Capnography Product Application Details

Terminology

Capnography is the monitoring of the concentration or partial pressure of carbon dioxide (CO_2) in *respiratory gases**. Capnography is displayed graphically either as instantaneous CO_2 concentration versus time (time capnogram), or expired volume (volume capnogram) during a respiratory cycle. However, time capnography is the most commonly used in clinical practice, as more elaborate equipment is necessary for volume Capnography.

A **Capnograph** is the machine that generates a waveform.

A **Capnogram** is the actual real-time waveform record of the concentration of CO_2 in the respiratory gases.

Capnometry is the measurement and numerical display of maximum inspiratory and expiratory CO_2 concentrations during a respiratory cycle.

A **Capnometer** is the device that performs the measurement and displays the reading (without a waveform).

However, the capnograph or capnogram, is vastly preferable to a capnometer or even a fast digital display. In anaesthetic practice a breath-by-breath waveform needs to be displayed to permit continuous monitoring and analysis.

Abbreviation Definitions

$EtCO_2$	End-tidal concentration of expired CO_2. The CO_2 concentration reaches a maximum at the end of exhalation. The normal value of $EtCO_2$ is around 5% or 35 – 37 mm Hg.
$FiCO_2$	Fractional concentration of inspired CO_2
SpO_2	Oxygen saturation as derived by a pulse oximeter
RR	Respiration Rate
PR	Pulse Rate

CO_2 concentration can be reported as:

- Vol. % – units of volume percent
- mmHg – millimetres of mercury
- kPa – Kilo Pascal

What is Capnography?

Principle

Capnography directly reflects the elimination of CO_2 by the lungs. Indirectly, it reflects the production of CO_2 by tissues and the delivery of CO_2 to the lungs by the *circulatory system**.

Therefore, Capnography constitutes an important non-invasive technique that can monitor CO_2 production, *pulmonary perfusion** and *alveolar ventilation** as well as respiratory patterns.

Of all the monitoring parameters currently in use during cardiac arrest*, capnography furnishes the best real-time, continuous information regarding the effectiveness of resuscitation.

The measurement of CO_2 in gas mixtures is based on the fact that different gases absorb infrared light at specific wavelengths. The amount of light 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, thus the less light that passes through the gas, the higher the amount of CO_2 present. The VM-2500 monitor therefore, continuously measures the infrared light absorption in the gas flow through an infrared spectrometer.

This spectrometer uses an infrared radiation source to transmit light through the gas sample. Before reaching the gas sample, the light path is intersected by narrowband optical filters that only let through light corresponding to selected wavelength peaks of the measured gasses.

At the other end of the light path, a sensor detects the portion of light that is not absorbed by the gas. The amplitude of the detector output is an inverse function of the gas concentration. Thus, at a concentration of zero, the amplitude is at its maximum.

Respiratory gasses however are always a mixture of several components. To determine the concentration of CO_2 in the gas sample, a filter has to be inserted before the detector.

The VM-2500 uses the strong absorption peak at 4.2μm to determine the CO_2 concentration. In addition to the measurement filter, two optical filters appropriately located within the 4 to 10μm range are used as references.

Where is Capnography Used?

Some common application areas for capnography include the following:
NB. This is not an exhaustive list.

1. Emergency Medical Services

Capnography is increasingly being used by paramedics to aid in their assessment and treatment of patients in the pre-hospital environment. These uses include verifying and monitoring the position of an *endotracheal tube** (ET tube). A correctly positioned ET tube in the trachea* guards the patient's airway and enables the paramedic to breathe for the patient.

Capnography, which indirectly measures *cardiac output**, can also be used to monitor the effectiveness of *Cardiopulmonary Resuscitation** (CPR) and as an early indication of the return of spontaneous circulation (ROSC). Studies have shown that when a person conducting CPR tires, the patient's $EtCO_2$ falls, this then rises when a new resuscitator begins CPR.

