Capnography in Critical Care Medicine

INTRODUCTION

This publication is intended to illustrate the clinical utility of capnography in Critical Care Medicine. The cases presented are based on actual situations in which capnography can provide continuous, non-invasive information which can alert healthcare professionals to unexpected changes in a patient's metabolic, cardiopulmonary and ventilatory status.

For additional information or references, please contact your Respironics Area Sales Representative or call Respironics at 1-800-345-6443 or 724-387-4000.

Table of Contents

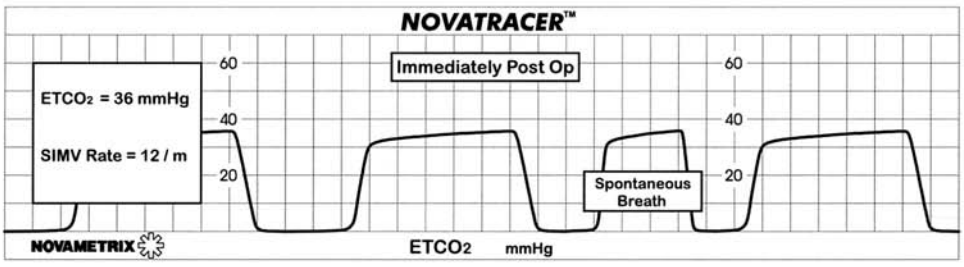
Capnography Can Reduce ABG's in Weaning Mechanically Ventilated Patients

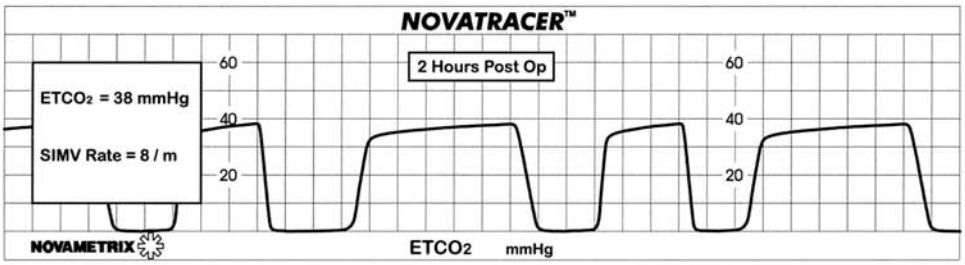
Case Report:

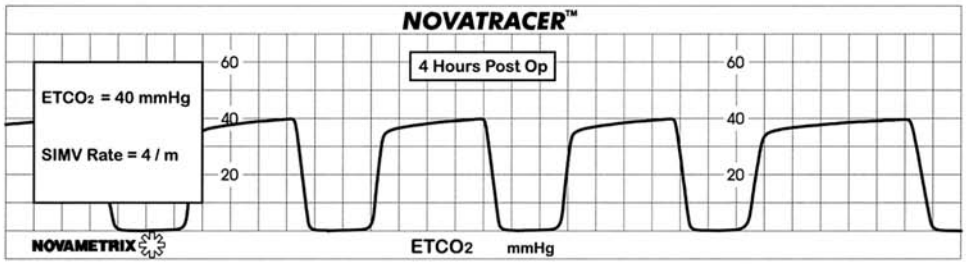
Post-op coronary artery bypass patient being weaned from mechanical ventilation

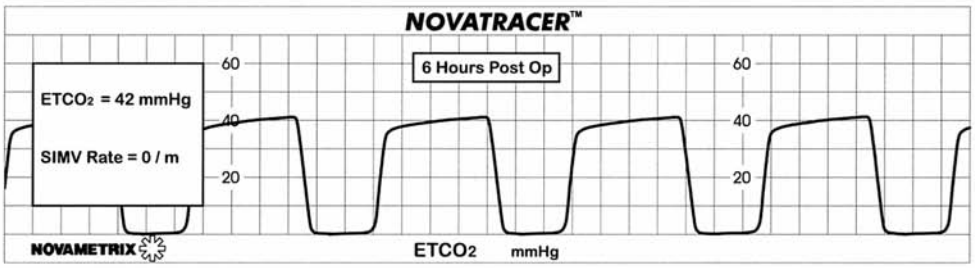
Profile:

A 56 year old post coronary artery bypass surgical patient was mechanically ventilated with settings of SIMV 12/m, VT 900 ml, PSV 7.5 cmH_2O and FiO_2 .4. Approximately 2 hours after admission to the ICU, the patient was awake, alert and able to breathe spontaneously. Arterial blood gases were drawn and readings were simultaneously recorded from the capnograph/pulse oximeter. Results were: pH 7.41, $PaCO_2$ 39, PaO_2 99, $ETCO_2$ 36 mmHg and SpO_2 98%. The physician ordered the patient weaned from the ventilator by decreasing the SIMV rate by 2 breaths per hour and maintaining $ETCO_2$ between 30-45 mmHg and SpO_2 greater than 92%. Over the next several hours, the patient was successfully weaned and extubated without the need for additional arterial blood gases.









Discussion:

Weaning from mechanical ventilation often requires that multiple arterial blood gas samples be obtained. This practice is not only invasive but also costly to both the hospital and the patient. The CO_2SMO® capnograph/pulse oximeter provided an excellent adjunct to arterial blood gases during the weaning process. Capnography and oximetry are valuable tools to alert the clinician to unexpected changes in cardiopulmonary status during weaning from mechanical ventilation.

"Therefore non-invasive monitoring may provide substantial cost savings by reducing the number of ABG's obtained during weaning from mechanical ventilatory support."

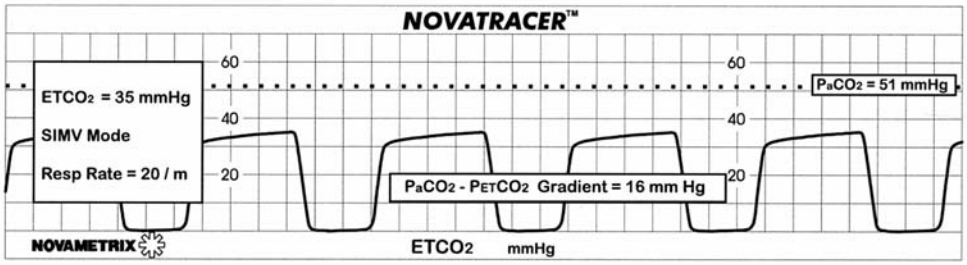
Safesak K., Nelson L., "Cost Effectiveness of Non-invasive Monitoring During Weaning from Mechanical Ventilation," Chest, 102: 1845, 1992.

