Capnography: principles, applications and uses in trauma and emergencies

Darryl Wood
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‘Capnography: principles, applications and uses in trauma and emergencies’

Darryl Wood
(WDXDAR001)
MBBCh, B.Pharm, DipPEC, DA

SUPervisor
Prof. MFM James
(Head of Anaesthetics, UCT Medical School, Groote Schuur Hospital)
MBChB, PhD, FRCA, FCA(SA)

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BASIC PRINCIPLES AND UNDERSTANDING CAPNOGRAPHY

1. AIMS

- Literature review substantiating the use of capnography in emergencies
- To assess the level of knowledge and use of capnography among medical personnel in emergency departments in the Western Cape
- To assess the cost effectiveness of capnography in emergency departments
- To make recommendations to emergency departments in The Western Cape on capnography

2. METHODS

i) A current literature review on the use of capnography in emergencies. A literature search was conducted (Medline, PubMed, Cochrane Collaboration, other search engines) using MESH terms "capnography, capnograph, capnometry, CO2 monitoring, emergency, accidents, trauma, A&E, emergency medicine, aeromedicine, ventilation, resuscitation, paediatrics, diagnosis"

ii) A survey questionnaire was given to doctors, nurses and paramedics in emergency and trauma departments in the Western Cape. In addition, aero-medical paramedics were also questioned. A list of these hospitals is included in the appendices. All questionnaires were anonymous, encouraging candidates to answer truthfully. Candidates were asked to only respond in the positive (yes) or negative (unsure or no).

The staff complement numbers and percentages for each individual unit was not included in the study. The number and category of staff was broadly grouped by level of care of emergency units rather than individual institutions; i.e. primary, secondary, tertiary and private hospitals.

Respondents: Inclusion and exclusion criteria
A random sample of emergency unit staff was achieved by the investigator when transporting critically ill patients (Red Cross Helicopter Service) to or from a spectrum of emergency units in the Western Cape. The Red Cross Air Mercy Service services any emergency unit or hospital in the Western Cape. The specific days chosen for sampling were thus done randomly without prior knowledge of the complement of staff in the emergency unit questioned.

Staff included in the study were registered nurses, paramedics and doctors on duty at the time in the emergency unit or on the helicopter.

Each emergency unit was questioned only once and the staff on duty were asked to fill in the questionnaire anonymously.

Other emergency unit staff working a different shift or who were not present did not answer the questionnaire and were excluded from the study.

The percentage of staff questioned depended on the size of the unit and varied. The exact sample size and percentage from each unit was not assessed for reasons of anonymity of the respective institution.

**Questionnaire: inclusion and exclusion criteria**

**Inclusions**

Only questions answered in the positive, i.e. 'yes', were included in the graphic interpretation of the results.

**Exclusions**

Those questions answered unsure or no were treated identically and excluded from the results represented graphically. Respondents who answered question one in the negative (unsure or no) were assumed to be unable to answer questions 2 to 10 in the positive. This correlated with the raw data from the questionnaires. If question 3 was answered in the negative it was assumed that candidates were unable to answer question 4. This also correlated with the raw data from the questionnaires.

iii) Current pricing and types of capnographs commercially available in South Africa was assessed to
establish cost effectiveness of capnography in casualty units. A search for available portable capnographs was performed through distributors, manufacturers, sales representatives and the internet (google) using terms capnograph, capnometer, colorimeter, CO₂, portable, monitor.

3. INTRODUCTION

Capnography is the science of measuring carbon dioxide (CO₂) from respiratory gases in order to monitor ventilation in a patient. The principle that CO₂ absorbs infra-red light was used by Luft in 1943 to develop what is known today as capnography (D'Mello J 2002). Current capnographs measure CO₂ partial pressure in a gas mixture (exhaled tidal gas volume) using infra-red light or mass spectography. In effect, the measurement of CO₂ gives the clinician a tool to assess correct positioning of endotracheal intubation and a patient's ventilation during ventilation. Capnography continually analyses and records CO₂ in respiratory gases, which provides invaluable information about CO₂ production, pulmonary perfusion, alveolar ventilation, respiratory patterns and elimination of CO₂ from the ventilator circuit. Practically it gives clinicians a rapid and reliable method to detect life threatening problems such as endotracheal tube malposition, ventilatory failure, circulatory failure and breathing circuit malfunctions.

4. PHYSIOLOGY

CO₂ is produced in the tissues of the body during respiration and is removed via the lungs. The average adult at rest produces 2.5mg/kg/min CO₂ (Ward, 1998 ) It is transported from the tissues in the blood by venous return to the lungs dependant on cardiac output. CO₂ physically dissolves in blood as bicarbonate (60-70%) but also binds to various proteins such as haemoglobin (20-30%). The majority of CO₂ is delivered to the alveoli if the cardiac output and pulmonary blood flow is adequate (Genuit T et al 2000). CO₂ diffuses into the lungs as a result of the partial pressure difference between pulmonary capillary and alveolar CO₂ in air. (Ward, 1998 ). CO₂ diffuses across the alveoli-capillary interface into the alveolar sac until equilibrium is reached and is eliminated from the alveoli during expiration. This process takes less than 0.5 secs and in the normal lung, arterial CO₂ (PaCO₂) depends on the efficiency of ventilation. The effectiveness of CO₂
elimination depends on the ventilation:perfusion (V:Q) ratio.

The normal ration of V:Q is 0.8 (mid zone in lung); the upper lobes have higher ventilation ratios (V:Q > 0.8) while the lower lobes have higher perfusion ratios (V:Q < 0.8). Dead space is the tidal volume that is not involved in gas exchange. Dead space accounts for 20-30% of the tidal volume in a normal person. Conditions which cause alveoli to be ventilated but not perfused (Figure 1) such as pulmonary embolus, cardiac arrest and hypovolaemia result in larger dead space values (60-70%). Less expired CO₂ will be detected as a result of poor gas exchange.

![Diagram of Normal V:Q and Abnormal V:Q with Increased Dead Space](image)

**Figure 1 - Increased dead space ventilation**

Low V:Q ratios are a result of perfusion disturbances, i.e. normal to increased vascular perfusion to areas of the lung that have less well ventilated alveoli (Figure 2). Causes of this include bronchial intubation, mucous plugging, increased secretions in the bronchi/alveoli and atelectasis.
Figure 2 - Decreased ventilation (shunt ventilation)

Just before expiration the CO₂ concentration in the airways is maximal. It is then removed from the lungs through exhalation during minute ventilation. The end tidal CO₂ tension (PETCO₂) at the end of expiration can be measured. PETCO₂ can be used to estimate the arterial CO₂ concentration (PaCO₂).

\[
V_D/V_T = (\text{PaCO}_2 - \text{PETCO}_2)/\text{PaCO}_2
\]

\[
V_D/V_T = (\text{dead space/tidal volume})
\]

The proximal part (bronchi) of the respiratory tract has little to no CO₂. The CO₂ free gas in the lungs is termed "dead space" since there is no gaseous exchange between inspired gases, O₂ and CO₂, and the blood.

In the normal, healthy, well perfused and well ventilated patient, the PaO₂ is almost equal to the PETCO₂ (i.e. the P_a-ETCO₂ gradient is small). PETCO₂ in the normal individual is usually 2-5 mmHg lower than PaCO₂. The
concentration of CO₂ in the alveoli is determined by the ventilation and perfusion into the alveoli (V:Q ratio). Physiological factors that affect the ventilation or perfusion of the lung will alter the Pₐ-ETCO₂ ratio. The Pₐ-ET CO₂ is an index of alveolar dead space and an increase in this value reflects increases in dead space and is an indirect estimate of V:Q mismatch. Other causes of this are poor sampling techniques and abnormal ventilation with decreased alveolar emptying (Ward, 1998).

Under the correct conditions PETCO₂ may be used to estimate PaCO₂. Such conditions demand that the ventilated patient be haemodynamically stable and without rapidly deteriorating pulmonary pathology (Ward, 1998). As discussed above, the difference between PaCO₂ and PETCO₂ under normal circumstances is less than 5 mmHg. Stable patients should maintain this gradient at a constant level, enabling non-invasive PETCO₂ measurements to be used to estimate and monitor PaCO₂. PaCO₂ measurements have the disadvantage of being invasive and only representative of a single moment in time. PETCO₂ is a continuous measurement of CO₂ and is more effective in monitoring trends in ventilation. However, PETCO₂ has the disadvantage of being a potentially inaccurate estimate of PaCO₂ in patients who are haemodynamically unstable with pulmonary complications.

5. PHYSICS

The measurement of arterial CO₂ (PaCO₂) enables clinicians to assess the ventilatory status of a patient. A normal PaCO₂ value is about 40mmHg or 5.3kPa (Davis PD 2002). By using an instrument called a Severinghaus CO₂ electrode, CO₂ in liquids can be measured indirectly through (H⁺) ions. This is achieved because CO₂ reacts with water to produce hydrogen ions:

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3^- \leftrightarrow \text{H}^+ + \text{HCO}_3^- 
\]

CO₂ dissolved in blood (PaCO₂) is not the only CO₂ in the body. CO₂ is also present as bicarbonate (HCO₃⁻) and carbonate in association with haemoglobin (Davis et al). However, for purposes of ventilatory monitoring, PaCO₂ is the most important.
5.1 Infrared (IR) analyser

Capnography utilises a different method of CO₂ measurement to the above system; the most common being infrared radiation. With capnography we measure CO₂ in expired gases from the lungs. The basic principle is as follows:

Infrared radiation is absorbed by gases that have 2 or more different atoms in their molecular structure. This is a result of the vibrations between bonded atomic nuclei, especially diatomic molecules with different atomic masses such as CO₂, N₂O and NO (Sykes 1981). The imbalance caused by different size atoms causes a fluctuation around the magnetic dipole creating a magnetic field. The magnetic field caused by the vibrating frequency of diatomic molecules absorbs IR at specific wavelengths. Diatomic molecules with atoms of equal masses (e.g. O₂ and N₂) do not display the above characteristics and hence do not absorb IR (Sykes et al 1981).

