

REFERENCE MATERIAL

COMPARISON OF THE EFFECTIVENESS AND RELIABILITY OF OXYGEN DELIVERY AND ET_{CO}₂ MONITORING IN 3 ET_{CO}₂ NASAL SAMPLING CANNULAS

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Comparison of the Effectiveness and Reliability of Oxygen Delivery and EtCO₂ Monitoring in 3 EtCO₂ Nasal Sampling Cannulas

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Introduction

Monitoring patients' end-tidal CO₂ (EtCO₂) in various settings throughout the care continuum is the standard of care. While pulse oximetry monitors a patient's oxygenation status, capnography monitors EtCO₂ throughout the breathing cycle. Capnography is an effective method to diagnose early respiratory depression and other airway disorders, leading to a reduction in serious complications. Deitch and associates showed capnography displayed evidence of respiratory depression to hypoxia 60 seconds (range 5 to 240 seconds) before pulse oximetry. (1)

There are a multitude of indications for capnography that include both pre-hospital and various locations within the hospital. While this list is not exhaustive, indications include:

- Monitoring ventilation / respiratory status in ICU, PACU, ER, OR, Endoscopy, and pre-hospital environments
- Confirmation of endotracheal tube placement
- Monitoring patients during pain management, or moderate to deep sedation
- Monitoring the effectiveness of chest compression and return of spontaneous circulation (ROCS)

Importance of Capnography

More than 50 medical societies worldwide have established guidelines and standards for using capnography to monitor the ventilation status of patients undergoing general anesthesia, sedation, or analgesia, and as a method to verify endotracheal tube placement.

Capnography use combined with pulse oximetry was introduced by the American Society of Anesthesiologists (ASA) in the mid-1980s, based on a review of adverse events that indicated capnography together with pulse oximetry could have prevented 93% of anesthesia mishaps that contributed to anesthetic morbidity and mortality. According to the ASA Standards of Basic Anesthetic Monitoring, "During moderate or deep sedation the adequacy of ventilation shall be evaluated by continual observation of qualitative clinical signs and monitoring for the presence of exhaled carbon dioxide unless precluded or invalidated by the nature of the patient, procedure or equipment" (2)

The AAGBI (Association of Anesthetists of Great Britain and Ireland) (Association of Anesthetists of Great Britain and Ireland)) 2021 Guidelines state, "General anesthesia requires minimum monitoring of ECG, SpO₂, NIBP, and capnography, which should be checked for correct function and begun before induction of

anesthesia and continue throughout anesthesia, transfer to the post-anesthesia care unit (PACU) and recovery."(3) Continuous EtCO₂ can be used to monitor patients recovering from surgery to detect hypoventilation. One study showed continuous EtCO₂ was 6 times more effective than pulse oximetry at detecting respiratory depression (4). The sensitivity of capnometry to detect respiratory events is superior to that of clinical examination findings or pulse oximetry. During the transfer between the operating room and PACU, PEtCO₂ monitoring allows early detection of hypoventilation and residual sedation, especially by respiratory rate measurements. The use of capnography in the PACU by trained nurses led to the recognition of earlier airway obstruction and the reduction of these complications. (5) The most common respiratory adverse events detected by capnography included hypocapnia, apnea, tachypnea, bradypnea, and hypoxemia. These data indicate that respiratory adverse events are frequent in the PACU and that the addition of capnography to pulse oximetry monitoring, including utilization of integrated pulmonary index (IPI), gives potentially clinically useful information on the respiratory status. (6)

For patients having endoscopic procedures, the ASA issued a statement: "Monitoring for exhaled carbon dioxide should be conducted during endoscopic procedures in which sedation is provided with propofol alone or in combination with opioids and/or benzodiazepines, and especially during procedures on the upper gastrointestinal tract. Careful attention to airway management must be provided during complex upper endoscopic procedures and procedures performed in the prone position where ventilatory monitoring, airway maintenance, and resuscitation may be especially difficult" (7)