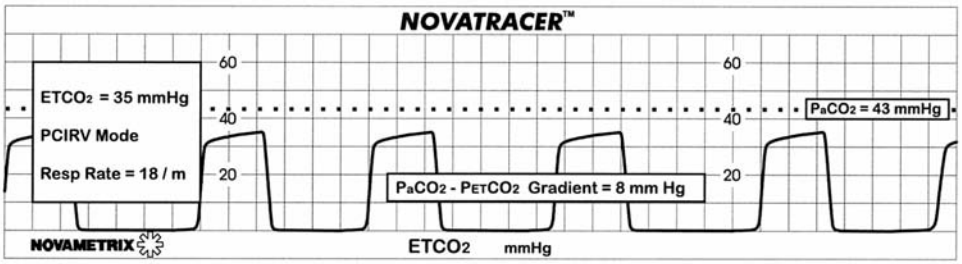
Case Report:

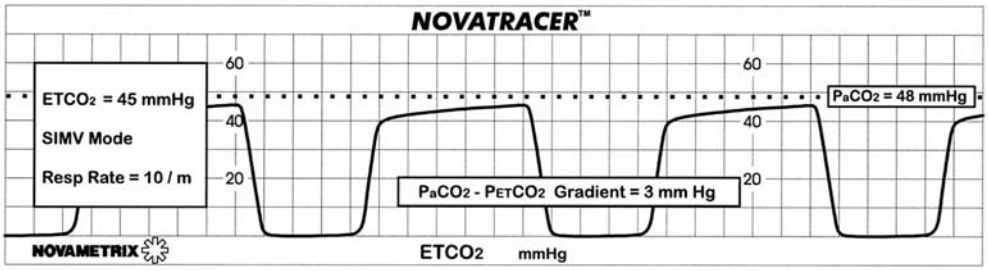
Patient with ARDS from septic shock requiring Mechanical Ventilation

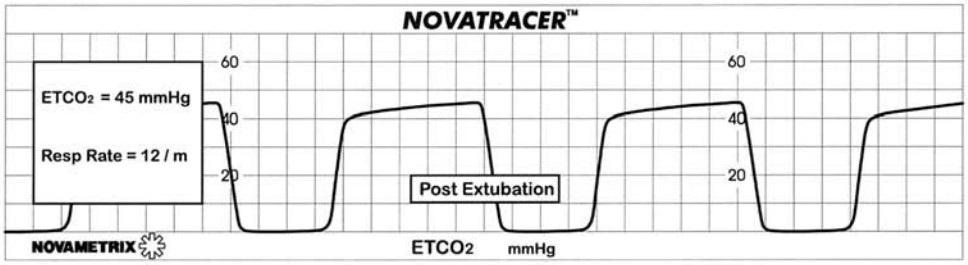
Profile:

A 36 year old female with sepsis was being ventilated in the Medical ICU. A chest x-ray revealed bilateral white-outs consistent with ARDS. During mechanical ventilation in the SIMV mode, the patient's arterial blood gases were pH 7.29, $PaCO_2$ 51 and PaO_2 56. The patient was connected to a capnograph/pulse oximeter with measurements of $ETCO_2$ 35 mmHg and SpO_2 87%. With a $PaCO_2$ of 51 and $ETCO_2$ 35 mmHg, there existed an arterial to end tidal CO_2 gradient of 16 mmHg. The patient was sedated and the mode of ventilation changed from SIMV to Pressure Control Inverse Ratio Ventilation (PCIRV). The patient received a course of IV antibiotics, systemic steroids and diuretic therapy. Approximately one week later, the patient's chest x-ray showed slight improvement and the arterial to end tidal CO_2 gradient had improved to 8 mmHg. Due to the patient's improvement, as indicated by a decrease in the arterial to end tidal gradient, the decision was made to change back to conventional ventilation using the SIMV mode.









Over the next several days the SIMV rate was gradually decreased from 18 to 10. On the fifteenth day after admission, arterial blood gases were: pH 7.35, $PaCO_2$ 48 and PaO_2 92. $ETCO_2$ was 45 mmHg and SpO_2 was 96%, indicating a normal arterial to end tidal CO_2 gradient (2-5 mmHg). A repeat chest x-ray showed significant clearing. The patient was then weaned and extubated.

Discussion:

Capnography allowed the clinician to assess changes in cardiopulmonary status and to objectively validate the degree of ventilation/perfusion mismatch by providing $ETCO_2$ values to compare with arterial blood gases. The normal arterial to end tidal CO_2 gradient is 2-5 mmHg. When this gradient is widened it verifies that significant ventilation/perfusion mismatching is occuring. Improvement in ventilation/perfusion is also verified when this gradient narrows.

"However, there is always a gradient between arterial and end tidal CO_2. The wider the gradient, the greater the ventilation-perfusion mismatch in the lung. Thus capnometry is not only an excellent monitor of breath-to-breath quality of ventilation, but the arterial-to-alveolar CO_2 gradient gives the clinician some sense of wasted ventilation caused by V/Q abnormalities."

Hoyt J., "Mechanical Ventilation: State of the Art," Advances in Anesthesia, Vol. 11, Mosby Yearbook, Inc., 1994.

Case Report:

Utilizing the $PaCO_2$- $P_{ET}CO_2$ gradient to optimize PEEP in a ventilated patient with pneumonia

Profile:

A 72 year old woman with the diagnosis of bacterial pneumonia was admitted to the ICU from a nearby nursing home. Upon admission, the patient had a Respiratory Rate of 40 and Temperature of 39° C. She was receiving 40% oxygen via a face mask and arterial blood gases were: pH 7.20, $PaCO_2$ 65 and PaO_2 58.