Other studies have shown that when a patient experiences ROSC the first indication is often a sudden rise in the $EtCO_2$ as the rush of circulation washes un-transported CO_2 from the tissues. Likewise, a sudden drop in $EtCO_2$ may indicate the patient has lost pulses and CPR may need to be initiated.

2. During Anaesthesia

During anaesthesia, there is interplay between two components: the patient and the anaesthesia administration device (which is usually a breathing circuit and a ventilator or respirator). The critical connection between the two components is either an endotracheal tube or a facemask, and CO_2 is typically monitored at this junction. Capnography directly reflects the elimination of CO_2 by the lungs to the anaesthesia device. Indirectly, it reflects the production of CO_2 by tissues and the circulatory transport of CO_2 to the lungs.

Capnography provides a rapid and reliable method to detect life-threatening conditions (miss-position of tracheal tubes, unsuspected ventilatory failure, circulatory failure and defective breathing circuits) and to avoid potentially irreversible patient injury.

According to an ASA (American Society of Anesthesiologists) closed claim study; the combination of pulse oximetry and capnography "could be expected" to help prevent anaesthetic-related *morbidity**and *mortality**.

3. Respiratory Care
A capnograph is used to monitor the respiratory rate of exhaled CO_2 in non-intubated patients breathing spontaneously. *Apnoea** or airway obstruction can be detected.

Rising $FiCO_2$ indicates that the patient is rebreathing expired CO_2, which could be the result of inadequate ventilation of the breathing space.

Why is Capnography Used?

To measure the effectiveness of CPR
Monitoring exhaled CO_2 concentrations is useful in determining which patients are likely to be successfully resuscitated. The patient is more likely to be resuscitated if the concentration of exhaled CO_2 is greater than 10 – 15 mmHg.

Emergency medical services
Because capnography provides a breath by breath measurement of a patient's ventilation, it can quickly reveal a worsening trend in a patient's condition, providing an early warning system into the patient's respiratory status.

To verify endotracheal intubation
The endotracheal tube serves as an open passage through the upper airway. The purpose of endotracheal intubation is to permit air to pass freely to and from the lungs in order to ventilate the lungs. If the tube is inadvertently placed in the oesophagus (right behind the trachea), adequate respirations will not occur. Brain damage, cardiac arrest, and death can occur. Aspiration of stomach contents can result in pneumonia and ARDS (Acute Respiratory Distress Syndrome), placement of the tube too deep can result in only one lung being ventilated and can result in pneumothorax as well as inadequate ventilation.

Monitoring the respiratory system
It provides information about CO_2 production, pulmonary perfusion, alveolar ventilation, respiratory patterns and elimination of CO_2 from the anaesthesia circuit and ventilator. Thus it provides a rapid and reliable method to detect life threatening conditions such as the incorrect positioning of tracheal tubes, ventilatory failure, circulatory failure and defective breathing circuits.

Measuring *metabolism**
Capnography can also be used to measure carbon dioxide production, a measure of metabolism. Increased CO_2 production is seen during fever and shivering. Reduced production is seen during anaesthesia and hypothermia.

During the use of muscle relaxants
Patients who are partially paralysed with muscle relaxants may make respiratory efforts. This can alert the anaesthetist that the muscle relaxant is wearing off.

The Capnograph is also useful in the following circumstances:

- To assess the adequacy of ventilation
- Detect *oesophageal intubation**
- Diagnose circulatory problems and *malignant hyperthermia**
- As a disconnection alarm for a ventilator or a breathing system. There is sudden absence of the Capnogram
- May detect *air embolisms** 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 $EtCO_2$.

NB. This is not an exhaustive list.