Each gas absorbs infrared at a specific wavelength as depicted in figure 3.

![Graph](Absorbance.png)

Figure 3 – Absorption of IR by carbon dioxide and nitrous oxide
Thus, by measuring the appropriate wavelength of infrared absorbed by a specific gas such as CO₂ (4.28μm), one can reduce the interference of other gases such as nitrous oxide (Davis PD 2002). The principle of IR analysis (Figure 4) is as follows:

IR is produced by a heated nichrome wire or a Nerst filament (Sykes et al 1981). IR is emitted by the hot wire and passed through a filter in order to obtain the particular wavelength. Variations of these filters allows one to select a particular gas, i.e. specific wavelength. Filters can be mounted on a rotating disc allowing simultaneous analysis of several gases. A sample chamber with sapphire windows (glass absorbs IR while sapphire is transparent) is used after the filters have selected a specific gas. The selected IR wavelength is then focused onto a photodetector which electronically indicates the partial pressure of gas present (usually in mmHg or kPa). The amount of IR absorbed is proportional to the partial pressure of absorbing molecules. To avoid variations in the interpreted concentration of CO₂, some instruments use a second beam that passes through a control (reference cell or standard) containing CO₂ free air. Such a system is called a double beam instrument.

![Figure 4 - Infrared analyser](image-url)
Certain physical processes cause gas molecules to absorb radiation over a restricted wavelength centred about a peak (Figure 3) rather than at a specific wavelength. Intermolecular forces vary the distance between molecules causing their energies to alter slightly. This affects the energy at which they absorb IR. This process is called the collision broadening effect. When molecules that absorb IR at a similar wavelength to CO₂ are added to the gas mixture (e.g. N₂O), the wavelength at which CO₂ absorbs light is affected. Since most anaesthetic mixtures contain N₂O, most analysers compensate for the above disturbance.

The accuracy of a capnograph relies on a rapid response time from the sampling of CO₂ to its display on the capnograph. Two components are important, i.e. transit time and rise time.

**Transit time** – the time for the sample to be transferred to the analyser. Ultimately this is dependent on gas flow.

**Rise time** – the time for the analyser to respond to the signal particularly when there is a change in CO₂ concentration. This depends on the size of the sample chamber and the gas flow. Too low a flow will give an unacceptably long rise time. Too high a flow can give incorrect results because it may sample extraneous gas and dilute expired gases.

IR analysis is the main technique for analysing CO₂. Other methods include gas chromatography, mass spectrometry and colorimetric analysis. These methods are seldom employed although colorimetric analysis is used in portable devices, particularly in the emergency medical field. Colorimetric devices are qualitative measures of CO₂ only.

### 5.2 Colorimetric CO₂ detector

Colorimetric CO₂ detectors use a pH sensitive chemical indicator that is connected to the exhaled portion of the breathing circuit. The chemical indicator changes colour (room air = purple, CO₂ = yellow) when it is exposed to CO₂. Colorimetric CO₂ detectors are not very sensitive when CO₂ output is low such as low cardiac output states and CPR. (Bhavani-Shankar 2004).
6. TYPES OF CAPNOGRAPH ANALYSERS

Capnometry is the quantitative measurement of exhaled end-tidal CO₂. Capnography is the graphic display of CO₂ versus time, i.e. continuous analyses of ventilation (Anderson, 2000). For example, the respiratory rate can be calculated by measuring the time differences between consecutive peak PETCO₂ levels. There are 2 techniques for sampling PETCO₂:

6.1 Mainstream capnometry

(Anderson, 2000), (Stock, 1995) (D'Mello 2002)

Mainstream analysers have an adaptor cuvette sensor attached in-line with the ventilator circuit and close to the endotracheal tube (ETT). The cuvette itself incorporates an infra-red light source and sensor.

Advantages include:

- Gas flows directly over the sensor in the circuit enabling a rapid response.
- The sample cuvette lumen is wide reducing the risk of blockage from secretions.

Disadvantages include:

- The airway cuvette is relatively bulky and heavy, requiring support to prevent kinking or dislodgement of the ETT.
- The analyser is warmed to avoid condensation affecting sampling; the result being an increased risk of burns and pressure necrosis should it rest on the patient's skin.
6.2 Sidestream capnometry.

(Anderson, 2000), (Stock, 1995), (D'Mello 2002)

Sidestream analysers aspirate gas from the airway circuit, via a T-piece and capillary tube to a remote analyser. Optimal gas flow is considered to be 50-200ml/min. A moisture trap is connected to the sampling tube to reduce the likelihood of moisture occluding the tube. (Davis PD 2002).

Advantages include:

(Anderson, 2000), (Stock, 1995), (D'Mello 2002)

The sampling tubing is small bore and flexible

The T-piece adaptor is light and can be easily adapted to non-intubated forms of airway control.

The above system adds little to the dead space of the breathing circuit.

Disadvantages include:

The narrow sampling tube lumen can become occluded by secretions or condensate, affecting the true CO₂ reading and potentially damaging the instrument. The use of in-line filters can prevent this problem.
The delay time (up to several seconds) from sampling gas to analyser is slightly longer than mainstream analysers. This is due to the length and narrowness of the sampling tube but can be reduced (Davis PD 2002) with correct flow of gas resulting in as little as a 1 second delay.

Figure 6 – Side Stream Capnograph

7. SOURCES OF ERROR WITH CAPNOGRAPHY

There are numerous potential sources of error with capnography (Ford S 2002). At a basic level the breathing circuit should be checked for:

- Any leaks in the breathing system
- The non-rebreathing valve should be functioning well
- The inspired gas should be of constant composition

Major errors may occur in other systems such as the machine; sampling problems and patient related errors.
Machine related errors

The overlap of IR absorption bands of different gases may occur. N₂O may absorb some of the IR energy within the CO₂ bandwidth causing a false high CO₂ level. In addition, the collision broadening effect may also result in an abnormally wide absorption spectrum for CO₂ in the presence of other gases such as N₂O and N₂. New technology such as microprocessors are able to correct for these errors.

Response time

A rapid response time (discussed above) is essential for accuracy. Slow response times may result in failure to reach the true maximum CO₂ values during normal respiration. The capnograph profile may falsely show a prolongation of phase II (discussed below) and a steeper phase III. This profile could falsely mimic asthma. Furthermore, the peak CO₂ level measured may be lower than the actual CO₂ expired, falsely indicating poor ventilation.

Water vapour

Water vapour and secretions may occlude the long thin sampling tube in side stream analysers causing false CO₂ readings or total obstruction of the system with no reading. The use of a water trap reduces this problem by siphoning water from the sampling tube.

Calibration

Atmospheric pressure changes can cause errors in CO₂ detection. This is called the Ram-gas effect. A drop in atmospheric pressure may cause a pressure drop across the sampling line with inadequate suctioning. The result may be an underestimation of CO₂. Regular calibration of capnographs with the background gas and known CO₂ partial pressure is essential to maintaining accurate equipment.

Sampling errors

The ideal sampling site is at the top of the tracheal tube. However, the fresh gas flow of certain breathing circuits (e.g. Bain/Mapelson D) can dilute the exhaled gas mixture causing errors in the CO₂ reading.

Barometric pressure
Barometric pressure can affect exhaled CO₂ values. Capnometers measure the partial pressure of PETCO₂. Day to day variations in barometric pressure does not require adjustment of the capnometer (Ward 1998). The internal calibration system of a capnograph may produce errors when such equipment is used at altitude (James 1984). A common misconception is to think of capnograph CO₂ values as a concentration or percentage rather than true partial pressure. Capnographs measure the partial pressure of CO₂ and not percentage. This property must be taken into account when using a capnograph during the transport of patients at high altitude.

The effect of temperature on the partial pressure of CO₂ is slight (0.3%) since exhaled air temperature is relatively constant (Ward, 1998).

8. INTERPRETATION OF TIME CAPNOGRAM WAVE FORM

The capnograph can provide the clinician with a large amount of information through understanding and interpreting the expired respiratory CO₂.