The decision was made to intubate and mechanically ventilate the patient. Initial ventilator settings were: SIMV 12/m, V_T 600 ml, PEEP 2 cmH_2O and FiO_2 .5. The patient was connected to a capnograph/pulse oximeter. After 30 minutes arterial blood gases were: pH 7.28, $PaCO_2$ 55 and PaO_2 65. $ETCO_2$ was 38 mmHg and SpO_2 was 85%. Respiratory mechanics measurements demonstrated a decreased compliance of 20 ml/cmH_2O. The judgement was made to treat the patient's hypoxemia by optimizing PEEP (the smallest gradient between arterial and end-tidal carbon dioxide tension ($PaCO_2$-$P_{ET}CO_2$) coincides with the level of PEEP which provides the best oxygenation and least pulmonary shunt).

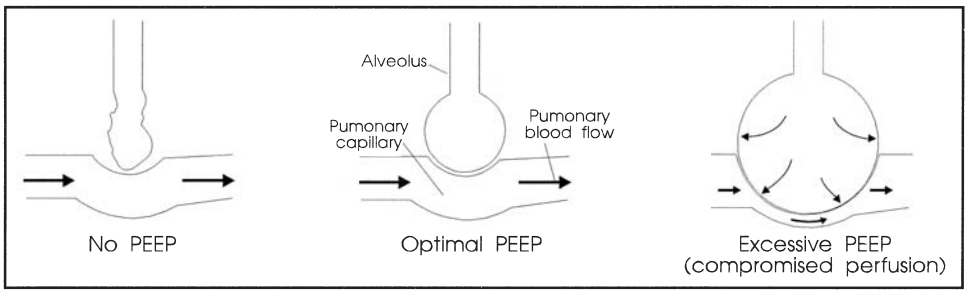
The level of PEEP was increased by 2 cmH_2O increments over the next two hours (allowing 30 minutes stabilization at each level). Arterial blood gases were drawn with $ETCO_2$ and SpO_2 values noted after stabilization at each level. Results were as follows:

PEEP	$PaCO_2$ - $P_{ET}CO_2$	SpO_2
2 cmH_2O	17 mmHg	85%
4 cmH_2O	13 mmHg	87%
6 cmH_2O	10 mmHg	92%
8 cmH_2O	12 mmHg	86%
10 cmH_2O	16 mmHg	84%

The PEEP level was re-adjusted to 6 cmH_2O which resulted in the minimal $PaCO_2$-$P_{ET}CO_2$ gradient. Over the next several days the patient was treated with antibiotics, bronchopulmonary suctioning and continued ventilatory support. On the 10th day following admission she was successfully weaned from mechanical ventilation.

Discussion:

The $PaCO_2$-$P_{ET}CO_2$ gradient provided a non-invasive method to titrate an appropriate level of PEEP. The smallest gradient between arterial and end tidal carbon dioxide tension correlates with the level of PEEP which provides the best oxygenation and the least pulmonary shunt. Application of PEEP above that level produces overdistension of the alveoli causing compromised pulmonary perfusion.



". . . use of the $PaCO_2$-$PetCO_2$ gradient permits the rapid titration of PEEP without the need for a pulmonary artery catheter."

MurrayJ.P., Modell J.H., Gallagher T.J., Banner M.J., "Titration of PEEP by the Arterial Minus End-Tidal Carbon Dioxide Gradient," Chest, 85: 100-4, January 1984.

Case Report:

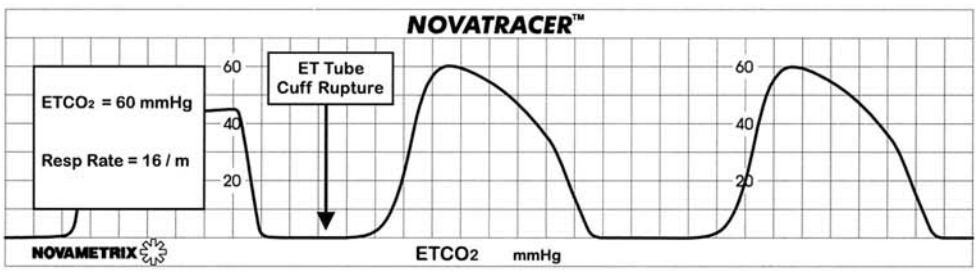
Patient requiring re-intubation following rupture of endotracheal tube cuff

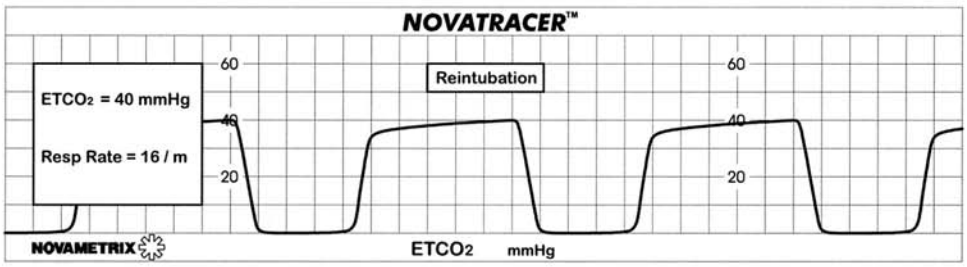
Profile:

A 19 year old female sustained facial fractures and pulmonary contusions in a motor vehicle accident. She subsequently developed ARDS, requiring mechanical ventilation. Initial mechanical ventilator settings were: SIMV 10/m, V_T 800 ml, PEEP 8 cmH_2O and FiO_2 .4. On the fourth day following admission, delivered tidal volume decreased from 800 ml to 550 ml and peak pressure decreased from 50 cmH_2O to 30 cmH_2O. $ETCO_2$ increased from 40 mmHg to 60 mmHg and SpO_2 decreased from 92% to 85%. Auscultation of the patient's neck revealed a significant leak on exhalation. These findings suggested that the ET tube cuff had ruptured and the decision was made to re-intubate the patient.

The patient was hyperoxygenated and re-intubation was attempted. Direct visualization of the cords was obstructed by soft tissue swelling. The decision was made to use capnography to perform a blind nasal intubation, and a capnograph was connected to the proximal end of the ET tube.

The ET tube was introduced into the hypopharynx. CO_2 waveforms became higher and started to plateau as the larynx was approached. When the tip of the ET tube slipped behind the larynx, the capnogram immediately dropped to zero. The tube was pulled back slightly and advanced once more. Entrance of the tube into the trachea was rapidly detected as typical CO_2 waveforms were observed. The re-intubation was successful and the patient was returned to the previous ventilator settings, with $ETCO_2$ 40 mmHg and SpO_2 94%.





