RESPIRATORY GAS ANALYSIS IN THEATRE

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CAPNOGRAPHY

Capnography is the measurement of carbon dioxide (CO_2) in each breath of the respiratory cycle. The capnograph displays a waveform of CO_2 (measured in kiloPascals or millimetres of mercury) and it displays the value of the CO_2 at the end of exhalation, which is known as the end-tidal CO_2.

It is useful to measure CO_2 to assess the adequacy of ventilation, to detect oesophageal intubation, to indicate disconnection of the breathing system or ventilator, and to diagnose circulatory problems and malignant hyperthermia.

Applications of Capnography

Provided the patient has a stable cardiac status, stable body temperature, absence of lung disease and a normal capnograph trace, end-tidal carbon dioxide ($ETCO_2$) approximates to the partial pressure of CO_2 in arterial blood ($PaCO_2$.) Normal $PaCO_2$ is 5.3kPa (40mmHg). In these patients, $ETCO_2$ can be used to assess adequacy of ventilation i.e. hypo-, normo-, or hyperventilation. $ETCO_2$ is not as reliable in patients who have respiratory failure. The increased V/Q mismatch is associated with a widened P(a-ET) gradient, and can lead to erroneous $ETCO_2$ values.

The capnograph is the gold standard for detecting oesophageal intubation. No or very little CO_2 is detected if the oesophagus has been intubated.

The capnograph is also useful in the following circumstances:

- As a disconnection alarm for a ventilator or a breathing system. There is sudden absence of the capnograph trace.
- May detect air embolism as a sudden decrease in $ETCO_2$, assuming that the arterial blood pressure remains stable.

- To recognise sudden circulatory collapse as a sudden decrease in $ETCO_2$.
- To diagnose malignant hyperthermia as a gradual increase in $ETCO_2$.

Techniques of Measurement

Most analysers in theatre work using 2 principles:

Infrared absorption spectroscopy is the most commonly used technique in anaesthesia. Gases of molecules that contain at least two dissimilar atoms absorb infrared radiation. Using this property, carbon dioxide concentration can be measured continuously throughout the respiratory cycle to give a capnograph trace.

CO_2 absorbs infrared radiation particularly at a wavelength of 4.3 μm. A photodetector measures radiation reaching it from a light source at this wavelength. The amount of infrared radiation absorbed is proportional to the number of CO_2 molecules (partial pressure of CO_2) present in the chamber, according to the Beer-Lambert Law. This allows the calculation of CO_2 values.

Photo-acoustic spectroscopy The sample gas is irradiated with pulsatile infrared radiation, of a suitable wavelength. The periodic expansion and contraction produces a pressure fluctuation of audible frequency that can be detected by a microphone. The advantages of photo-acoustic spectrometry over conventional infrared absorption spectrometry are:

- The photo-acoustic technique is extremely stable and its calibration remains constant over much longer periods of time.
- The very fast rise and fall times give a much truer representation of any change in CO_2 concentration.

Other techniques for measuring CO_2 include Raman scattering and mass spectrometry.

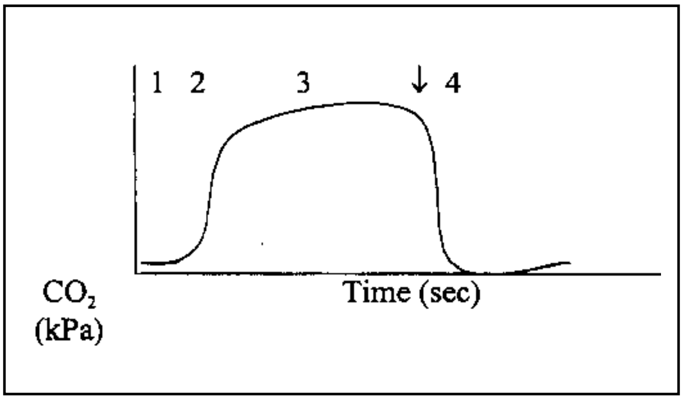
Position of Sampling

Gas from the breathing system can be sampled either by a sidestream or a mainstream analyser.

Sidestream: Gas is drawn from the breathing system by a 1.2mm internal diameter tube. The tube is connected to a lightweight adapter near the patient's end of the breathing system. It delivers the gas to the sample chamber. It is made of Teflon so it is impermeable to CO_2 and does not react with anaesthetic agents. Only the precise tubing recommended by the manufacturer should be used, and only of the recommended length. Typical infrared instruments sample at a flow rate between 50 and 150 ml/minute. When low fresh gas flows are used the sampled gas may be returned to the breathing circuit. It is important that the tip of the sampling tube should always be as near as possible to the patient's trachea, but the sampled gas mixture must not be contaminated by inspired gas during the expiratory phase.