A time capnogram (capnograph) is a graphic display of inhaled air and exhaled CO₂ vs time. Although PETCO₂ is vital in terms of monitoring and diagnosis, there are other aspects of inspiratory and expiratory CO₂ measurement that the clinician will find valuable. Initially, early exhalation shows no CO₂ since the initial gas sampled is CO₂ free dead space (D'Mello J 2002). Further exhalation shows a rise in CO₂ until a peak level is reached as CO₂ rich gases from the alveoli are sensed at the mouth sensor. Once exhalation is complete the CO₂ level decreases to zero while the patient begins to inspire CO₂ free air. The above description of CO₂ movement from the lungs gives the characteristic capnographic wave form. The waveform can be represented as a trace on a scrolling oscilloscope or on fast moving paper. Important clinical information can be gleaned from the patterns of the rising and falling concentrations of CO₂ during inspiration. The time capnogram can be demarcated into inspiratory and expiratory segments. The CO₂ curve is divided into phases I-IV (Figure 7).
Figure 7: Normal time capnogram

Phase I – CO₂ free gas (dead space) from the airways during the first portion of expiration (D’Mello J 2002, Bhavani-Shankar, 2000). This is called the respiratory baseline and should be zero. Increases in the baseline are usually a result of rebreathing of previously exhaled CO₂ (Ward, 1998 #38).

Phase II – a sharp S-shape upswing during early expiration; this phase represents a mixture of dead space and alveolar gas. This expiratory upstroke is usually steep but in some conditions this may become less steep (D’Mello J 2002), (Bhavani-Shankar, 2000). The most common physiological cause of this is obstructive airway disease or bronchospasm (Figure 8). This may also occur with mechanical problems such as kinking (Ward, 1998) of the ETT (Figure 9).
Figure 8 – obstructive airway capnograph

Figure 9 – kinking in the ETT during ventilation
Phase III – represents CO\(_2\) rich gas from the alveoli, called the alveolar plateau (D'Mello J 2002, (Bhavani-Shankar, 2000). The plateau has a slightly positive slope until it reaches a peak (PETCO\(_2\)). This represents the end of expiration. The alveolar CO\(_2\) plateau may become steeper as is the case during slow expiration (delayed alveolar emptying) in conditions of airway obstruction such as Asthma or COPD. (Figure 8). The height of the plateau may be increased (Figure 10) when the alveoli are under ventilated, i.e. minute ventilation is inadequate and CO\(_2\) accumulates. Other causes of the above waveform on the capnograph include hypermetabolic states, administration of bicarbonate and CO\(_2\) absorption from external sources (Ward, 1998). The PETCO\(_2\) alveolar plateau can be decreased while maintaining the waveform (Figure 11) when the alveoli are over ventilated, i.e. hyperventilation (D'Mello J 2002), (Bhavani-Shankar, 2000).

![Figure 10 - Hypoventilation](image-url)
Patients who have been given muscle relaxants for paralysis during mechanical ventilation may be seen to emerge from the effects of the drug by observing the capnograph. This results from the patient attempting a breath (inspiration) during the expiratory phase of the mechanical ventilator (Ward, 1998). A small dip in the expiratory plateau is seen on the capnograph waveform (Figure 12); also called the "curare cleft". This may also be due to inadequate sedation/anaesthesia, hypoxia or hypercarbia stimulating the patient to inhale and breathe over the ventilator. The use of capnometry without capnography will not detect this process.
Phase IV – Normally inspiration begins once phase III is complete. The capnograph CO₂ level rapidly decreases to zero (D’Mello J 2002), (Bhavani-Shankar, 2000). During this phase CO₂-free gas is inhaled. Phase IV is represented graphically by the descending limb of inspiration to the beginning of expiration (including the initial part of the horizontal base line). This inspiratory down-stroke is a near vertical drop to baseline. However, if there is a cuff leak in the ETT, the down-stroke may be prolonged (Ward, 1998) and even blend into the expiratory phase (Figure 13). Once again this effect will not be picked up with capnometry.
**Figure 13 – cuff leak**

**Alpha angle** – this is the angle between phase II and III and increases as the slope of phase III increases (D'Mello J 2002), i.e. V:Q status of the lung (e.g. obstructive airway disease).

**Beta angle** – close to 90°, this angle can be used to assess the extent of re-breathing (it can increase up to 180°) (Bhavani-Shankar, 2000).

A capnograph that shows no PETCO₂ may be as a result of (Ward, 1998):

I. Failure to ventilate the lungs
II. Oesophageal intubation, tracheal extubation, ETT obstruction or disconnection
III. Apnoea
IV. No cardiac output (e.g. cardiac arrest, pulmonary embolus, exsanguinations)
9. POTENTIAL USES OF CAPNOGRAPHY IN EMERGENCIES

9.1 INTUBATION AND VENTILATION

Capnography is regarded as the gold standard for confirming correct endotracheal tube (ETT) placement (Cardosa M 1998). Unrecognised oesophageal intubation is a leading cause of death or brain damage in anaesthesia (Knapp, 1999). It has been shown that ETT are placed in the oesophagus of 8% of critically ill patients, when emergency airway intubation is attempted (Figure 14). A number of factors contribute to the failure to intubate ill patients correctly. These include inexperience, lack of monitoring equipment, unfavourable conditions, urgency of the situation, and inadequately auscultating the lung fields and epigastrium post intubation. One of the most reliable signs of correct ETT placement is visualization of the tube entering through the vocal cords. However, in emergencies, this may not always be possible. One study (Katz 2001) showed that 25% of patients intubated by paramedics in the field had ETT misplaced. This is contrary to other evidence which quote figures of 1-5%. Of these 67% of ETT were placed in the oesophagus and 33% were placed in the hypopharynx; the tip being above the vocal cords. A reliable method to confirm ETT placement is imperative. One study assessed and compared 4 methods of clinically evaluating ETT placement (Knapp, 1999). These included:

- Auscultation of the lungs and epigastrium
- Capnograph ETCO₂ determination
- Oesophageal detection method using a syringe or self inflating bulb
- Tracheal trans-illumination technique using a lighted stylet

The outcome showed that capnography is the most reliable method for detecting tube position, despite the experience level of the operator. To be noted is that Katz et al (Katz 2001) demonstrated that 56% of ETT placed in the hypopharynx by paramedics had evidence of ETCO₂ when tested for in the referral emergency unit. Oesophageal intubation was associated with no expired ETCO₂.

The capnograph is the best tool to evaluate ventilation post intubation. A change in the CO₂ level or waveform
on the capnograph is an early detector of endotracheal tube accidents (Murray, 1983). When PETCO₂ on the capnograph suddenly drops to zero and no waveform can be identified in a ventilated patient, the clinician should be immediately alerted to the possibility of a catastrophic event. Such events may result from accidental oesophageal intubation, accidental tracheal extubation (e.g. rough handling of patient), disconnection of the endotracheal tube from the ventilator or obstruction of the ETT (e.g. kinking, mucous plug). Any interruption in the sampling of expired gases, i.e. total loss of ventilation, will result in the loss of detection of CO₂. Thus, monitoring CO₂ during ventilation is an accurate method of immediate detection of misplaced ETT or loss of ventilation.

PETCO₂ values that decrease exponentially over a period of time (seconds to minutes) with a discernable waveform (Figure 15), may indicate a major compromise of the cardiopulmonary system, causing a sudden increase in dead space (Ward, 1998). The above effects are due to reduced pulmonary blood flow. Physiologically, the arterial-alveolar CO₂ difference widens (a-A CO₂). Causes include cardiac arrest, pulmonary embolism and exanguinating haemorrhage. Such states of low pulmonary perfusion may not allow PETCO₂ detection without adequate chest compressions.
This may result in a false negative for correct ETT placement using capnometric confirmation.

In addition, capnography may be used as an adjunct to awake blind nasal intubation (Ward, 1998). This is a technically challenging means of intubation requiring considerable experience and skill from the clinician. As the ETT is passed via the nasal passage into the hypopharynx PETCO$_2$ will be detected from the patients spontaneous respirations. The tip of the tube, when in the correct position will allow continual PETCO$_2$ detection. However, should the tip be positioned away from the vocal cord (e.g. oesophagus) the PETCO$_2$ value will drop dramatically. Using capnography the clinician can move and position the tube until adequate PETCO$_2$ values indicate correct ETT positioning.

Types of CO$_2$ detectors

There are 2 main types of CO$_2$ detectors for correct ETT placement:

1. Colourimetric

This device uses litmus paper which changes colour when CO$_2$ is detected. The colourimetric device is limited by its inability to detect CO$_2$ levels greater than 38 mmHg (Krauss, 2003). In addition it cannot monitor continuous ventilation after intubation is complete. In a small percentage of cases the colourimetric device may react to CO$_2$ expelled from the stomach during misplaced oesophageal intubation causing a slight colour change. This may cause a false positive CO$_2$ result. CO$_2$ in the stomach may result from bag/mask ventilation prior to intubation when exhaled gases are forced into the stomach, ingestion of carbonated drinks or antacids (Cardosa M 1998). The problem is minimised by allowing for 6 breaths before taking a reading, which allows CO$_2$ from the stomach to be washed out. However, false positive results are rare with colourimetric devices which are qualitative only.

2. Capnography/capnometry

Standard capnography is the gold standard for assessing ETT intubation and ventilation (Krauss, 2003). Methods such as auscultation, tube condensation, epigastric auscultation, symmetric chest expansion and chest radiography are not 100%
reliable. Viewing the ETT placement through the vocal cords followed by capnometric confirmation are the most reliable methods of correct ETT placement (Ward, 1998). Monitoring the continuous waveform can immediately alert one to a misplaced ETT. Ventilation efficiency and patterns can also be continuously assessed (Krauss, 2003). Changes in the capnograph waveform can help guide the clinician to identifying the underlying cause, e.g. CO₂ accumulation with re-breathing. This method has particular benefits during transport of patients, especially paediatric patients who have uncuffed tubes that can easily be dislodged during movement.