Discussion:

When the ET tube was passed into the nasopharynx, the capnogram and $ETCO_2$ values were immediately registered. As the tube was advanced, loss of the CO_2 waveform signified that the ET tube had passed behind the larynx. Only direct visualization and capnography have uniformly confirmed correct endotracheal tube placement in the trachea versus the esophagus.

"Thus capnography facilitates orientation during blind nasotracheal intubation and rapidly detects esophageal intubation."

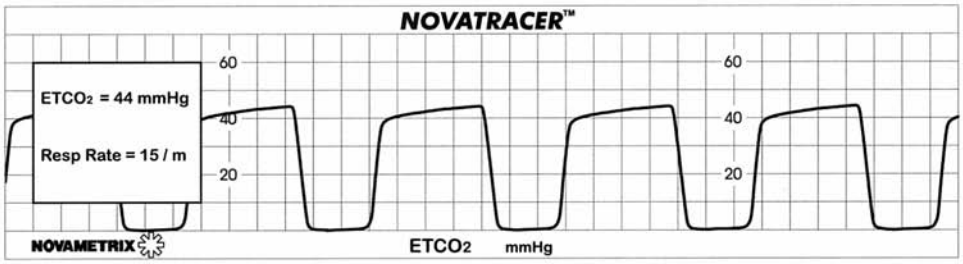
Linko K., Paloheimo M., "Capnography Facilitates Blind Intubation," Acta Anaesthesiol Belg, June 34 (2), 117-22, 1983.

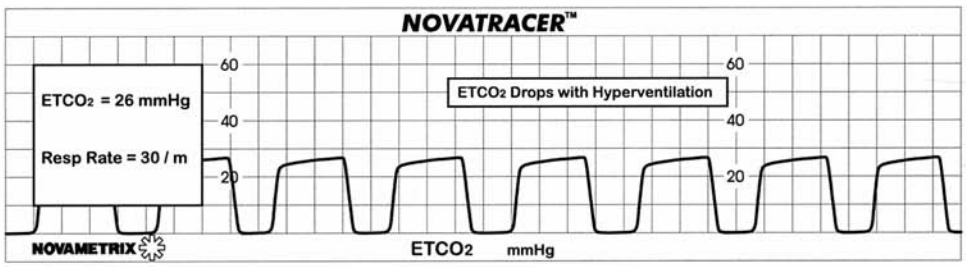
Case Report:

Child in the Pediatric ICU being hyperventilated for head trauma

Profile:

An 11 year old girl was admitted to the Pediatric ICU following a motor vehicle accident. The patient was unconscious and intubated. A CT scan revealed a skull fracture with moderate cerebral edema. The patient was connected to a capnograph showing $ETCO_2$ 44 mmHg and Respiratory Rate 15. The physician ordered an increase of the mechanical ventilator rate to maintain an $ETCO_2$ value between 25-30 mmHg.





Discussion:

The use of capnography provided the clinician with a continuous assessment of the ventilator settings required to maintain a prescribed level of hyperventilation. Because $PaCO_2$ must be maintained in a very narrow range, end tidal CO_2 monitoring is vital in guiding the mechanical hyperventilation of head injured patients.

"Hypocapnic cerebral vasoconstriction induced by mechanical hyperventilation is essential for rapid control of elevated intracranial pressure in patients with severe head injuries. The ability to establish rapidly an appropriate degree of cerebral vasoconstriction in the setting of acute head injury depends on an accurate estimation of the minute ventilation ($\dot{V}$) that will produce a desired $PaCO_2$. End Tidal ($P_{ET}CO_2$) monitoring offers a simple, rapid means of estimating $PaCO_2$."

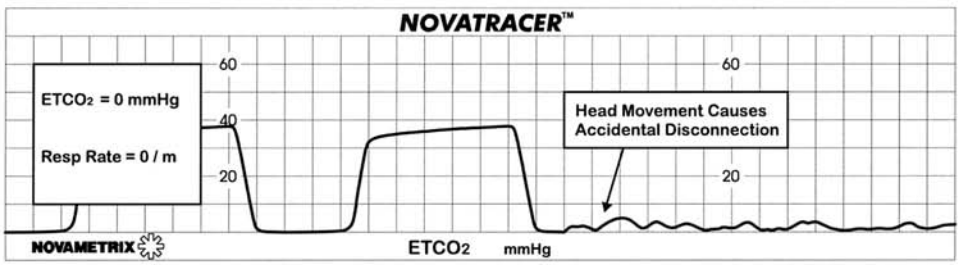
Karagianes T.G., Mackersie R.C., "Use of End Tidal Carbon Dioxide Tension for Monitoring Induced Hypocapnia in Head Injured Patients," Critical Care Medicine, 18:7, 764.

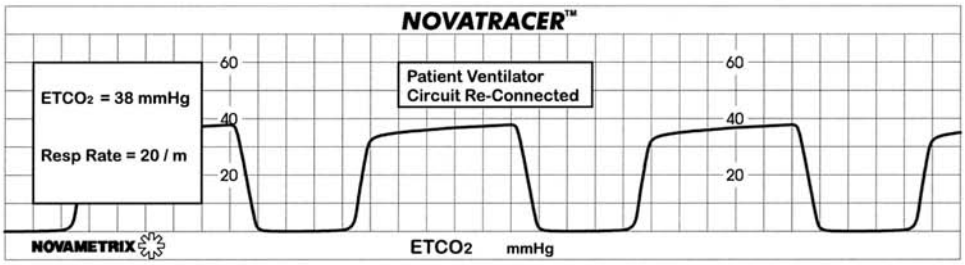
Case Report:

Accidental patient disconnection from mechanical ventilator in the Medical ICU

Profile:

A 43 year old male was admitted to the Medical ICU with a diagnosis of status epilepticus requiring complete sedation with Phenobarbital. The patient required mechanical ventilation for respiratory depression and was subsequently connected to a capnograph/pulse oximeter. During a seizure the patient became accidentally disconnected from the mechanical ventilator; however, no ventilator alarms alerted the clinical staff to this potentially life-threatening situation. During the seizure the ventilator circuit wye settled under the patient, allowing the ventilator to generate enough pressure and volume to satisfy its alarm parameters. The capnograph/pulse oximeter, however, alarmed immediately and displayed a flatline waveform as illustrated below. The respiratory therapist was alerted to the situation, reconnected the patient to the ventilator and the capnogram returned to normal.