Methods of Capnography

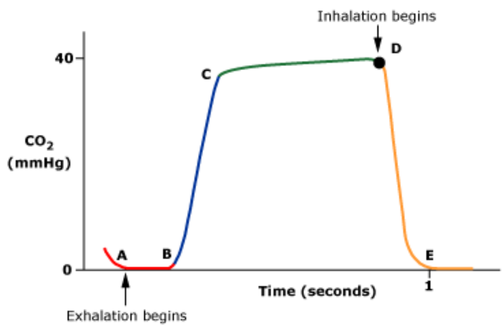
Determining the CO_2 concentration of respiratory gases is done either using the mainstream method or the sidestream method. In both cases the measurement principle is very similar (infrared spectroscopy) the position of the sensor in the measurement setup however differs:

In ***mainstream capnography (non-diverting)*** an airway adapter is inserted between the endotracheal tube and the Y-piece of the breathing circuit. The airway adapter has an optical window over which the infrared mainstream CO_2 sensor is positioned. The respiratory CO_2 measurements are obtained by continuously measuring the infrared light absorption, through the optical windows, in the gas flow.

For ***sidestream capnography (diverting)*** a sampling line is connected to an endotracheal tube with the help of a sidestream airway adapter or directly from the nose via a nasal cannula. Gas samples are continuously taken from the patient at a constant flow rate and transferred to the infrared CO_2 sensor incorporated in the capnograph. The CO_2 measurement is taken within the device and after measurement the waste gas is exhausted through the gas outlet.

The Capnogram in More Detail

The capnogram waveform is typically divided into 4 phases (Bhavani-Shankar & Philip, 2000).



A – B: Phase I - Baseline ($FiCO_2$)
B – C: Phase II – Positive expiration slope (alveolar gas)
C – D: Phase III – Alveolar plateau ($EtCO_2$)
D – E: Phase 0 – Inspiration

The capnogram waveform provides crucial information to the clinician; subtle changes can reflect impending problems. Only when a plateau is present in the capnogram can the user be certain that end-tidal gas is being measured, and the presence or absence of this plateau can only be detected by visually inspecting the waveform.

Abnormal waveforms can help in the diagnosis of underlying clinical or technical abnormalities such as partial airway obstruction, accidental extubation, and ventilation circuit disconnections etc. This permits early implementation of the corrective measures, before irreversible damage is caused to the patient.

Abnormalities should be found by analysing the various phases of the capnogram for individual breaths as well as observing trends over a period of time.

Five characteristics should be inspected:

- Height
- Frequency
- Rhythm
- Baseline
- Shape

The normal value of $EtCO_2$ is around 5% or 35 – 37 mmHg.

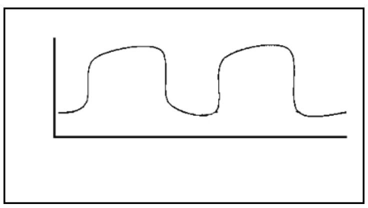
The Alpha Angle
The angle between phase II and III, which is referred to as the alpha angle, increases as the slope of phase III increases. Normally it is between 100˚ and 110˚. The alpha angle is an indirect indication of ventilation/perfusion (V/Q) ratio of the lungs.

Airway obstruction causes an increased slope and a larger angle. Other factors that can affect the angle are the response time of the capnograph and the respiratory cycle.

The Beta Angle
The almost 90˚ angle between phase III and the descending limb in a time capnogram has been termed as the beta angle. This can be used to assess the extent of rebreathing. During rebreathing, there is an increase in the beta angle from the normal 90˚. Occasionally, other factors such as prolonged response time of the capnograph compared to the respirator cycle time of the patient, particularly in children, can produce increase in the beta angle with the elevation of the baseline.

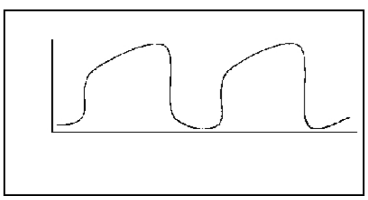
Abnormal Traces
Alterations in the “normal” waveform may be as follows:
NB. This list is not exhaustive

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.

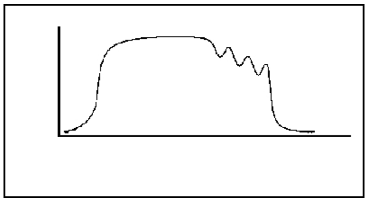
2. Sloping Plateau
A waveform that plateaus during phase III.