Secondary devices such as capnography have been included in guidelines by the American Heart Association, American College of Emergency Physicians and the National Association of EMS Physicians to verify ETT placement and to continually monitor ETT position during the transport of ventilated patients (Cardosa M 1998).

9.2 CAPNOGRAPHY USE IN CARDIO-PULMONARY RESUSCITATION

End tidal CO₂ (PETCO₂) is a non invasive way of estimating alveolar ventilation, CO₂ production, CO₂ delivery to the lungs and arterial CO₂ content (PaCO₂). It has been shown that PETCO₂ correlates to cardiac output. It has also been demonstrated that alveolar CO₂ concentration decreased when pulmonary blood flow decreased in a range of conditions during cardiothoracic surgery such as systemic hypotension, cardiac failure and ineffective cardiopulmonary resuscitation (Isserles, 1991). A major factor for the above observation is that a decrease in cardiac output reduces CO₂ delivery to the lungs. When cardiac output decreases below a level that supports critical oxygen delivery to the tissues, venous PCO₂ (PVCO₂) increases. However, the accumulating PVCO₂ is not delivered effectively to the pulmonary vasculature as a result of poor cardiac output. Thus the PETCO₂ measured will be low.

Pre-cordial chest compression only maintains about 25% of cardiac output pre-arrest levels (Falk, 1988),(Garnett, 1987). Monitoring the effectiveness of chest compressions during cardiopulmonary resuscitation (CPR) is not simple. PETCO₂ correlates to the cardiac output and can be used via capnography to assess the efficacy of CPR. PETCO₂ is affected by the production of
CO₂, alveolar ventilation and pulmonary perfusion, i.e. cardiac output. It has been shown that after the onset of circulatory arrest, PETCO₂ on the capnograph drops precipitously (Falk, 1988). As discussed previously, cardiac arrest creates a large dead space which increases the a-A CO₂ gradient (Ward, 1998).

![Decreasing PETCO₂ levels](image)

**Figure 15 – Reduced cardiac output and pulmonary blood flow**

Traditionally the haemodynamic assessment of CPR is usually based on insensitive markers such as carotid/femoral pulse palpation or pupil reflexes. Capnography (PETCO₂) is a more dynamic and accurate correlation tool for assessing CPR. Sanders et al showed that PETCO₂ fell with the onset of cardiac arrest, increased when pre-cordial compressions were applied and further increased following a return to spontaneous circulation (Sanders, 1989). When ventilation is kept constant, critically reduced blood flow to the lungs secondary to poor cardiac output, reduces the excretion of CO₂ (Pernat, 2003). Once cardiac output improves to above 40% of normal pulmonary blood flow, PETCO₂ reflects normal values for V:Q relationships and minute ventilation. In order to monitor resuscitative efforts, i.e. cardiac output, using capnography, minute ventilation must be kept relatively constant throughout (Ward, 1998).
A trend has been observed that patients undergoing resuscitation with an average PETCO₂ level less than 10 mmHg had a markedly poor survival rate. Those with an average PETCO₂ greater than 10 mmHg had an increased likelihood of survival (Sanders, 1989). Further evidence (Pernat, 2003) demonstrated that when PETCO₂ declined to below 10 mmHg after 20 minutes of CPR, it was predictive of death. This observation may be used with other clinical variables to facilitate decisions about discontinuing resuscitative efforts. Thus, by monitoring PETCO₂ levels on the capnograph, the clinician can assess the effectiveness of CPR.

Two scenarios can be observed:

1. The return to spontaneous circulation as evidenced by an increase in PETCO₂.

2. A poor response to cardiopulmonary resuscitation as evidenced by a low or decreasing PETCO₂.

By altering the technique of cardiac massage while observing the capnograph, one can improve the overall CPR efficacy. Fatigue from the CPR provider can be detected by decreasing PETCO₂ values, allowing for a replacement health provider to continue the CPR effectively. The trend toward increasing PaCO₂ values (>10 mmHg) during resuscitation is an indicator of a good outcome. The converse effect (<10 mmHg) can assist clinicians in terminating futile resuscitations that are prolonged.

The above evidence was confirmed in a study (Levine, 1997) where the estimated survival in patients with cardiac arrest was 3.9%, when PETCO₂ levels measured after 20 minutes of resuscitation was ≤ 10 mmHg. Thus, a threshold of less than 10 mmHg PETCO₂ measured at 20 minutes of advanced life support can assist the clinician to terminate futile resuscitation. PETCO₂ values during resuscitation is a useful predictor of death in patients with cardiac arrest with electrical activity and no pulse. However, PETCO₂ cannot be used to predict long term survivors in patients who have PETCO₂ > 10 mmHg and return to spontaneous circulation. The failure of PETCO₂ levels to recover > 10 mmHg during CPR should also prompt the clinician to look for other causes such as pulmonary embolus, oesophageal intubation, cardiac tamponade, ineffective CPR, equipment malfunction and
hyperventilation before heading to the decision for termination of the resuscitation (Genuit T 2000).

Factors that affect PETCO₂ levels during CPR include the use of resuscitation drugs.

1. Adrenaline/epinephrine is routinely administered during CPR but may decrease PETCO₂ levels (Cantineau, 1996). It is thought to produce a transient V:Q mismatch causing a sudden but short-lived reduction in PETCO₂ (Pernat, 2003).

2. Sodium bicarbonate produces excess CO₂ and an increase in PETCO₂ levels (Pernat, 2003).

An additional application of PETCO₂ in CPR is to calculate the (Pa-ET)CO₂ difference. Normally in erect, spontaneously breathing adults there is minimal difference between arterial and end tidal CO₂ (Pa-ET)CO₂ is 0-2mmHg (Tyburski, 2003). This value increases up to 6mmHg in anaesthetised supine patients who are under general anaesthesia. A decrease in pulmonary blood flow or cardiac output causes an increase in P(a-ET)CO₂ difference. This was evidenced by patients who died after CPR who showed an increase in the (Pa-ET)CO₂ value of 12-16 mmHg (Tyburski, 2003). Minute ventilation can significantly influence the PETCO₂ and PaCO₂. The advantage of comparing the PaCO₂ (obtained from an arterial blood gas) and the PETCO₂ is that minute ventilation has little influence on the difference between the two. It has been suggested that a P(a-ET)CO₂ difference of greater than 10mmHg indicates a significantly higher probably of mortality.

In summary, a reduction in cardiac output and pulmonary blood flow results in a decrease in PETCO₂ (monitored via capnograph) and an increase in P(a-ET)CO₂.

9.3 CAPNOGRAPHY USE IN VENTILATED HEAD INJURY PATIENTS

Head injuries are common in trauma and require careful management to prevent complications. The main complication is an increase in the intra-cranial pressure (ICP). Numerous factors may cause a rise in ICP but the 2 most common primary effects in trauma are due to intra-cranial haemorrhage and cerebral oedema.
Attempts to reduce the rise in ICP are the focus of head injury management.

The normal ICP is about 10 mmHg (ATLS manual 1999). Abnormal pressures above 20 mmHg can cause a poor outcome in the head injured patient e.g. brain damage and death. According to the Munroe-Kellie Doctrine, ICP rises until a point of decompensation is reached (> 40mmHg). Hereafter the cerebral perfusion pressure (CPP) drops dramatically resulting in inadequate cerebral blood flow and oxygenation.

$$\text{CPP} = \text{MAP} - \text{ICP}$$

(MAP = mean arterial pressure)

Perfusion pressures less than 70mmHg are associated with poor outcomes (ATLS manual 1999). Maintaining CPP within normal limits requires maintaining blood pressure while reducing ICP.

Causes of secondary brain damage following head injury include hypoxia, hypercapnoea, hypotension, anaemia and seizures. Of these, hypoxia, hypercapnoea, and cardiovascular instability (hypotension) are chiefly responsible for secondary brain injury (Neuroanaesthesia Society of GB 1996, (Broka, 2002). Thus managing head injuries includes maintaining blood pressure, preventing blood loss and anaemia, preventing seizures, providing adequate oxygenation and reducing hypercapnoea.

Both hypoxia and hypercapnoea cause cerebral vasodilatation and concomitant increase in ICP. Patients who are unable to protect their airways (Glasgow Coma Scale < 8) or who are ventilating poorly with low oxygen saturation, should be intubated and ventilated. The aim of ventilation should be to achieve a $\text{PaO}_2 > 13$ kPa and a $\text{PaCO}_2$ of 4.0-4.5 kPa (Neuroanaesthesia Society of GB 1996). Both these parameters should be monitored closely using monitors such as a saturation probe and a capnograph. Traditional thinking that hyperventilation with the aim to reduce $\text{PaCO}_2$ levels to below 4 kPa are no longer recommended. Aggressive hyperventilation causing a drop in $\text{PaCO}_2$ levels to below 3.3kPa can result in severe cerebral vasoconstriction, reduced cerebral perfusion and ischaemia (ATLS Manual 1999). Thus, careful monitoring of ventilation (capnography) oxygenation (saturation) plays a vital role in reducing cerebral damage in head injured patients.
Recent evidence has demonstrated a significant improvement in outcomes and reduced mortality for patients with severe head injury who were intubated and ventilated appropriately before transfer to hospital (Broka, 2002). Adequate resuscitation of severely head injured patients in the pre-hospital phase is the most critical time in determining the outcome of that patient. Measures most crucial are restoring circulating volume and adequate oxygenation and ventilation. One area of concern is the quality of ventilation in the pre-hospital phase of resuscitation. A trend to hyperventilate intubated patients with head injuries using an ambu-bag is prevalent, with a resultant risk of cerebral vasoconstriction and ischaemia. Ventilating patients using a ventilator allows for better control (tidal volumes and respiratory rates can be set) and with the addition of a capnograph to monitor PETCO₂, the quality of ventilation can be improved.