Discussion:

Mechanical ventilator alarm systems can be inadvertently defeated and alarm conditions may go undetected. The capnograph/pulse oximeter was a valuable tool in assessing changes in the cardiopulmonary status as well as alerting the clinician to possible mechanical ventilator failures.

"CO_2 analysis in the ventilator circuit can provide a disconnection alarm that is particularly sensitive and responds rapidly."

U.S. Department of Health and Human Services, Public Health Services, Food and Drug Administration, "Increasing Early Detection of Accidental Disconnections.", June 1991.

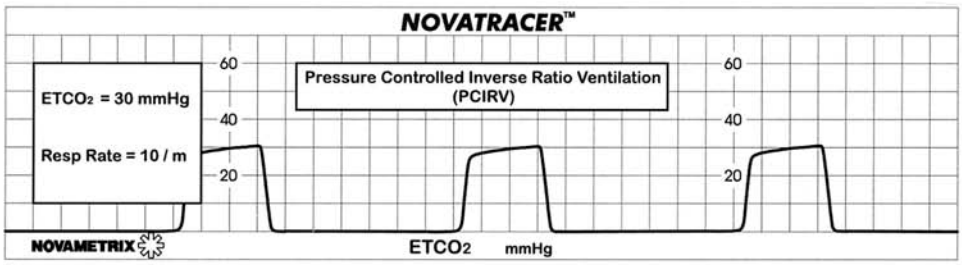
Case Report:

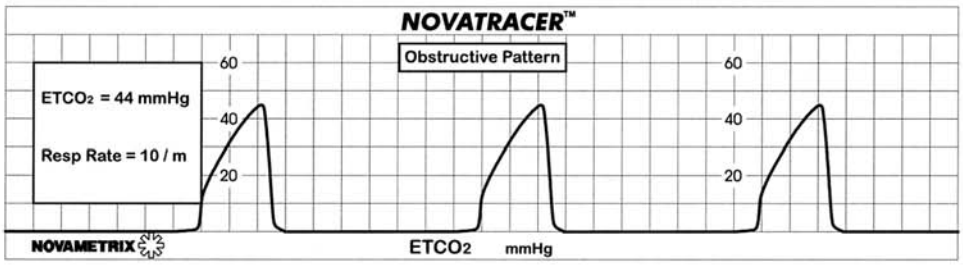
Patient being inadequately ventilated due to a partially obstructed ET tube

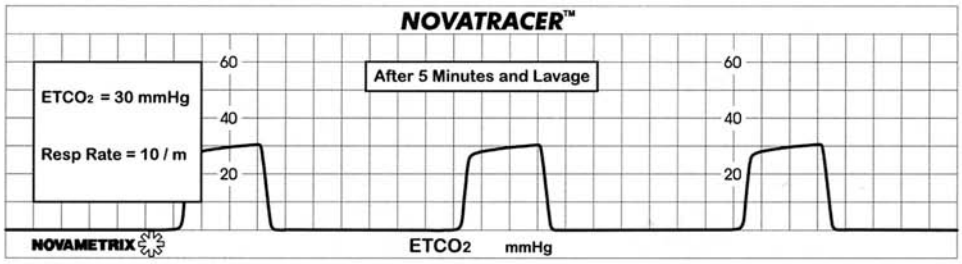
Profile:

A 45 year old male developed ARDS after being admitted to the ICU with pneumococcal pneumonia. Because of extremely high pressures (90 cmH_2O) required to volume ventilate this patient, the decision was made to change ventilation to Pressure Control Inverse Ratio Ventilation (PCIRV). Pressure was set at 45 cmH_2O with 15 cmH_2O PEEP. Inspiratory time was set at 60% and expiratory time at 40%. The patient was sedated and connected to a capnograph/pulse oximeter. Arterial blood gas results were: pH 7.34, $PaCO_2$ 48 and PaO_2 60. $ETCO_2$ was 30 mmHg (indicating a widened $PaCO_2$-$P_{ET}CO_2$ gradient, which is consistent with this disease) and SpO_2 was 87%.

Several hours later, the capnograph/pulse oximeter alarmed with an $ETCO_2$ reading of 44 mmHg. The nurse was alerted to the patient's inadequate ventilation and attempted to suction the patient but discovered that the suction catheter would not advance down the ET tube. The patient was bagged and lavaged with saline and inspissated secretions were suctioned from the tube. The patient was reconnected to the ventilator and with the return of adequate ventilation, the capnograph/pulse oximeter values returned to previous readings.







Discussion:

Over time, the ET tube had become partially occluded with secretions, which resulted in inadequate tidal volumes being delivered to the patient. The capnograph/pulse oximeter alerted the nurse to the inadequate tidal volume delivery and the problem was corrected before the patient decompensated. End Tidal CO_2 monitoring is important during PCIRV because of the possibility of minute-to-minute changes in tidal volume. In addition, capnography provides a higher degree of safety for patients that require sedation and paralyzation for Pressure Control Inverse Ratio Ventilation.

"If end tidal CO_2 is increasing, the clinician must be suspicious that tidal volume and minute volume are decreasing secondary to changes in lung compliance or airway resistance or both."

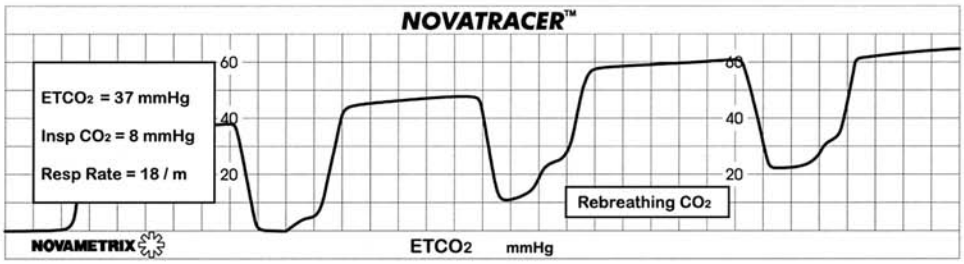
Hoyt J., "Mechanical Ventilation: State of the Art," Advances in Anaesthesia, vol. 11, Mosby Year Book, Inc., 1994.