Cause:
Obstructive airways disease, because of impairment of the V/Q ratio. In patients with obstructive airway 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**.

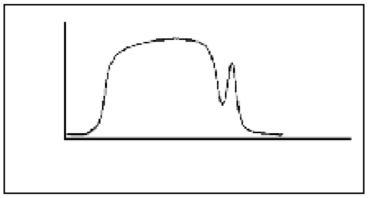
This results in the sloping plateau on the Capnograph trace, as the CO_2 from those parts of the lungs with more severe bronchial narrowing is exhaled later than those parts with less severe narrowing.

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



Cause:
Cardiac impulse is transmitted to the capnograph.

4. “Curare Cleft”
When a paralysed patient starts taking small breaths as the neuromuscular blocking agent reverses, deep “clefts” are seen on the Capnograph trace.



Cause:
Reversal of the neuromuscular blockade in a ventilated patient.

*Key Words

Respiratory Gases – Gases transported between exchange surfaces and the individual cells of an organism.

Circulatory system – Made up of the heart, blood and blood vessels the circulatory system is the body’s delivery system. Blood moving from the heart transports nutrients, water and oxygen to every part of the body and carries away waste such as carbon dioxide that the body produces.

Pulmonary Perfusion – The volume of blood flowing through the lungs.

Alveolar Ventilation – The amount of air that reaches the alveoli and is available for gas exchange with the blood per unit time.

Cardiac Arrest – Also known as **cardiopulmonary arrest** or **circulatory arrest**, is the abrupt cessation of normal circulation of the blood due to failure of the heart to contract effectively.

Cardiac Output – The volume of blood being pumped by the heart, in particular by a ventricle in a minute.

Endotracheal Tube - An endotracheal tube is used in general anaesthesia, intensive care and emergency medicine for airway management and mechanical ventilation. The tube is inserted into a patient's trachea in order to ensure that the airway is not closed off and that air is able to reach the lungs. The endotracheal tube is regarded as the most reliable available method for protecting a patient's airway.

Trachea – Also known as the windpipe, is a tube that connects to pharynx (the part of the neck and throat situated behind the mouth), allowing the passage of air to the lungs.

Cardiopulmonary Resuscitation (CPR) – An emergency medical procedure for a victim of cardiac arrest. CPR involves physical interventions to create artificial circulation through rhythmic pressing on the patient’s chest to manually pump blood through the heart, called chest compressions. CPR is unlikely to restart the heart; its main purpose is to maintain a flow of oxygenated blood to the brain and the heart, thereby delaying tissue death and extending the brief window of opportunity for a successful resuscitation without permanent brain damage.

Morbidity – Illness, disease

Mortality – susceptible to death

Apnoea – The suspension of external breathing. During apnea there is no movement of the muscles of respiration and the volume of the lungs initially remains unchanged.

Oesophageal Intubation – The Oesophagus is an organ which consists of a muscular tube through which food passes to the stomach. Oesophageal intubation occurs when the resuscitation tube is inserted into the oesophagus and down to the stomach, no or very little CO_2 is detected if the oesophagus has been intubated.

Malignant Hyperthermia – is a rare life-threatening condition that is triggered by exposure to certain drugs used for general anaesthesia, nearly all gas anaesthetics, and the neuromuscular blocking agent succinylcholine. In susceptible individuals, these drugs can induce a drastic and uncontrolled increase in skeletal muscle oxidative metabolism, which overwhelms the body's capacity to supply oxygen, remove carbon dioxide, and regulate body temperature, eventually leading to circulatory collapse and death if not treated quickly.

Air Embolisms - Gas bubbles in the bloodstream.

Metabolism - is the set of chemical reactions that happen in living organisms to maintain life. These processes allow organisms to grow and reproduce, maintain their structures, and respond to their environments.

Alveoli - The alveoli are the final branches of the respiratory tree and act as the primary gas exchange units of the lung.

Bronchi – Plural of bronchus, is a passage of airway in the respiratory tract that conducts air into the lungs.