Therefore, intubating and ventilating severe head injured patients while monitoring PETCO₂ and oxygen saturation, can vastly improve the quality of ventilation and reduce the risk of secondary brain injury due to hypoxia and hypercapnoea. Where manual ventilation is used, capnography is the only way of getting correct minute ventilation.

9.4 CAPNOGRAPHY AND BRONCHOSPASM

Patients with COPD or Asthma have impaired ventilation and severe cases require admission into hospital. The clinical hallmarks of severe obstructive airways are tachypnoea, cyanosis, wheezing and poor PaO₂ saturation. With the addition of capnography, one can diagnose obstructed ventilation patterns and assess the effectiveness of treatment. Severe COPD causes a significant difference in the PaCO₂/PETCO₂ levels as a result of increased alveolar dead space (Brown, 1998). The resultant airway obstruction causes a prolonged expiratory phase during respiration.

Early stages of an asthma attack (acute bronchospasm and airway obstruction) see patients initially hyperventilating in order to maintain adequate oxygenation. This causes a decrease in the PETCO₂ to below 4.5kPa (Krauss, 2003). The respiratory effort required to maintain this rate results in the patients eventually tiring with a slowing of ventilation rate. Without treatment the patient will enter a stage of
Hyperventilation with an increase in PETCO\textsubscript{2} levels. Values greater than 6.7kPa are dangerous (acid/base disruption) and aggressive airway management such as intubation and ventilation may be required.

The capnograph is ideally placed as a monitor to detect this precipitous rise in PETCO\textsubscript{2} as an assessment of the severity of bronchospasm. Furthermore, the capnograph waveform produces a characteristic gradual upslope in the plateau (phase III) part of the trace (Figure 8). Thus the capnograph can be used to diagnose bronchospasm from the trace and the severity can be assessed from the PETCO\textsubscript{2}. An additional benefit is that the patient's response to treatment can be continually monitored, and decisions on further treatment can be made more objectively (Figure 16).

Figure 16 – Determining the need and/or the effectiveness of bronchodilator therapy in asthma
One diagnostic dilemma facing clinicians is differentiating between cardiac and respiratory causes of respiratory failure, i.e. COPD and pulmonary oedema respectively. Many of the symptoms and signs overlap. Usually a combination of signs and symptoms lead the clinician to one or the other causative conditions. A PEFR (peak expiratory flow rate) has been suggested as a more objective measure (Brown, 1998). Unfortunately, only a PEFR less than 150 L/min had some significance for differentiating COPD from pulmonary oedema, while more moderate cases of COPD with higher PEFR were not as definitive. Studies have not shown one single PEFR value to be 100% accurate in differentiating between cardiac and obstructive causes of respiratory failure. This led investigators to assess the value of PETCO₂ as a differentiator between obstructive and cardiac causes of respiratory distress. The outcome of one study (Brown, 1998) showed that patients in respiratory distress who had a PETCO₂ greater than 37 mmHg (5 kPa) were unlikely to have pulmonary oedema or congestive cardiac failure. However, the above cut off value is not definitive for asthma/COPD, since several patients had PETCO₂ levels less than 37 mmHg. Therefore, a PETCO₂ > 37 mmHg is inconsistent with cardiac causes of respiratory distress, while being suggestive of asthma/COPD despite a poor sensitivity.

9.5 CAPNOGRAPHY IN PREHOSPITAL AND AEROMEDICINE

Intubated and ventilated critically ill patients requiring transfer to a tertiary facility face additional complications during transport. These include ETT displacement on moving the patient, poor quality and monitoring of ventilation, and the inability of medical staff to auscultate the chest adequately during transfer.

Severely injured trauma victims requiring early intubation on scene can usually be adequately oxygenated. This can be monitored with the aid of a saturation monitor. However, the quality of ventilation following intubation is often inadequate and difficult to assess. It has been shown that tracheal intubation and ventilation in the field, significantly improves outcome in major trauma victims (Helm, 2003). Manual ventilation using a self inflating bag (e.g. AMBU-bag®) does not measure minute ventilation and the quality of ventilation depends on the experience and skill of the person compressing the bag. Automatic portable ventilators are more accurate with respect to respiratory rate and
minute volume but the quality of the patient's actual ventilation is still largely unknown. PaCO₂ values in these cases measured upon hospital admission (arterial blood gas analysis) ranged from 16 to 86 mmHg in one study (Palmon, 1996). This highlights the degree of variability with respect to the quality of ventilation in the pre and inter-hospital transport of critically ill patients.

The use of portable capnographs has enabled medical personnel to continually assess minute ventilation and improve the quality of ventilation. At the scene of an accident it can confirm ETT placement, diagnose ETT disconnection during transfer, can guide resuscitation, assess the efficiency of CPR and monitor and improve the quality of ventilation. This is of particular importance in certain patients. Tight control of PaCO₂ is crucial in head injured patients with raised intracranial pressure or patients with pulmonary hypertension (Palmon, 1996). In each case respectively, a rise in PETCO₂ above normal (about 40mmHg) can cause vasodilatation and worsen both the intracranial pressure and the pulmonary hypertension. The pre-hospital phase of ventilation seems to be critical in improving the ultimate outcome in traumatic brain injury.

One specialised niche where capnography plays a crucial role in monitoring ventilation is aero-medical transport of critically ill patients. New, light weight portable devices can easily be fitted into aircraft and helicopters. High ambient noise levels, particularly in helicopters, make it impossible to auscultate patient's lung fields. One study (Hunt, 1991) assessed the average breath sounds to be at an intensity of 26.3 decibels. Various helicopters were assessed for sound intensity. Measured sound levels ranged from 93 -103 decibels during flight, making it impossible for medical staff to accurately auscultate lung fields. Critically ill patients who have the potential for deteriorating respiratory status, require therapeutic interventions as soon as possible. The inability to auscultate lung fields in order to assess these patients may prevent timeous therapeutic interventions. The capnograph is not affected by sound and the ability to constantly monitor ventilation during flight can alert the flight medical officer to any changes in the patient's respiratory status. One limitation of capnometry is its inability to locate and characterise the nature of the pulmonary pathology. However, the trace of capnography can allude to the underlying cause of the respiratory problem.
Capnography is a crucial part of monitoring ventilated patients in the aeromedical environment.

9.6 CAPNOGRAPHY IN PAEDIATRICS

Neonates and infants have a relatively greater metabolic rate and oxygen consumption than adults (APLS Manual 2001). Although tidal volume remains relatively constant to body weight through to adulthood, lung compliance is initially low at birth as a result of reduced surfactant. In addition infants are diaphragmatic dependant breathers with little assistance from the intercostal muscles. Added to this are a decreased proportion of recruitable alveoli and narrower airways that increase resistance to air flow and airways are more easily obstructed. All these factors make the infant more prone to respiratory distress. Paediatric patients have reduced lung reserve which predisposes them to rapid deterioration in their respiratory status following pulmonary compromise. Continual monitoring of an ill child's respiratory status is crucial in order to respond to any pulmonary deterioration.

The use of capnography in paediatrics has similar applications to adult use, but has specific benefit in non invasive respiratory monitoring in sedated infants and children (discussed below). One of the greatest benefits of capnography is to confirm ETT placement.

The American Academy of Paediatrics (APLS Manual 2001, Bhavani-Skankar website 2004) has issued minimum guidelines and levels of care for paediatric intensive care units and the monitoring O₂ and CO₂ in all critically ill paediatric patients is included. Arterial blood gas (ABG) measurement remains the gold standard in monitoring oxygenation and ventilation. Repeated ABG's are invasive and time consuming. The use of O₂ saturation probes and transcutaneous CO₂ monitoring reduce the need for repeated ABG's. However, unlike pulse oximeters, the heated electrodes of transcutaneous CO₂ sensors are associated with complications such as burns in the neonate, damages to the skin by adhesive, excessive drift of electrodes and erratic behaviour in the presence of acidosis and the need to change the sensor every 2-4 hours (Bhavani-Skankar website 2004). In contrast capnography has no such problems and provides a continuous assessment of exhaled CO₂. In addition, fewer invasive procedures are required, avoiding repeated arterial blood gas sampling. The above standards should also apply to treatment and
monitoring critically ill paediatric patients in the emergency unit.

