APPLICATIONS OF CAPNOGRAPHY IN ANESTHESIA PRACTICE

Dr. Aruna Parameswari

Professor

Department of Anesthesiology, Critical Care and Pain Medicine

Sri Ramachandra University

Chennai

INTRODUCTION

The most important responsibility of the anesthesiologist is to prevent hypoxia and its disastrous consequences in the patient. Although pulse oximeter is the best monitor to detect hypoxia, capnography helps in identifying the adverse events leading on to hypoxia even before it is manifest as oxygen desaturation in the pulse oximeter. It thus helps in earlier identification of events leading on to hypoxia and their management before deterioration. Together with pulse oximetery, it has been proved that capnography can help in detection of 93% of preventable anesthetic mishaps. It is thus not surprising that it is recognized as a minimum mandatory monitoring standard under anesthesia by the American Society of Anesthesiologists. In addition to its use in operating rooms, the role of capnography is exploding in other avenues as well, especially in the intensive care unit, emergency room, during transport to and within the hospital and in procedures done in remote locations in the hospital. It is only a matter of time before it becomes a minimum mandatory monitoring standard in these locations as well.

DEFINITIONS

Capnometry refers to the numerical display of CO_2 concentrations in inspired and expired air.

Capnography refers to the graphic display of CO_2 concentrations in exhaled air. The graph can be a volume capnogram (where the FCO_2 is plotted against exhaled volume) or time capnogram (where the FCO_2 is plotted against time).

PARTS OF A NORMAL CAPNOGRAM

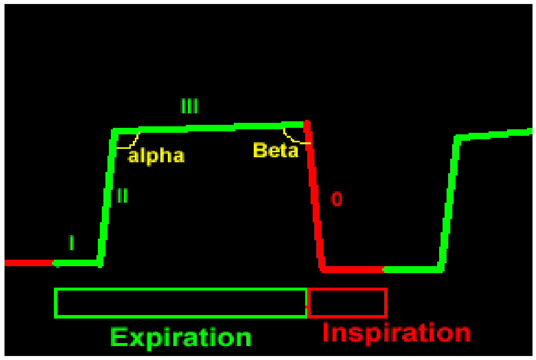

Fig1. Parts of a normal capnogram

As the patient exhales, the initial gas which comes out is that from the dead space, both apparatus and anatomical deadspace, that is free of CO_2. This is responsible for the initial horizontal line seen on the capnogram (Phase I). With continued exhalation, CO2 concentration in the exhaled air rises leading to a rapid upstroke in the trace (Phase II) that is due to mixing of dead space gas and alveolar gas. It then reaches a plateau, called the alveolar or expiratory plateau (Phase III), which almost always has a positive slope. This may be followed by a terminal upswing (Phase IV) in some situations like pregnancy and obesity. At the end of exhalation, the CO2 concentration decreases to zero as the patient commences inhalation of CO2 free gases. This is represented in the trace as the descending limb (Phase 0). The angle between Phase II and III is called the alpha angle and is between 100 - 110° normally. The nearly 90° angle between Phase III and the descending limb (Phase 0) is called the beta angle.

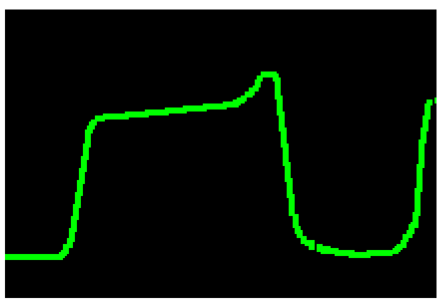

Fig 2. Terminal upswing (Phase IV) seen in pregnancy and obesity

APPLICATIONS

Capnography directly indicates changes in the elimination of CO_2 from the lungs. Indirectly, it also indicates changes in the production of CO_2 at the tissue level and in the delivery of CO_2 to the lungs by the circulatory system. Thus, it constitutes an important non-invasive technique of monitoring CO_2 production, pulmonary perfusion, alveolar ventilation, respiratory patterns and the integrity of the artificial airway and anesthesia administration device.