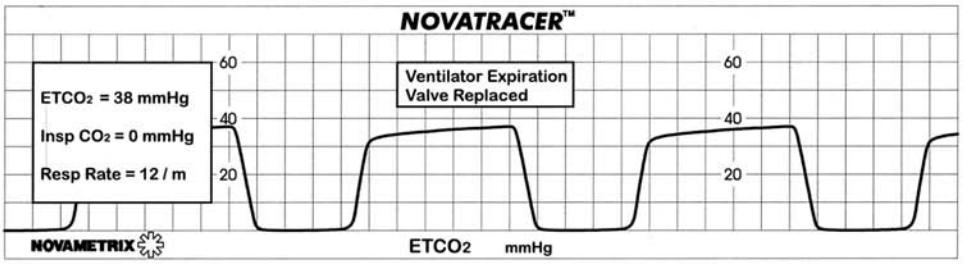
Case Report:

Post-op open heart patient requiring mechanical ventilation in the Surgical ICU

Profile:

A 62 year old man was admitted to the Surgical ICU following coronary artery bypass graft surgery. Upon admission from the Operating Room, the patient was placed on a mechanical ventilator and monitored with a capnograph/pulse oximeter. After 5 minutes of ventilation, the clinician noted a high inspired CO_2 value and a rising baseline of the CO_2 waveform. The clinician was immediately alerted to the fact that the patient was rebreathing CO_2. Upon inspection of the mechanical ventilator, a defective expiratory valve was discovered. The mechanical ventilator expiratory valve was quickly replaced and the CO_2 waveform returned to baseline indicating that normal ventilation had resumed.





Discussion:

Even the most sophisticated mechanical ventilators may experience some degree of mechanical failure. The presence of inspired CO_2 on the capnograph alerted the clinician to the situation. A capnograph/pulse oximeter is an excellent monitoring tool to alert the clinician to unexpected changes in cardiopulmonary status or technical failures during mechanical ventilation.

". . . the PSRV was ruptured, causing loss of gas from the ventilator during both inspiration and exhalation. The ventilatory effect was a reduction of tidal volume, peak airway pressure and minute ventilation, with resulting hypercarbia."

Sommer R.M., Bhalla G.S., Jackson J.M., Cohen M.I., "Hypoventilation Caused by Ventilator Valve Rupture," Anesthesia Analgesia 67: 999-1001, 1988.

Case Report:

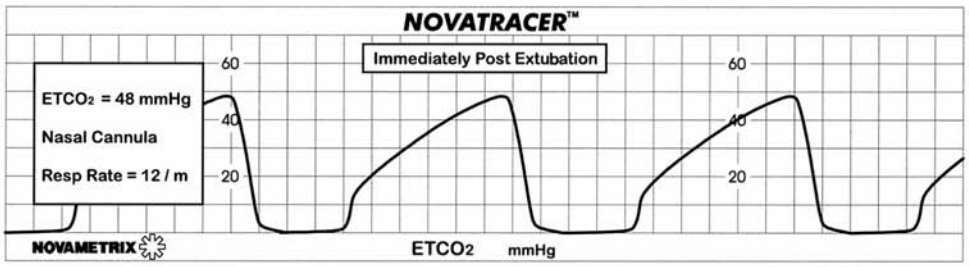
Patient requires re-intubation due to respiratory failure

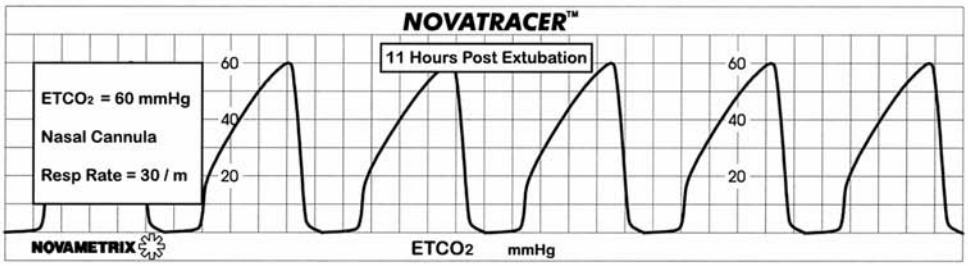
Profile:

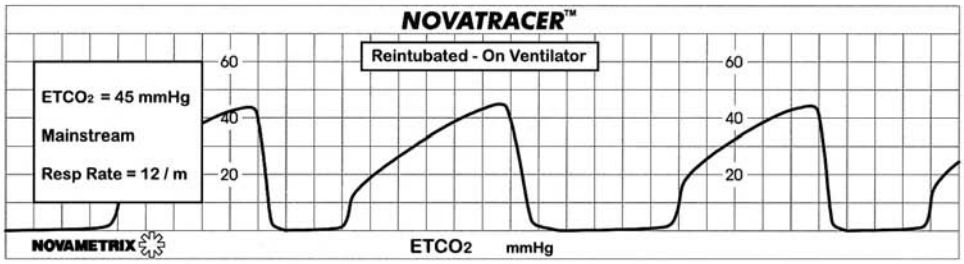
A 58 year old man with chronic lung disease was hospitalized for a bowel resection. Due to his underlying lung disease, he required mechanical ventilation post-operatively. On the 5th day post-op, routine weaning parameters indicated that he was ready to be weaned from mechanical ventilation. Over the next several hours, he was weaned to a T-piece. The T-piece trial was well tolerated, and he was extubated and given 2 lpm oxygen via nasal cannula.

Because of his lung disease, a capnograph/pulse oximeter for continuous monitoring of the adequacy of the patient's oxygenation and ventilation was deemed necessary. The capnograph was connected to the patient using a nasal cannula that was designed to simultaneously deliver oxygen and sample respiratory gases. $ETCO_2$ was 48 mmHg and SpO_2 was 92%. Arterial blood gases were also drawn to establish a baseline gradient. The results were: pH 7.34, $PaCO_2$ 54 and PaO_2 90.