Mainstream: The sample chamber is positioned within the patient's gas stream near the patient's end of the breathing system. Although heavier and more cumbersome, it does have advantages over sidestream sampling: there is no delay in the rise and fall times of gas composition changes, no gas is lost from the attachment, no mixing occurs along the capillary tube before analysis, and there are fewer problems with water vapour condensation.

The capnograph trace



1: Inspiratory baseline

2: Expiratory upstroke

3: Expiratory plateau

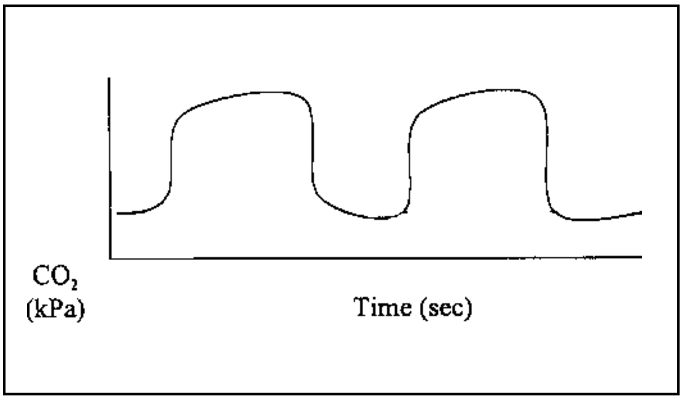
4: Inspiratory downstroke

↓ End-tidal CO_2 ($ETCO_2$)

The first phase occurs during inspiration. The second phase is the onset of expiration, which results in a rapid increase in CO_2. The third phase, the expiratory plateau, occurs as the CO_2 is exhaled from all the alveoli. The highest point of the plateau is known as the end-tidal CO_2 ($ETCO_2$). This marks the end of expiration. Phase four is the onset of inspiration.

Abnormal Traces

1. Rebreathing

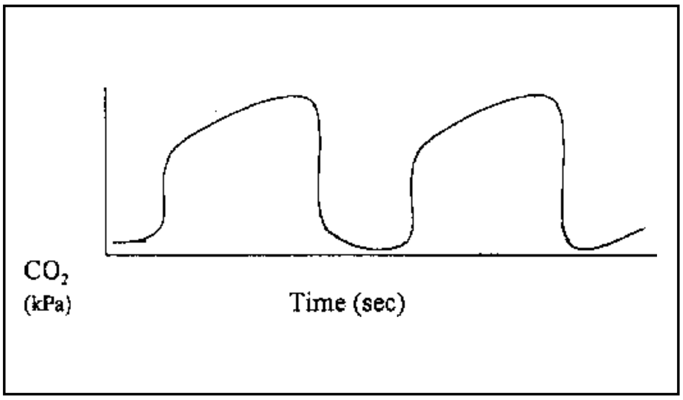


A waveform that does not return to the baseline during inspiration indicates that rebreathing of exhaled gas is occurring.

Causes:

- Fresh gas flow too low in non-rebreathing system.
- Soda lime depleted in circle system.

2. Sloping Plateau

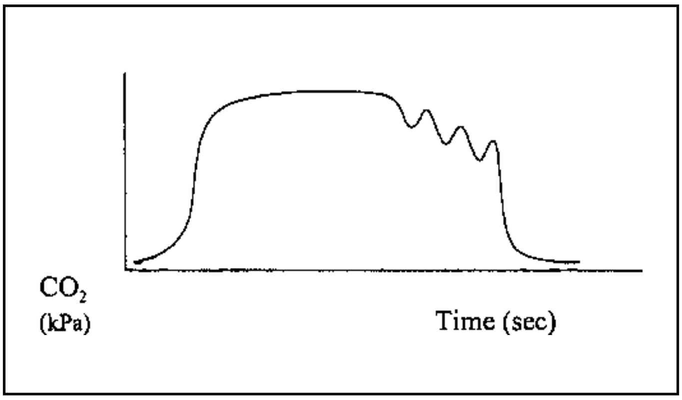


Cause:

- Obstructive airways disease, because of impairment of V/Q ratio.