OPERATING ROOMS

Capnometry

Various conditions can be diagnosed from either increasing or decreasing $PEtCO_2$ values

Causes of abnormal $PEtCO_2$	**Increase in $PEtCO_2$**	**Decrease in $PEtCO_2$**
Metabolic	Shivering Malignant hyperthermia Neuroleptic malignant syndrome Thyroid storm Severe sepsis	Hypothermia Metabolic acidosis
Circulatory	Tourniquet release CO_2 insufflation – laparoscopy Treatment of acidosis	Induction of anesthesia Pulmonary embolism Profound hypovolemia Cardiogenic shock Haemorrhagic shock Intracardiac shunt
Respiratory	Hypoventilation COPD Asthma	Pulmonary edema Intrapulmonary shunt Hyperventilation
Technical	Exhausted CO_2 absorber Contamination of the monitor	Disconnection Blockage in tubing

Table 1. Causes of increased and decreased $PEtCO_2$

Capnography is useful in operating rooms to diagnose several events and also in assessing response to therapy. The different applications in the operating roomsinclude diagnosis of events related to:

Anesthesia machine and artificial airway

Capnography has an important role to play in detecting the integrity of the anesthesia apparatus. Leaks and disconnections in the breathing system can be picked up by capnography before it leads to hypoxia. Capnography also is useful to diagnose CO_2 retention due to an exhausted CO_2 absorbent, malfunction of valves in the breathing system or inadequate fresh gas flows. A totally occluded endotracheal tube or accidental extubation leads to sudden disappearance of the capnogram. A partially obstructed tube can result in changes in the waveform and a decrease in $PEtCO_2$.

Capnography is probably the best method to confirm endotracheal intubation or to detect esophageal intubation. It is used to guide the tube into the larynx during a blind nasal intubation. It is also used to confirm proper placement of double lumen tubes and supraglottic airway devices.

Fig3. Capnographic trace in apnoea, disconnections, accidental extubation

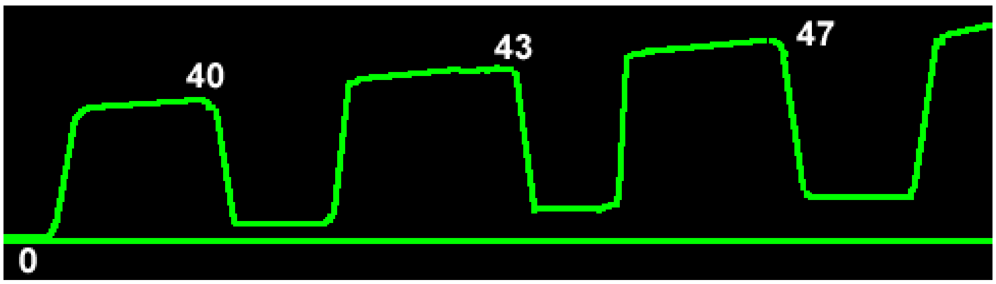

Fig 4. Capnographic trace in hypoventilation; there is a gradual rise in $PEtCO_2$

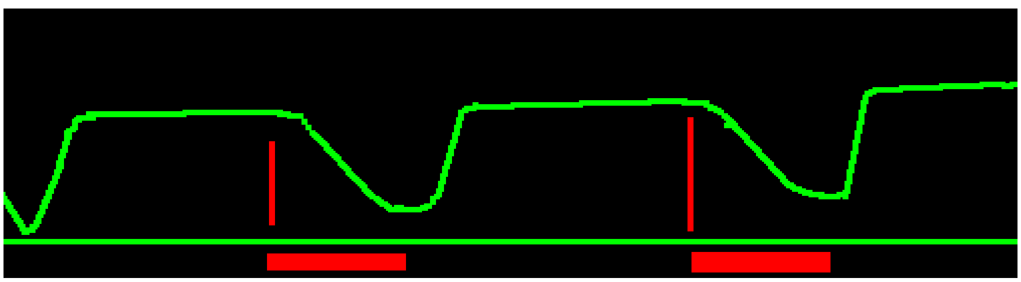

Fig 5. Capnographic trace in inspiratory valve malfunction. Phase 0 is prolonged

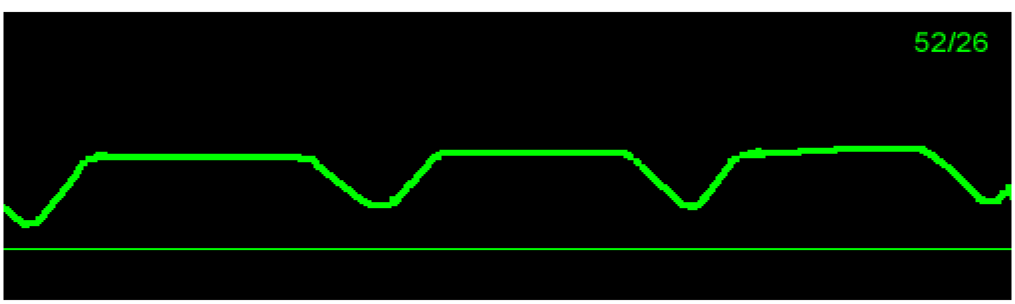

Fig 6. Capnographic trace in expiratory valve malfunction with prolonged, abnormal Phase II and Phase 0