Regarding sedation in the Emergency Department, there is an update to the guideline from 2018, Clinical Practice Guideline for Emergency Department Procedural Sedation with Propofol: 2018 Update; "Monitoring: Continuous cardiac monitoring, capnography, and pulse oximetry required for deep sedation, with respiratory rate and blood pressure recorded at least every 5 min. Supplemental oxygen is recommended for both adult and pediatric patients undergoing propofol sedation". (8)

The American Society of Interventional Pain Physicians (ASIPP) Guidelines for Sedation and Fasting Status of Patients Undergoing Interventional Pain Management Procedures (2019) adopted the ASA-published standards for monitoring patients under sedation, regardless of location or setting of the procedure. These standards include blood pressure monitoring, assessment of real-time EKG, temperature measurement, pulse oximetry, and continuous quantitative EtCO₂. The omission of end-tidal CO₂ monitoring can significantly delay the identification of hypoventilation and appropriate airway support, and result in catastrophic complications including anoxic brain injury and even death. Supplemental oxygen by nasal cannula is also recommended, particularly for deep sedation. (9) An observational study detected one or more opioid-

induced respiratory depression episodes in 614 (46%) of 1335 patents on the general care floor. The authors concluded that a tool for respiratory depression risk assessment and continuous monitoring with capnography and oximetry of patents identified as high risk for respiratory depression may improve their safety when parenteral opioid analgesia cannot be avoided (10). During hyperventilation, capnography values change instantaneously giving clinicians an immediate warning of the patient's declining respiratory status. An enhanced monitoring program with capnography is an effective intervention to reduce transfers of surgical spine patents to the ICU due to opioid-induced respiratory depression. (11)

Importance of Oxygen (O₂) delivery

When monitoring EtCO₂ utilizing a cannula that monitors EtCO₂ as well as delivers oxygen, there are several parameters to be considered. Obviously, one is end tidal CO₂ and another oxygen saturation (SpO₂). Since these patents are typically receiving analgesics or have comorbidities, the ability to deliver adequate oxygen cannot be overstated.

Guidelines regarding monitoring of exhaled CO₂, also recommend delivery of supplemental O₂. In the study by Kuroe et al, (12) the incidence of respiratory compromise was 5.9 % in elderly patents and 9.0 % in obese patents, with the most frequent cause being hypoxemia. Therefore, it is paramount to utilize a sampling cannula that not only effectively monitors exhaled carbon dioxide, but also adequately delivers oxygen.

In a previous study by Ebert (13) different nasal cannula designs were tested for oxygen delivery and monitoring of EtCO₂. The study evaluated the Hudson Softec Bi Flo #1845, Medline Mac -Safe HCW #4561, Oridion Micro stream Filter Line #006912, and the Salter Labs #4707 at flow rates of 1 LPM, 2 LPM, and 4 LPM. The author concluded that for oxygen delivery, the multi-vented, blow-by facepiece design resulted in lower O₂ delivery at higher flow rates. The divided nasal cannula design (Salter Labs) consistently achieved higher pharyngeal O₂ percentages. Improved O₂ delivery is highly beneficial during moderated sedation or when needing to deliver high FiO₂ to maintain oxygen saturation.

Study Design and Protocol

There are many studies evaluating the efficacy of nasal sampling cannulas to monitor EtCO₂. Hypoxemia is the most frequent cause of respiratory compromise; therefore, the purpose of this study was to compare the EtCO₂ accuracy and oxygen delivery of 3 EtCO₂ / O₂ nasal sampling cannulas with a single sidestream bedside capnography monitor. Three EtCO₂ / O₂ nasal cannulas design with a reflective end connector (SunMed VentFlo #5107F-SE, Medtronic Microstream Advance #MVANO and Salter STAT 4MSF3-7-6)

were tested at 3 different O₂ flowrates, 1LPM, 2LPM, and 4 LPM. In addition, the rise Anne was evaluated as that can impact how well EtCO₂ is monitored at higher minute ventilation. study outcomes were (1) FiO₂ delivery at a variety of O₂ flows, (2) EtCO₂ sampling accuracy at a variety of O₂ flows, and (3) rise time at a variety of O₂ flows.