Over the next 6 hours, the patient's Respiratory Rate increased to 20, while $ETCO_2$ and saturation remained constant. By hour 8, Respiratory Rate was 30 and $ETCO_2$ began to rise. By hour 11, Respiratory Rate was 30, $ETCO_2$ was 60 mmHg and SpO_2 decreased to 87%. A diagnosis of weaning failure with imminent respiratory failure resulted in re-intubation for ventilatory support.







Discussion:

Continuous monitoring of oxygenation and ventilation with a capnograph/pulse oximeter allowed the immediate diagnosis of impending respiratory failure, enabling the medical staff to re-intubate the patient in a safer, controlled environment prior to significant clinical deterioration.

"End tidal carbon dioxide measurements correlate well with $PaCO_2$ in non-intubated patients presenting with a variety of underlying problems. Determinations are rapid, inexpensive and non-invasive and may obviate the need for arterial blood gases in selected groups of patients."

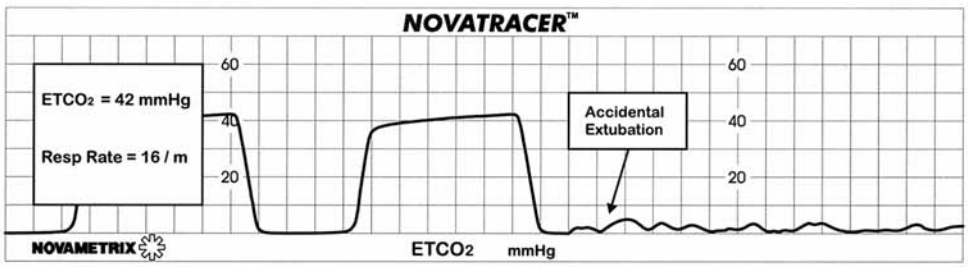
Barton C.W., "Correlation of End Tidal CO_2 Measurements to Arterial $PaCO_2$ in Non-intubated Patients," Annals of Emergency Medicine, 23:3, 562-563, March 1994.

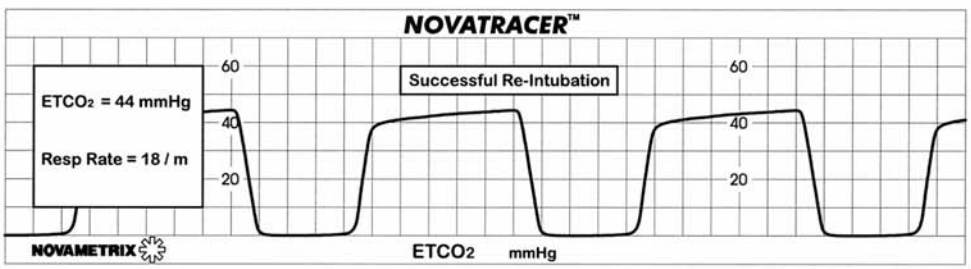
Case Report:

Intubated patient being transported from Surgical ICU to CT Scan Suite

Profile:

A 48 year old male with sepsis following a liver transplant was transported to the Radiology Department for an abdominal CT Scan. The patient was intubated and being ventilated with a hand-resuscitator. Ventilation and oxygenation was continuously monitored with a mainstream capnograph/pulse oximeter. During transport to the CT Scan Suite, the capnograph tracing changed dramatically, the $ETCO_2$ value dropped to zero and the monitor's alarm sounded. Once alerted to this change, the physician checked the airway and found that the endotracheal tube had become dislodged. The endotracheal tube was removed and the patient was rapidly re-intubated. The appearance of a normal capnogram confirmed successful re-intubation.





Discussion:

Use of the CO_2SMO® capnograph/pulse oximeter provided essential ventilation/oxygenation monitoring during the hectic intra-hospital transport. The capnograph provided the physician with an outstanding tool for the assessment of airway patency and ventilation during a time when monitoring respiratory status is often overlooked.

"End Tidal CO_2 monitoring may develop into the standard of care for critically ill patients both in the hospital and during transport. . . The monitor can assist with patient care both during mechanical and manual ventilation procedures and can assist with the verification of endotracheal tube placement."

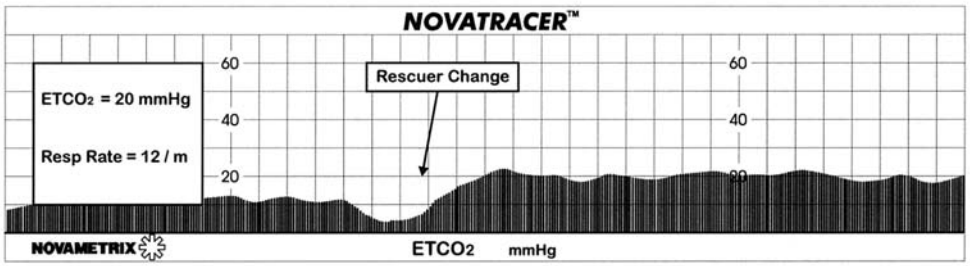
Morris M., "Transport Considerations for the Head-Injured Patient: Are We Contributing to Secondary Injury?," The Journal of Air Medical Transport, 9-13, July 1992.

Case Report:

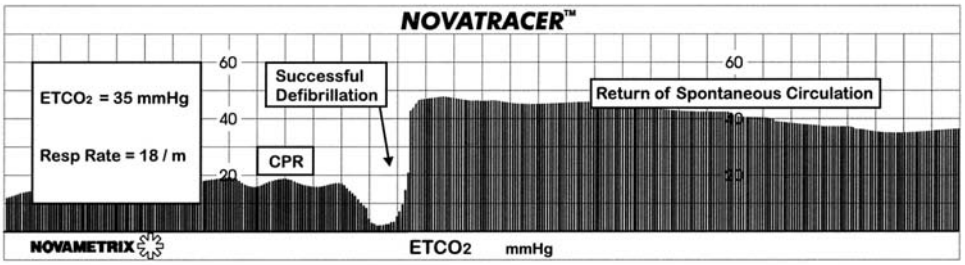
Patient in Cardiac Care Unit receiving CPR

Profile:

A 62 year old man was admitted to the Cardiac Care Unit following an anterior myocardial infarction. Approximately 1 hour after admission the patient became unresponsive and arrested. The patient was intubated and ventilated with a hand resuscitator. EKG tracings showed that the patient was in coarse ventricular fibrillation. The patient was being monitored with a mainstream capnograph which displayed end tidal CO_2 trends over the past several minutes. By viewing the trend screen, it became apparent that $ETCO_2$ values fell as the rescuer performing chest compression became fatigued. Following a rescuer change, the $ETCO_2$ values increased due to more effective chest compressions.