**Capnography in paediatric ETT placement**

The importance of correct placement of ETT in paediatrics is vital since a reduced respiratory reserve decreases the time from adequate arterial O\textsubscript{2} saturation to unacceptably low levels. Improperly placed tubes can result in serious complications such as hypoxia and cardiac arrest. The incidence of oesophageal intubations has been reported to be 40% in one neonatal intensive care study and 18.5% in infants and children intubated in the emergency department and pre-hospital environment (Bhende, 2001). As discussed before, capnography is central to confirming correct ETT placement. Most studies in this regard have been in adults and infants/children weighing more than 2kg with spontaneous circulation. One study assessed capnography during paediatric cardiac arrest (Bhende, 1995). It showed that the use of a colorimetric end-tidal CO\textsubscript{2} detector for verification of ETT placement was effective (sensitivity of 84.6%, specificity of 100%). The detector showed no colour change (negative test) when the oesophagus was intubated. A false negative test may result from airway intubation in patients with an absent cardiac output or poor blood flow as seen with cardiac arrest and severe hypovolaemia. Capnography has been shown to be superior to pulse oximetry in the early detection of oesophageal intubation especially in pre-oxygenated patients with 100% O\textsubscript{2}. The American Heart Association guidelines for Advanced Cardiac Life Support and Paediatric Advanced Life Support, requires the use of capnography as a secondary measure to confirm proper ETT placement immediately after intubation and during transport.

**Capnography in paediatric transport**

Following the correct placement of the ETT, clinicians must make certain that the ETT stays in place. The use of uncuffed ETT in children less than 6 years of age predisposes to dislodgement from the airway. In addition, the distance between the vocal cords and the carina is small in children. Any movement of the neck or ETT can easily pull the ETT out of its correct position. Paediatric patients are particularly vulnerable to ETT dislodgement during pre and inter-hospital transport, especially when the child is moved. Airway problems
represent a large part of preventable mishaps during transport of critically ill paediatric patients.

**Capnography in paediatric sedation**

Performing certain painful or uncomfortable procedures on children can be daunting for most emergency clinicians. Conscious sedation is often required in order to carry out a procedure safely and to control the child’s anxiety and pain levels. However, providing safe sedation/analgesia requires skill and training in order to prevent adverse sedation related outcomes. Documented problems that lead to adverse outcomes include the following (Cote, 2000):

- Inadequate medical evaluation
- Inadequate monitoring during and after the procedure
- Inadequate skills in problem recognition and timely intervention
- Lack of experience with a particular age of patient or with an underlying condition

The American Academy of Pediatrics and the American Academy of Pediatric Dentistry’s revised guidelines for caring for children requiring sedation places emphasis on monitoring, including pulse oximetry and capnography. The adverse events observed in the study by Cote et al listed respiratory compromise as the main clinical adverse event (>80% of patients). This was followed by bradycardia and cardiac arrest. The causes for these events were also listed. The main causes included:

- Drug-drug interaction
- Drug overdose
- Inadequate monitoring
- Inadequate resuscitation
- Inadequate medical evaluation
- Premature discharge

Inadequate monitoring features high up on the list of problems and causes for adverse events in sedated children. Since the most common adverse event was respiratory compromise it stands to reason that monitoring the child's respiratory status should be mandatory when sedation/analgesia is attempted by clinicians in the emergency room. Cote et al recommend the mandatory use of pulse oximetry with added CO₂
monitoring (ventilation) using capnometry/raphy. The American College of Emergency Physicians (1998) advocate the use of capnography and pulse oximetry for monitoring selected patients undergoing conscious sedation. The use of opioids and benzodiazepines (usually in combination) decreases the hypoxic drive resulting in hypoventilation. Early hypoventilation can be detected rapidly using capnography by a noticeable drop in respiratory rate and an increase in $\text{ETCO}_2$. Capnography is more sensitive to rapid changes in respiratory rate and minute ventilation, while pulse oximetry allows assessment of tissue oxygenation. Any hypoventilation or apnoeic episodes due to oversedation can be picked up rapidly with $\text{CO}_2$ monitors. Capnography has been shown to be the earliest detector of acute airway obstruction, respiratory compromise, apnoea, laryngospasm and respiratory rate (Green 2003). Pre-oxygenation with high flow oxygen allows a longer period of hypoxic tolerance by the patient and saturation monitoring may not detect early respiratory compromise. This is especially important in infants and toddlers who have a smaller functional residual capacity (reserve) and greater oxygen consumption than children and adults. Early detection via capnometry is crucial in this population group (Green 2003).

Non invasive $\text{PETCO}_2$ monitoring via oral/nasal cannulas are being employed for this purpose. Emergency practitioners can respond quickly to respiratory adverse events using these monitors improving patient safety and outcomes. Pulse oximeters have a delayed reaction time in patients on oxygen whose respiratory function deteriorates as a result of inadequate minute ventilation. Capnographs are more sensitive in these patients and rapidly detect changes in minute ventilation.

However, there is little evidence (Walker 2004) showing that capnography use results in a lower rate of complications such as hypoxic injury and aspiration during conscious sedation (comment made with propofol sedation).

**Noninvasive monitoring of $\text{PETCO}_2$ in children**

Monitoring $\text{PETCO}_2$ in spontaneously breathing children who are sedated improves patient safety and care. This method of monitoring continually assesses ventilation and in more severe cases may limit the need and cost of invasive procedures such as arterial blood gas analysis. The use of nasal cannulas in spontaneous breathing
The measurement of PETCO₂ via nasal cannulas has been shown to be accurate during spontaneous ventilation. Tobias et al. separated the two prongs of the nasal cannula so that O₂ could be delivered through one side and CO₂ sampled from the other side (Figure 17). They showed that PETCO₂, within a PaCO₂ range of 30-48mmHg (4-6.4kPa), correlated with PaCO₂ during spontaneous ventilation in children. A compact sidestream capnograph using infra-red spectroscopy was used to measure PETCO₂. A few factors may interfere with the accuracy of this form of monitoring:

1. sampling errors:
   - hypoventilation
   - mouth breathing
   - low tidal volumes
   These conditions lead to low flow rates through the nasal prong which may cause air entrainment and a false low PETCO₂ reading
2. alterations in pulmonary V:Q status
3. blockage of the cannula or sampling tube
A flow rate of 150ml/min was suggested to reduce these problems from affecting PETCO₂ readings.

The measurement of PETCO₂ levels using nasal cannulas in children with spontaneous circulation with profound hypocarbia (< 30 mmHg/<4kPa) has also been shown to be accurate (Flanagan, 1995). Such instances may occur in children with metabolic acidosis who are compensating with respiratory hyperventilation. The resultant increases in minute ventilation and tidal volumes cause a decrease in PETCO₂ and ultimately PaCO₂. Investigators (Flanagan, 1995) found that monitoring PETCO₂ during diabetic ketoacidosis was helpful in monitoring the patients' overall acidosis. In the absence of respiratory depression, the continued increase in PaCO₂ correlated well with the correction of acidosis and base deficit.

CO₂ monitoring may also be useful in paediatric patients who have seizures. Respiration can be severely impaired during and after seizure activity and is responsible for some mortality statistics in this patient group (Abramo, 1997). This may be due to airway obstruction, diaphragmatic contractions, or an imbalance between neurological and mechanical respiratory drives. The main respiratory consequence of this is hypoxia and hypercapnoea with respiratory acidosis. Pulse oximetry is effective in assessing oxygenation and supplemental oxygen can reduce the likelihood of severe hypoxia. CO₂ monitoring via nasal/oral cannulas have been shown to effectively assess patient ventilation and respiratory rate. Measured PETCO₂ levels were shown to correlate with capillary PCO₂ and arterial PaCO₂ levels in paediatric patients, who suffered from seizure attacks. Thus the clinician can use capnometry/graphy to assess the respiratory status, the PETCO₂ level with respect to potential respiratory acidosis and observe restoration of the patients' respiratory status. Oral/nasal capnometry was shown to be more sensitive than pulse oximetry in predicting a trend towards changes in respiratory rate and respiratory failure in paediatric seizure patients. Continuous end-tidal CO₂ monitoring assists the clinician to reliably assess the pulmonary status of a patient with regard to decisions on provision of ventilatory support.

9.7 CAPNOGRAPHY IN PULMONARY EMBOLISM

Pulmonary embolism (PE) poses diagnostic dilemmas for emergency clinicians who do not have a rapid reliable test to confirm their suspicions. PE can mimic other
cardiopulmonary conditions which may result in over and underdiagnosis of the condition. The gold standard for confirming a PE is a pulmonary angiogram (Goldhaber, 2004). Ventilation-perfusion isotope scans are less reliable but do assist in diagnosing PE. Unfortunately these are invasive diagnostic procedures not available in the emergency room. Clinical features, Xrays and electrocardiograms (ECG) suggestive of PE cannot reliably diagnose PE. However, between the suggestive clinical features in the emergency room and the more invasive investigations in the radiological suite, is room for a simple diagnostic test to assist in diagnosing PE.

PE produces an increase in alveolar dead space and redistribution of blood flow. The resultant decrease in perfusion to ventilation causes impairment of gas exchange (Goldhaber, 2004). The fact that PE produces a V:Q mismatch as a result of both vascular and airway effects, has led to investigators assessing the capnogram as a simple tool in aiding diagnosis of this condition.