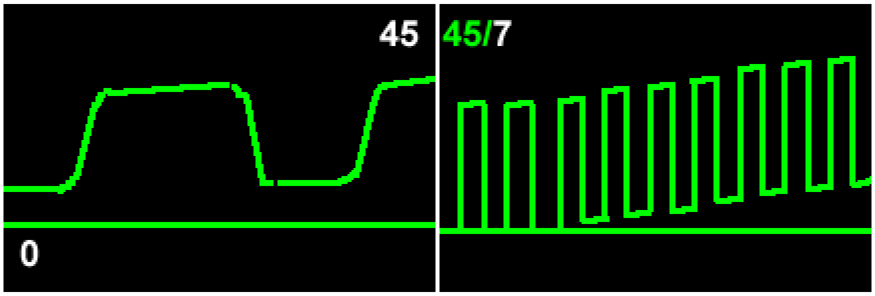

Fig 7. Rebreathing; Gradual elevation of the baseline

Respiration

Capnography is useful in the diagnosis of apnea, hypoventilation, hyperventilation, upper airway obstruction during mask ventilation, laryngospasm and bronchospasm. It is also possible to diagnose spontaneous respiratory efforts in a paralyzed patient, by looking at the curare cleft.

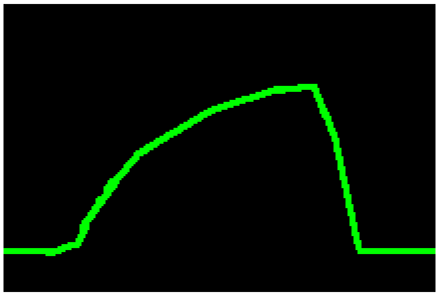

Fig 7. Bronchospasm

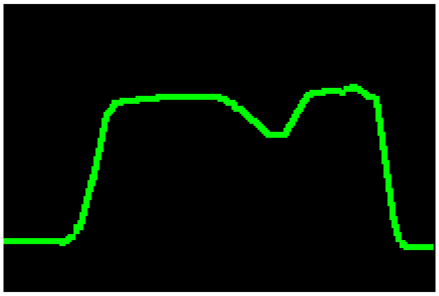

Fig 8. Curare cleft

Circulation

Capnography is useful to gauge any change in cardiac output, if ventilation remains constant. A fall in $PEtCO_2$ is seen with hypotension and hypovolemia and with surgical manipulations of the heart and thoracic vessels.

Capnography is also useful to detect air embolism, which causes a sudden decrease in $PEtCO_2$. It is also useful to diagnose venous CO_2 embolism during laparoscopy, manifest as a rapid rise in $PEtCO_2$.

