopping of compressions for pulse checking. The restoration of rhythm is associated with a dramatic increase of $PETCO_2$, at which point chest compressions should stop and the ECT rhythm and blood pressure are assessed. Despite these considerations, the 2015 resuscitation protocol maintains that there is no clear indication that the use of capnography during CPR contributes to the improvement of patient results. Nevertheless, it has been very clearly established the relevance of capnography in detecting the oesophageal position of the endotracheal tube.
- $PETCO_2$ is most feasible in intubated patients but may also be used in patients with supraglottic airway devices.
- PETCO2 may indicate the recovery of spontaneous circulation and may prevent useless dosing of additional adrenaline.
- The precise determination of en-Tidal CO_2 depends on a series of factors such as: cardiac arrest, the quality of resuscitation carried out by the assistant, the ventilation rate and volume.

5. Establishing prognosis after initiation of cardiopulmonary resuscitation

- It may be used as a prognosis factor during resuscitation: a low level of end-Tidal CO_2 (i.e. < 10 mm Hg 20 minutes into the resuscitation procedure) may indicate a bad prognosis with low chances of spontaneous circuation recovery.

6. Identifying the cause of cardiac arrest

- Studies conducted in animals have revealed low end-Tidal CO_2 during cardiac arrest secondary to respiratory arrest as compared to values occurred during primary cardiac arrest caused by ventricular fibrillation.
- Similar results were obtained in patients with respiratory arrest (caused by a foreign object in the airways, aspiration, asthma or drowning), followed by cardiac arrest through asystole or pulseless electrical activity.

7. Serial determinations of $PETCO_2$ levels in patients suspected of increased intra-cranial pressure

- $PETCO_2$ is important for the control of ventilation in patients with brain injuries and suspected increased intra-cranial pressure.
- The level of carbon dioxide affects the cerebral blood flow:
    - high levels of carbon dioxide lead to cerebral vasodilation
    - low levels of carbon dioxide lead to cerebral vasoconstriction
- Sustained hypoventilation is harmful in patients with high intra-cranial pressure since it causes the increase of cerebral blood flow and – probably – the deterioration of intra-cranial pressure.
- Sustained hyperventilation is also harmful and is associated with the deterioration of the neurological status.
- Therefore, monitoring of the carbon dioxide level may prevent hyper- or hypoventilation, which may be harmful for the underlying cerebral injury.

Capnography indications in spontaneously breathing patients

1. The quick assessment of the critical patient with injuries or convulsions with the aid of airways, respiration and circulation
2. Assessment and sorting of terrorist attack or major accident victims
3. Appraisal of severity and response to treatment in patients with acute respiratory distress
4. Assessing appropriate ventilation in altered mental status patients
5. Assessing metabolic acidosis in diabetes patients and children with gastroenteritis.

1. ***The quick assessment of the critical patient with injuries or convulsions by means of ABC:***

- Primary ABC assessment may be carried out with the help of capnography.
- A normal capnographic value indicates spontaneous respiration and a permeable airway.
- Capnography is not affected by motion artifacts and generates trustworthy values in patients with abnormal perfusion status.

2. ***Assessment and sorting of terrorist attack or major accident victims***

- Capnography may serve as a non-invasive method to quickly assess life-threatening complications caused by chemical terrorist acts.
- In the mean time, it may quickly detect respiratory, airway and central nervous system related adverse reactions assoicated with nervous agents, including apnoea, upper airway obstruction, laryngospasm, bronchospasm, respiratory depression, convulsions and coma.

3. Assessing severity and response to treatment in acute respiratory distress:

- Capnography allows the dynamic monitoring of the ventilation status in acute respiration distress patients regardless of the etiology.

- By determining the $PETCO_2$ and the breathing rate of each respiratory cycle, capnography can acquire instant data regarding the chemical status of the patient.
- The assessment of the breathing rate through the oronasal mask is more relevant than the assessment through the transthoracic electrode by means of the respiratory impedance.
    - E.g. In the case of upper airway obstruction, detecting the breathing rate through transthoracic impedance may generate normal values, as opposed to capnography, which will indicate a linear waveform.
- $PETCO_2$ may be useful in diagnosing the effectiveness of the treatment in tachypneic patients.

4. *Procedural sedation and analgesia*

- Although pulse oximetry is the standard ER monitoring technique of procedural sedation, capnography has a crucial role since it can detect the common airway and breathing related adverse events associated with procedural sedation and analgesia and is considered an early indicator of compromised airway and breathing.
- Additionally, it assesses the breathing rate without using impedance, directly through the airways, especially in patients with obstructive pulmonary disorders or laryngospasm.
- Central apnoea equates with the loss of the capnogram, of the thoracic motion amplitude and as the lack of breathing sounds during auscultation.
- Obstructive apnoea equates with the loss of the capnogram, but with the persistence of thoracic motions and the lack of breathing sounds.
- There are 2 types of anaesthetic-induced hypoventilation during procedural sedation and analgesia:
    - Bradypneic hypoventilation – induced by opioids:
        - $PETCO_2$ → wide and high amplitude capnography waveforms
        - $PaCO_2$ increases
        - The breathing rate (BR) is depressed to a higher extent than the Tidal volume and is ensued by bradypnoea, the increase of the exhaling duration and an increase of

$PETCO_2$, graphically represented by a high waveform amplitude and a wide capnogram.
    - A predictable course ensues with the progressive increase of $PETCO_2$ before the onset of apnoea.
    - Although there is no threshold for apnoea onset, patients with high $PETCO_2$ volumes, of over 80 mm Hg are at a high risk of apnoea.
  - Hypopnoeic hypoventilation – induced by hypnotic sedatives
    - $PETCO_2$ decreases
    - $PaCO_2$ increases→ the air in the dead space is constant
    - Tidal CO_2 volume decreases more than the breathing rate, which contributes to the increase of the dead space, and to gradient increase between alveolar pressure of CO_2 and the end-Tidal CO_2.
    - 3 possibilities ensue:
      - Ventilation remains stable with a low Tidal level during breathing which resolves once the sedative concentration decreases in the CNS.
      - Hypoventilation progresses towards periodic breathing with apnoea intermittent pauses (which may resolve spontaneously or may advance towards central apnoea).
      - Hypoventilation may regress directly towards apnoea.

5. *Assessing appropriate ventilation in altered mental status patients*

- Patients with altered mental status due to alcohol abuse, intentional or accidental overdose and post-critical patients (especially those treated with benzodiazepines) may develop an abnormal ventilation function.
- Capnography may differentiate efficiently ventilated patients from non-efficiently ventilated patients.

6. Determining metabolic acidosis

- Capnography is performed in order to assess metabolic status with the aim of obtaining data regarding carbon dioxide production by cell metabolism.
- Recent studies have shown that the level of $PETCO_2$ and bicarbonate correlates very well in diabetes and gastroenteritis patients.
- When the patient develops acidosis (with bicarbonate decrease), compensatory respiratory alkalosis ensues with the increase of minute ventilation and subsequent decrease of $PETCO_2$ followed by the decrease of carbon dioxide concentration in arterial blood, in order to aid acidemia correction.
- There is a similar association between $PETCO_2$ and the level of bicarbonate in children with gaostroenteritis.

(Self-)Assessment form

Stage/Criterion	Correct	Incorrect
Ahat is capnography?		
Ahat are the normal values of capnography?		
What are the capnography indications in intubated patients?		
What are the capnography indications in spontaneously breathing patients?		
Which are the 4 stages of capnography?		