Acute PE increases the alveolar dead space, diluting the CO₂ and consequently decreasing the PETCO₂ level (Genuit T 2000). This will also increase the PaCO₂-PACO₂ difference to a level much greater than that measured by simple V:Q mismatch (usually about 5mmHg). PACO₂ is represented by capnometrically measured PETCO₂. The above CO₂ values can be achieved comparing arterial blood gas analysis and PETCO₂ values from capnography. Studies have shown that Vo/Vₜ (dead space/tidal vol) greater than 0.3-0.4 has a 100% sensitivity and 94% specificity in diagnosing PE (Ward, 1998). The specificity can be increased to 100% if one adds D-dimers to the diagnostic evaluation. Vo/Vₜ can be calculated as follows:

\[
\text{Vo/Vₜ} = \frac{(\text{PaCO₂} - \text{PETCO₂})}{\text{PaCO₂}}
\]

Normal Vo/Vₜ = 0.2-0.3

Bronchospasm may confound the diagnosis since it may also cause increases in the Pa-PACO₂ gradient (Chopin, 1990). (Ward, 1998). However, the PETCO₂ values in this group will be much higher than the PE group (e.g. 40mmHg vs 24mmHg respectively) on maximal exhalation (Figure 18). Thus, patients with PE will not show a major difference between PaCO₂ and PETCO₂ during maximal expiration (Chopin, 1990). In contrast, patients with
Severe COPD showed similar PaCO₂ and PETCO₂ values during maximal expiration (mean value of 1 mmHg).

Further studies are required in this field but the future may see capnography affording the emergency physician the ability to diagnose PE at the bedside without complicated radiographic studies.

10. SUMMARY

Capnography can confirm correct ETT placement, continuous ventilatory monitoring, the quality of ventilation, monitor cardiac output and allow early detection of cardiopulmonary deterioration in the critically ill patient. The Australian and New Zealand College of Anaesthetists have recommended that CO₂ monitoring be used in all intubated and ventilated patients (Williamson, 1993). The main advantage of capnography is the early warning it provides in potentially life-threatening events of critically ill patients.

The American Association for Respiratory Care (AARC) clinical practice guidelines support the use of capnography for all patients receiving mechanical ventilation (McArthur, 2003). They advise the following
indications for capnography during mechanical ventilation:

1. Evaluation of PETCO₂
2. Monitoring the severity of pulmonary diseases and evaluating response to therapy, especially therapy intended to improve dead space to tidal volume, and the matching of ventilation to perfusion (V:Q), and possibly to therapy intended to increase coronary blood flow
3. Determining that tracheal rather than oesophageal intubation has taken place
4. Continued monitoring of the integrity of the ventilatory circuit
5. Evaluation of the efficiency of mechanical ventilatory support by determination of the difference between PaCO₂ and PETCO₂
6. Reflecting CO₂ elimination
7. Monitoring adequacy of pulmonary and coronary blood flow
8. Monitoring inspired CO₂ when CO₂ gas is being therapeutically administered
9. Evaluation of the capnogram may be useful in detecting rebreathing of CO₂, obstructive pulmonary disease, waning neuromuscular blockade ('curare cleft'), oesophageal intubation, cardiac arrest and contamination of the monitor or sampling line with secretions

An audit on pitfalls in anaesthetic practice (Utting, 1987) more than 15 years ago highlights the importance of adequate airway and ventilation monitoring. The following errors pertaining to the emergency medical environment were listed:

1. Faulty technique of intubation – oesophageal intubation, kinking of ETT and prolonged attempts at intubation often leading to hypoxia and cerebral damage are some of the main causes of morbidity and mortality in anaesthetics
2. Inadequate monitoring during ventilation – BP, pulse, saturation and CO₂ are regarded as minimal monitor requirements during anaesthesia.

The capnograph is well placed to avoid pitfalls such as these in the emergency medical environment. The incidence of difficult intubations in the emergency room (3.3-3.5%) is almost double that of the operating room (1.15-3.8%) (Morton, 2000). A survey by Morton et al showed that 74% of emergency units in the UK had
capnographs as part of their monitoring equipment and 50% of emergency departments in East Anglia. 70% of Scottish emergency units used capnographs for ETT placement verification (Graham, 2003).

These promising figures have been mainly due to an increased awareness that CO₂ detection is the 'gold standard' for confirming ETT placement. In addition, the latest edition of the Advanced Trauma Life Support manual and Advanced Cardiac Life Support manual recommend the use of capnography when confirming ETT placement. Societies such as the Association of Anaesthetists in the UK, the American Society of Anesthesiologists and the European Resuscitation Council also recommend the use of having end tidal CO₂ monitors available in situations where endotracheal intubation is performed (Mallon, 2000). Thus, capnograph monitors should be available in all emergency departments where endotracheal intubation is performed.

Capnography, like its sister monitor, pulse oximetry, has been recognised as an essential monitor in critically ill patients. However, despite the clinical awareness of the value of capnography, the cost of such equipment has limited its use. The use of capnography has its origins and foundations in the operating theatres under the domain of the anaesthetist. Recent evidence has supported the use of capnography in the emergency environment, both pre-hospital and in the emergency room.
11. RESULTS

11.1 QUESTIONNAIRE ON CAPNOGRAPHY

The questionnaire (appendix 3) to the emergency departments and casualties in the Western Cape was designed to assess the following:

- The availability of capnography in these departments
- The use of capnography in emergencies
- The level of knowledge and understanding that emergency health care providers have of capnography

Hospitals in the Western Cape (primary, secondary, tertiary and private) and the aeromedical service (Red Cross AMS) were assessed when the investigator transported critically ill patients to or from these institutions. Appendix 2 lists these hospitals.

11.2 BREAKDOWN OF THE QUESTIONNAIRE

Basic awareness of capnography:
The health care providers' basic awareness of capnography was assessed through questions 1 and 2.

Availability of capnograph equipment:
Question 3 and 4 objectively established the availability of equipment for CO₂ monitoring in the respective casualties.

Usage of capnographs during emergencies:
The use of capnograph equipment was evaluated through questions 5, 6 and 7. The question was aimed at the day to day use of CO₂ monitoring, regardless of whether the equipment was present in the casualty department.

Knowledge and understanding:
Questions 8, 9 and 10 were included to establish a deeper level of knowledge of capnography among the questioned health care providers. Such a level of
understanding would be important for those who regularly use the capnograph during emergencies.

Level of interest:

The need for education and training with respect to CO\textsubscript{2} monitoring should be apparent from most of the questions in the questionnaire. Question 12 established the level of interest the questioned health care providers had for further education on capnography.

11.3 RESULTS DISCUSSION

BASIC AWARENESS

Q1 - Have you heard of capnography?
Q2 - Do you understand the principles of capnography?

The basic awareness for capnography among doctors in general was good, particularly among doctors working in tertiary and private hospitals (100% response to questions 1 and 2). This may be accounted for by the availability of capnographs in these institutions. Doctors in primary care were the least aware. Nurses were less aware of capnography, particularly those in primary care.
who showed 0% awareness. Paramedics in the aeromedicine environment fared relatively well with a 60-80% basic awareness. From the above data it is evident that the level of awareness for capnography among both doctors and nurses was highest in tertiary and private institutions while decreasing significantly from the secondary to the primary hospital environment.

AVAILABILITY

Q3 - Does your casualty/facility have a capnograph?  
Q4 - Do you know where the capnograph is stored?

The availability of capnographs in the Western Cape Hospitals was very low. Tertiary and private hospitals had similar results. It was interesting to note that despite a perceived 75% availability of capnographs in these institutions only 50% of doctors knew where the capnograph was stored. Only 20% of nurses in tertiary hospitals attested to the availability of a capnograph in their unit, compared to 70% of nurses in private units. Capnographs were not available to emergency health care providers in primary and secondary hospitals (0%).
BASIC USE

Q5 – Do you regularly make use of the capnograph during resuscitation?
Q6 – Would you always use a capnograph on intubated and ventilated patients if it was available?
Q7 – Do you think capnography is the best method of assessing endotracheal intubation?

The use of a capnograph during resuscitation was poor. Question 5 is probably the most important question for assessing the level of use of a capnograph in the emergency setting. The best response for using capnography during resuscitation was 50%; these being doctors in tertiary and private hospitals. Doctors in secondary and primary hospitals did not use a capnograph (0%) during resuscitations. The results for nurses showed a similar trend. Paramedics in the aeromedical field used a capnograph in 20% of resuscitations.

Despite the low level use of capnography, most health care practitioners indicated that they would use a capnograph in emergency intubations and ventilation were one available in the casualty.

The majority of doctors, nurse and paramedics felt that capnography was not the best method for verifying endotracheal tube placement (doctors 77%, nurses 73%, aeromed. paramedics 100%).

University of Cape Town
UNDERSTANDING

Q8 – Do you think capnography is a useful adjunct for diagnosing certain emergency conditions?
Q9 – Do you think capnography is helpful in assessing efficacy of CPR during resuscitation?
Q10 – Would you routinely use a capnograph with a saturation probe to monitor cardiopulmonary status?

Results for the above questions were varied and generally inconsistent, except tertiary care nurses who showed a 60% consistent level of understanding capnography. All other groups displayed erratic results which suggest that overall knowledge for capnography was relatively poor. Not included in the graph was the amount of 'unsure' answers which were significant. Overall, irrespective of awareness and use of capnography, a full understanding of capnography was relatively poor.
LEVEL OF INTEREST

Q12 – Would you be interested in learning more about capnography?

The overall interest in learning more about and using capnography in emergencies was very high. This suggests room for education programs for teaching emergency health care providers the principles and practice of capnography. Furthermore, the provision of capnographs in emergency units would round off any such training.
Of the doctors sampled, only 7/22 (32%) had done a rotation in anaesthetics. Overall awareness of capnography was very high. Despite this the level of knowledge and understanding of capnography and its use in emergencies was not as high as expected. Less than 60% understood the true value of capnography for use in emergencies.