Cardiopulmonary resuscitation

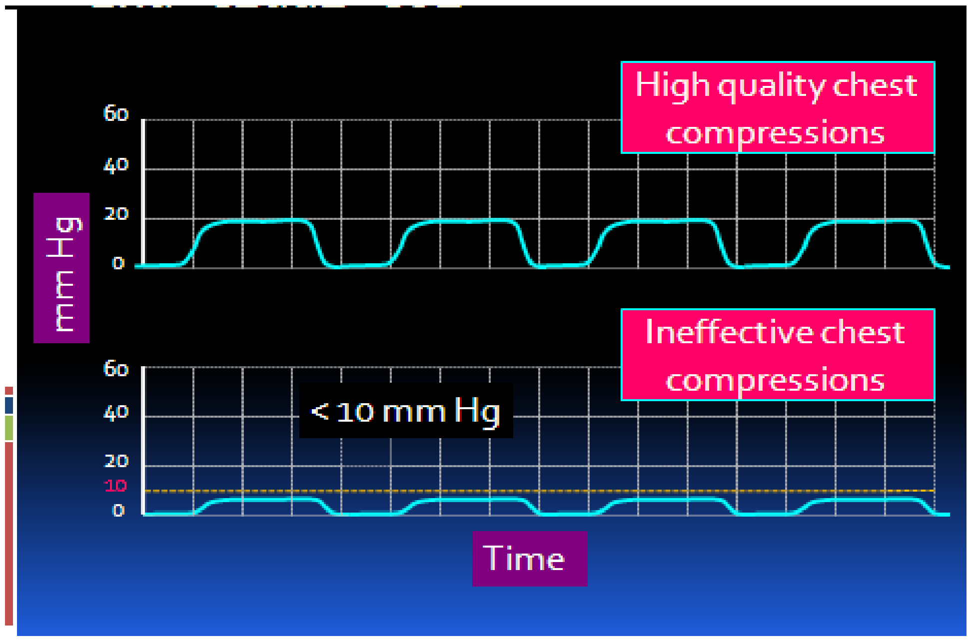

Fig 9. Capnography as a monitor of effective chest compressions during CPR

As per the American Heart Association 2010 guidelines, endtidal CO_2 can be a valuable tool during CPR.End tidal CO_2 monitoring is useful during cardiopulmonary resuscitation to confirm the adequacy of chest compressions. If the closed chest compressions are adequate to generate sufficient cardiac output to perfuse the lungs, the $EtCO_2$ will be > 20 mm Hg. If < 10 mm Hg, it indicates that the quality of chest compressions is ineffective and should be improved. Further $PEtCO_2$ also has a prognostic significance. It has been observed that non-survivors had lower $PEtCO_2$ values than survivors and with $PEtCO_2$< 10 mm hg, no patient could be successfully resuscitated.

Capnography is also useful in CPR to confirm ROSC (return of spontaneous circulation). A sudden increase in the $EtCO_2$ trace to > 40 mm Hg during resuscitation indicates ROSC.

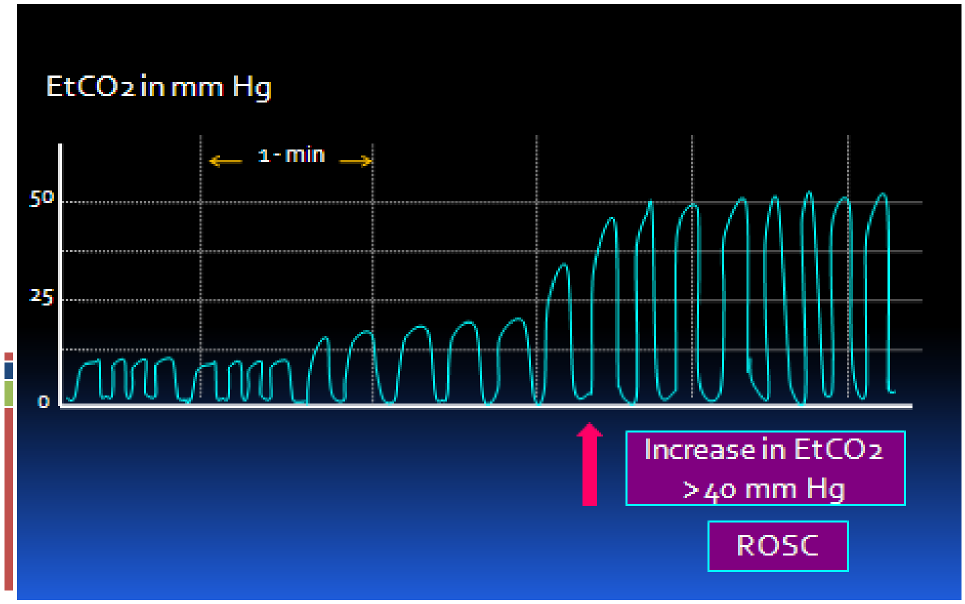

Fig 10. Capnographic trace showing return of spontaneous circulation during CPR

The 2010 Resuscitation Guidelines, published by the AHA and the Resuscitation Council (UK) emphasize the use of capnography to confirm and continually monitor tracheal tube placement, quality of CPR and to provide an early indication of return of spontaneous circulation.

Metabolism

Dangerous hypermetabolic conditions like malignant hyperthermia, thyrotoxic crisis and severe sepsis can be detected by CO_2 monitoring. Other metabolic causes of increase in $PEtCO_2$ include shivering, convulsions, excessive production of catecholamines, administration of bicarbonate, release of an arterial clamp or tourniquet and hyperalimentation. CO_2 production falls with hypothermia, muscle relaxation and increased depth of anesthesia.