Explanation In patients with obstructive airways disease, the lungs are perfused with blood as normal, but the alveoli are unevenly ventilated. CO_2 that is transferred to the alveoli from the bloodstream may take longer to exhale because of the narrowed bronchi. This delayed emptying of the alveoli varies in different parts of the lungs. This results in the sloping plateau on the capnograph trace, as the CO_2 from those parts of the lungs with more severe bronchial narrowing is exhaled later than those parts with less severe narrowing.

3. Cardiac oscillations

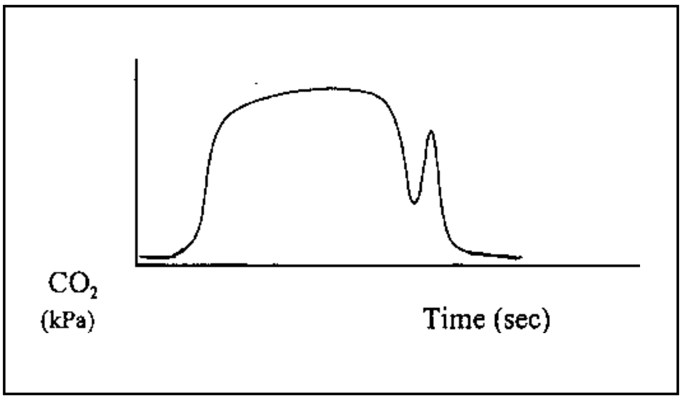


Cause:

- Cardiac impulses transmitted to capnograph.

Explanation The oscillations reflected on the capnograph trace result from transmission of cardiac impulses to the airways.

4. "Curare cleft"



Cause:

- Reversal of neuromuscular blockade in a ventilated patient.

Explanation When a paralysed patient starts taking small breaths as the neuromuscular blocking agent reverses, deep "clefts" are seen on the capnograph trace.

OXYGEN CONCENTRATION ANALYSERS

It is important to measure the oxygen concentration in the gas mixture delivered to the patient during anaesthesia. There are three techniques of measuring the inspired oxygen concentration (FiO_2): galvanic, polarographic, and paramagnetic techniques. The paramagnetic method is most widely used in anaesthesia. These analysers measure the oxygen partial pressure in a gas sample but they display a percentage. Regular calibration of oxygen analysers is vital.

Paramagnetic oxygen analysers Oxygen possesses the property of paramagnetism, which means that it is attracted to a magnetic field. This is because it has two electrons in unpaired orbits. Most of the gases used in anaesthesia are repelled by a magnetic field (diamagnetism).

The sample gas is delivered to the analyser via a sampling tube, which should be placed as close as possible to the patient's trachea. The analyser has two chambers separated by a sensitive pressure transducer. The sample gas is delivered to one chamber. Room air is delivered to the reference chamber. An electromagnet is rapidly switched on and off creating a changing magnetic field to which the sample gas is subjected. The magnetic field causes the oxygen molecules to be attracted and agitated. This results in changes in pressure on either side of the pressure transducer. The pressure difference across the transducer is proportional to the oxygen partial pressure difference between the sample gas and the reference gas (room air).

Paramagnetic oxygen analysers are very accurate and highly sensitive. The analysers should function continuously without any service breaks. They have a rapid response allowing measurement of inspiratory and expiratory oxygen on a breath-to-breath basis. They are affected by water vapour and have a water trap incorporated into their design.

The Galvanic Oxygen Analyser (Fuel Cell) The galvanic analyser is placed on the inspiratory limb of the breathing system. Oxygen molecules diffuse across a membrane and an electrolyte solution to a silver cathode, which is connected through an electrolyte solution to a lead anode. An electrical current is generated which is proportional to the partial pressure of oxygen in the inspired gas.

The galvanic analyser has a response time of approximately 20 seconds. It is accurate to within 3%. Calibration is achieved using 100% oxygen and room air (21% O_2). Water vapour does not affect its performance. It is depleted by continuous exposure to oxygen due to exhaustion of the cell, so limiting its life span to about one year.

The Polarographic Oxygen Analyser (Clark Electrode) The polarographic analyser has similar principles to the galvanic analyser. Oxygen molecules diffuse across a Teflon membrane. Current flows between a silver cathode and a platinum anode, which is proportional to the partial pressure of oxygen in the inspiratory gas. A battery powers it. Its life expectancy is limited to about three years because of deterioration of the Teflon membrane.

Further reading

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2. Schmitz BD, Shapiro BA. Capnography. Respiratory Care Clinics of North America. 1995; 1: 107-17

3. Al-Shaikh B, Essentials of Anaesthetic Equipment. Churchill Livingstone 1995.