**11.4 FACTORS INFLUENCING RESULTS**

Various factors may have influenced the results:

- The sample size (22 doctors, 22 nurses, 5 paramedics) may have been too small for a significant result. The subgroups within each group compounded the small sample sizes. However, certain trends in the answers were evident and basic conclusions shown were obvious. The overall aim of the study was confirmed with the collected data.

- The questionnaire included an 'unsure' answer which may have confounded the results. It would be reasonable to assume that an 'unsure' answer was a 'negative' to the question, in effect contributing to the number of 'no' answers. However, all graphs and discussed results were based on the 'yes'
answers, ultimately eliminating this confounder from the conclusions.

- Bias may have been associated with the pressure for health care practitioners to answer the questionnaire in the positive. Anonymity and random sampling attempted to reduce this. However, despite this certain questionnaires showed inconsistencies with the questions answered.

12. CONCLUSION

The evidence from my study strongly supports the use of capnography in emergencies. Worldwide, the literature and various anaesthetic and critical care organisations have supported the use of capnography for use in emergency resuscitations and ventilation. Capnography is a simple non-invasive tool, ideally placed to evaluate and monitor critically ill patients in the emergency room. Areas most benefited from the use of a capnograph include:

1. Intubation and ventilation
2. Cardiopulmonary resuscitation
3. Head Injuries
4. Bronchospasm
5. Patient transport
6. Paediatrics (including conscious sedation)
7. Pulmonary embolism

Emergency departments in the UK show good availability of capnographs in the units assessed (74% in the UK, 70% Scotland). The actual usage of capnography in these departments was not assessed in the literature reviewed.

The availability of capnographs in the Western Cape casualty units was low. Only tertiary and private hospitals had capnographs available (75% each) according to personnel in those departments. Despite this the usage of these capnographs in resuscitations was markedly low (50% respectively). Secondary and primary care hospitals had no capnographs in the casualties and subsequent use of capnography for emergencies was zero. The basic use and overall knowledge of capnography was relatively poor. The best results came from tertiary and private hospital staff (doctors and nurses) while being poorest in the
secondary and primary hospital setting. The availability of a capnograph greatly influenced the basic use and understanding of capnographs for use in emergencies.

Most of the questioned candidates were aware of capnography as a monitoring tool, but levels of use and understanding were relatively low. The most striking result was the low level of use of a capnograph in resuscitations, despite the presence of one in the casualty. Few questioned candidates were aware that capnography is the gold standard for confirming correct ETT placement.

Capnographs are relatively expensive and basic portable capnographs range from R14 000 to R70 000 (wholesale price). An exception is the coltrimetric devices which are relatively cheap. They are limited by only being qualitative and of short duration. Overall the extra cost and lack of knowledge of capnography has contributed to the lack of capnographs in the Western Cape casualties and trauma units. However, the cost benefit ratio for capnography and ultimately improved patient care is unequivocally favourable. Similar to the use of pulse oximeters monitoring oxygen saturation, capnographs are fast becoming minimum requirements for monitoring critically ill patients worldwide.

The Western Cape emergency and trauma units have not responded to the worldwide trend in acquiring capnographs for monitoring critically ill patients particularly those who require intubation and ventilation. The evidence clearly supports the use of capnographs in various emergencies. The Western Cape must respond by educating and training emergency health care staff and acquire capnographs in all casualties and trauma units. Although the cost of such equipment may be a deterrent, the benefit to patient care is without question.
APPENDIX 1 - DEFINITIONS

Capnometry:
The measurement and display of carbon dioxide (CO₂) on a digital or analogue monitor. Maximum inspiratory and expiratory CO₂ concentrations during a respiratory cycle are displayed.

Capnography:
A graphic display of instantaneous CO₂ concentration (FCO₂) versus time or expired volume during a respiratory cycle (CO₂ waveform or capnogram)

Capnograms:
CO₂ waveforms which can be of two types: FCO₂ can be plotted against expired volume (SBTCO₂ curve/volume capnogram/CO₂ expirogram) or against time (time capnogram) during a respiratory cycle.

PACO₂:
Partial pressure of CO₂ in the alveoli.

PaCO₂:
Partial pressure of CO₂ in arterial blood.

P_{ET}CO₂:
Partial pressure of CO₂ at the end of expiration.

(a-ET)PCO₂:
Arterial to end-tidal CO₂ tension/pressure difference or gradient.

PvCO₂:
Partial pressure of CO₂ in mixed venous blood.
APPENDIX 2

HOSPITALS INCLUDED IN THE SURVEY QUESTIONNAIRE

<table>
<thead>
<tr>
<th>LEVEL OF E.U.</th>
<th>DOCTORS SAMPLED</th>
<th>NURSES SAMPLED</th>
<th>PARAMEDICS SAMPLED</th>
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<tbody>
<tr>
<td>Tertiary:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Groote Schuur Tygerberg)</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(JF Jooste Victoria New Somerset)</td>
<td>11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Guguletu day clinic Kraaifontein day clinic Paramedic Services)</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Private</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Milton Medical Stellenbosch Medi Clinic Vincent Pallotti)</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

E.U. = emergency unit

*Individnual Emergency Units not assessed for staff breakdown on questionnaire*
APPENDIX 3
QUESTIONNAIRE ON CAPNOGRAPHY
TRAUMA AND EMERGENCY DEPARTMENTS

<table>
<thead>
<tr>
<th>Institution/hospital:</th>
<th>Government</th>
<th>Semi-private</th>
<th>Private</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of institution:</td>
<td>Primary</td>
<td>Secondary</td>
<td>Tertiary</td>
</tr>
<tr>
<td>Position:</td>
<td>Doctor</td>
<td>Nurse</td>
<td>Paramedic</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Question</th>
<th>Yes</th>
<th>Unsure</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Have you heard of capnography?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Do you understand the principles of capnography?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Does your casualty/facility have a capnograph?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4.</td>
<td>Do you know where the capnograph is stored?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Do you regularly make use of the capnograph during resuscitation?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Would you always use a capnograph on intubated and ventilated patients if it was available?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Do you think capnography is the best method of assessing endotracheal tube placement during intubation?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Do you think capnography is a useful adjunct for diagnosing certain emergency conditions?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Do you think capnography is helpful in assessing efficacy of CPR during resuscitation?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Would you routinely use a capnograph with a saturation probe to monitor cardiopulmonary status?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Have you done a rotation in anaesthetics?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Would you be interested in learning more about capnography?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX 4 - PRICE COMPARISON OF PORTABLE CAPNOGRAPHS

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>APPROXIMATE PRICE</th>
<th>FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novametrix:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Wave Sp ®</td>
<td>R 28 000</td>
<td>Capnograph + pulse oximetry with graphic display. Hand held portable miniature. <em>Side stream sampling</em></td>
</tr>
<tr>
<td>CO₂ SMO®</td>
<td>R 40 000</td>
<td>Portable capnograph and pulse oximetry with graphic waveform display. <em>Main stream sampling</em></td>
</tr>
<tr>
<td>CO₂ SMO® + Model 8100®</td>
<td>R70 000</td>
<td>As above with additional features for weaning patients from ventilators, e.g. VCO₂, alveolar minute volume, Vd/Vt, spirometry. More ideal for ICU</td>
</tr>
<tr>
<td><strong>BCI:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capnocheck II®</td>
<td>R25 000</td>
<td>Portable, handheld capnograph and pulse oximeter. Graphic waveform display. <em>Side stream sampling</em>. Infrared link for printer download</td>
</tr>
<tr>
<td>Capnocheck plus®</td>
<td>R35 000</td>
<td>As above with added features such as multiple display (pulse oximetry and capnography), moisture removal system, FiO₂ measurement</td>
</tr>
<tr>
<td>Capnocheck @ sleep capnograph/oximeter</td>
<td>R40 000</td>
<td>As above with added sleep screenings, reliable sats measurement, disappearing display with no audible alarm or pulse tones to minimise distraction in sleep studies.</td>
</tr>
<tr>
<td><strong>Nellcor:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPB-70/75®</td>
<td>R34000/R44000</td>
<td>70 = Portable hand held capnograph only plus multiple graphic display. Light weight 75 = Additional pulse oximetry. <em>Sidestream sampling</em></td>
</tr>
<tr>
<td>EasyCap®</td>
<td>R226 per ventilation</td>
<td>Colorimeter, easy in-line attachment, effective for 2 hrs. Bacterial filter part of unit</td>
</tr>
<tr>
<td>PediCap®</td>
<td>R226 per ventilation</td>
<td>Paediatric colorimeter. As above (EasyCap®)</td>
</tr>
<tr>
<td><strong>Nihon kohden:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pocket cap®</td>
<td>R16 000</td>
<td>Capnograph only. Very light weight. <em>Mainstream sampling</em>.</td>
</tr>
<tr>
<td><strong>Medair:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RespSense LS1R®</td>
<td>R15 300</td>
<td>Portable capnograph only. Light weight. <em>Sidestream sampling</em>. ETCO₂, RR and capnogram display with touch screen</td>
</tr>
</tbody>
</table>

Approximate pricing sourced directly from agents or distributors.
References:


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