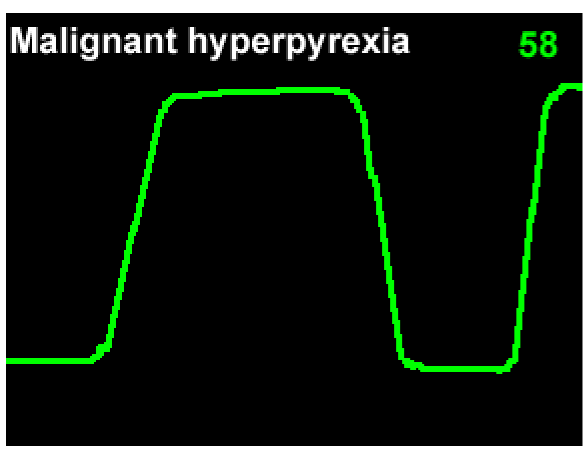

Fig 11. Hypercarbia in malignant hyperthermia

PACU

Patients who have their airway devices removed in the PACU should be monitored with capnography till the removal of the device (AAGBI guidelines for immediate post-anesthesia recovery). In addition to that, capnography can be useful to assess the respiration in patients in the immediate post anesthesia period in the PACU.

POSTOPERATIVE WARDS

Capnography is useful in postoperative wards where the patients are on patient controlled intravenous opioid analgesia, or those who have received neuraxial opioids to detect respiratory depression.

INTENSIVE CARE UNIT

The Fourth National Audit Project found that failure to use capnography contributed to 74% of death or persistent neurological injury in ICU related to airway complications. The Intensive Care Society has published guidelines for the use of Capnography in Critical Care in 2011. The recommendations include:

- Capnography should be used for all critically ill patients during the procedures of tracheostomy or endotracheal intubation when performed in the intensive care unit.
- Capnography should be used in all critically ill patients who require mechanical ventilation during inter-hospital or intra-hospital transfer.
- Capnography offers the potential for non-invasive measurement of additional physiological variables including physiological dead space and total CO_2 production.

In addition to these, there are several additional uses of capnography in the ICU

- AAGBI guidelines for the transfer of patients with head injury have also recommended the use of capnography during patient transfer
- Capnography can be used to diagnose inadvertent tracheobronchial placement of nasogastric tubes
- Capnography can be used to confirm cannula placement within the trachea during cricothyrotomy and percutaneous tracheostomy
- Capnography can be used to confirm brainstem death during the apnoea test

The routine use of capnography in critical care is common in some European countries, like The Netherlands, but not in all. The imperfect correlation between endtidal CO_2 and arterial CO_2 in several ICU patients could be one reason why this monitoring method has not become so ubiquitous in the ICU. But considering the innumerable advantages of capnography, it is slowly becoming an integral part of ICU monitoring as well. Some of the modern ventilators (Drager Evita 4 and Drager V500) provide capnography monitoring.

EMERGENCY MEDICINE AND RESPIRATORY DISEASES

Besides the same uses as in the operating room, capnography can also be used in the emergency room to routinely monitor respiratory pattern, rate etc in acute respiratory diseases. It also gives information on dead space ventilation. Though $EtCO_2$ values may not correlate well with arterial values in these patients, capnography provides an efficient and reliable measure and trends of the respiratory rate.

PROCEDURAL SEDATION

Capnography is useful in monitoring respiration during procedural sedation for diagnostic or therapeutic procedures. There can be upper airway obstruction or respiratory depression during these procedures which could be missed if we relied only on patient observation. Many of these procedures are done in dark, remote areas and the patient may be inaccessible for observation of the chest for movements. Continual monitoring using capnography can indicate the respiratory rate and patterns and helps in earlier diagnosis of airway obstruction, hypoventilation or apnea. In a recent meta analysis, it was shown that respiratory depression was approximately 17 times more likely to be detected in procedural sedation cases when capnography is used in combination with pulse oximetry and visual inspection of chest rise compared to the group without capnography.

NEONATAL RESUSCITATION

Capnography can be used to confirm endotracheal intubation even in very low birth weight neonates for resuscitation. Routine use of capnography may facilitate neonatal clinical assessment during active resuscitation.

CONCLUSION

Capnography is an integral part of anesthesia monitoring inside the operating room. Its role in the detection of several preventable mishaps has led to its use beyond the operating rooms, in the ICU, ER, during transport and in procedural sedation.

I would like to thank Prof. Bhavani Shankar Kodali for permission to use material from his website www.capnography.com in the preparation of this lecture.

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