After approximately 18 minutes of CPR, the patient was successfully defibrillated and functional cardiac rhythm was restored. Immediately upon return of spontaneous circulation, there was a dramatic rise in the patient's end tidal CO_2 values.



Discussion:

Continuous monitoring of end tidal CO_2 with the CAPNOGARD® capnograph during cardiac arrest provided a valuable non-invasive measurement of chest compression effectiveness. End tidal CO_2 correlates with cardiac output; as cardiac output falls so does end tidal CO_2. When spontaneous circulation returns, there will be an immediate increase in $ETCO_2$.

" . . . measurement of the end-tidal carbon dioxide concentration may be a practical, non-invasive method for monitoring blood flow generated by precordial compression during cardiopulmonary resuscitation and an almost immediate indicator of successful resuscitation."

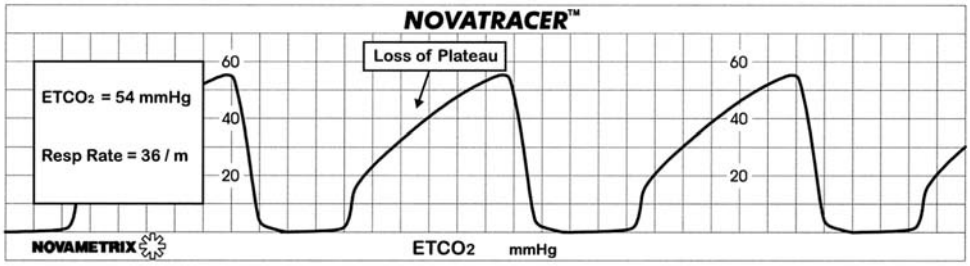
Falk J.L., Rackow E.C., Weil M.H., "End-tidal Carbon Dioxide Concentration During Cardiopulmonary Resuscitation," New England Journal of Medicine, 318(10): 607-11, March 10, 1988.

Case Report:

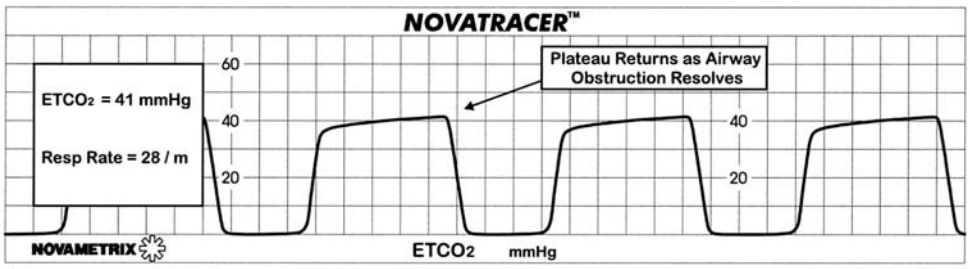
Patient with asthma in acute respiratory distress is admitted to the Medical ICU

Profile:

A 23 year old female was admitted to the Medical ICU from the Emergency Department in severe respiratory distress from asthma. The patient's vital signs were: Heart Rate 134, BP 176/76 and Respiratory Rate 36. Chest auscultation revealed bilateral inspiratory and expiratory wheezing. The patient was connected to a capnograph/pulse oximeter via nasal cannula, with results of $ETCO_2$ 54 mmHg and SpO_2 91%. The capnograph waveform tracing displayed a loss of plateau, which is consistent with significant bronchospasm.



The patient was administered low flow oxygen and an inhaled bronchodilator treatment with an Albuterol Solution (0.5 ml Albuterol in 2 cc N. Saline). Following the bronchodilator therapy, improvement was evident in the patient's capnogram even though no significant change in breath sounds was noted.



The patient was closely monitored via nasal cannula, and 1 hour later the capnogram reverted back to an obstructive pattern with an associated increase in $ETCO_2$. The patient was then administered another Albuterol treatment, with improving air exchange as indicated by the normal capnogram and $ETCO_2$ values.

Discussion:

Use of the CO_2SMO® capnograph/pulse oximeter in the assessment of bronchospasm provided an objective measurement of the severity of the airway obstruction. The capnogram then indicated effective bronchodilator therapy. Capnography has the added benefits of being non-invasive, patient effort independent and measurements can be made during normal tidal breathing.

". . . analysis of the capnogram's shape is a quantitative method for evaluating the severity of bronchospasm. This ability, added to specific advantages (non-invasiveness, effort-independency, measurements during tidal breathing) open new fields of application to capnography, such as measurement of bronchospasm in children. . ."

Smith T.C., Proops D.W., Pearman K., Hutton P., "Nasal Capnography in Children: Automated Analysis Provides a Measure of Obstruction During Sleep," Clinical Otolaryngology, 18:1: 69-71, February 1993.

Glossary of Terms:

ARDS - adult respiratory distress syndrome

CO_2SMO - combined capnograph/pluse oximeter manufactured by Respironics

ET tube - endotracheal tube

$ETCO_2$ - End Tidal CO_2 - the partial pressure of carbon dioxide at the end of expiration (the alveolar plateau), also refered to as $PetCO_2$ or $P_{ET}CO_2$

FiO_2 - the fraction of inspired oxygen

$PaCO_2$ - the partial pressure of carbon dioxide in arterial blood

PCIRV - pressure control inverse ratio ventilation

PCV - pressure control ventilation

PEEP - positive end expiratory pressure

SIMV - synchronized intermittent mandatory ventilation

SpO_2 - the percentage of oxygen saturation in arterial blood, as determined by a pulse oximeter

RESPIRONICS®
www.respironics.com

novametrix™
www.novametrix.com

Customer Service: 1-800-345-6443 or 724-387-4000
Respironics Europe: +33-(0)1-55-60-19-80
Respironics Asia Pacific: +852-234-342-18

BK1006 SB 04/04/03