The test procedure used an oxygen source to deliver O₂ to the simulated patient and a known baseline EtCO₂ level of 38 mmHg. Test samples included 3 cannulas of each design (n=9). Readings were taken after allowing the system to equilibrate for 3 minutes at each flow rate setting, then a full inhalation exhalation waveform to determine the EtCO₂ and FiO₂ measurements. The waveform was used to determine the rise time, defined as the amount of time it takes the measured CO₂ to rise from 10% to 90% of the known EtCO₂ value. For accurate EtCO₂ measurements, the CO₂ transducer needs to respond quickly to a change in the level of CO₂.

Results

The data obtained were analyzed by using the Excel program. All data were reported as mean + SD. Descriptive data are presented as the median, frequency, and percentage. Statistical analyses were performed using ANOVA.

There was no significant difference in the FiO₂ delivered at flow rates of 1 LPM and 2LPM. The VentFlo and SalterSTAT had significantly higher FiO₂ at 4 LPM (Figure 1 & Table 1). At the flow rates of 1 LPM and 2 LPM, there was no significant change in the EtCO₂ value. The Medtronic Advance EtCO₂ value was the least affected by increasing the flow rate to 4 LPM. With the increase to 4LPM, the VentFIO EtCO₂ mean value dropped from 36.3 to 35.0. The SalterSTAT EtCO₂ value dropped from a mean of 37.6 to 34.4 (Figure 2 and Table 2). There was no significant difference in the rise time between the 3 cannulas at the varying flow rates (Figure 3 and Table 3).

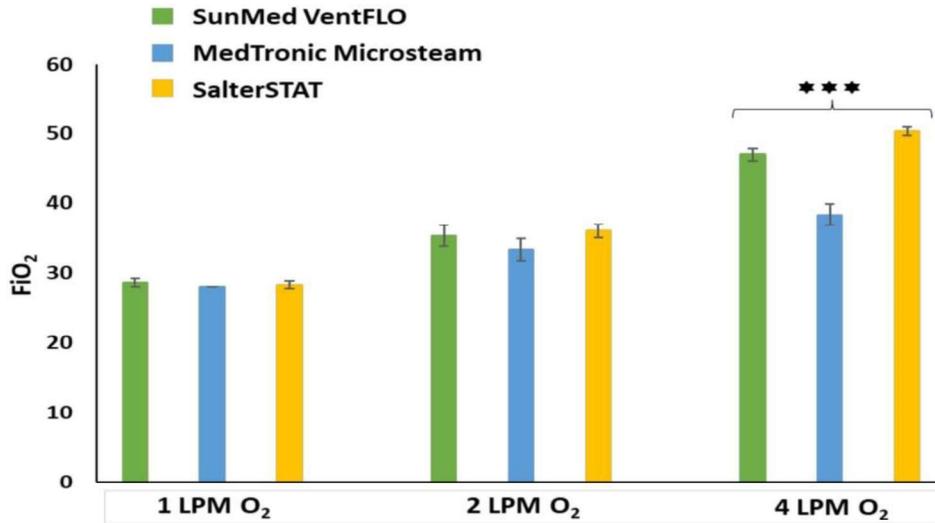


Figure 1- Indicated FiO_2 at varying flows of O_2 ; data show significant differences; ANOVA: $P \leq 0.001$ (***)

Cannula	Oxygen Flow=1 l/min FiO_2 %	Oxygen Flow=2 l/min FiO_2 %	Oxygen Flow=4 l/min FiO_2 %
VentFLO	28.67 ± 0.58	35.33 ± 1.53	47.00 ± 1.00
Microstream Advance	28.00 ± 0.00	33.33 ± 1.53	38.33 ± 1.53
SalterSTAT	28.33 ± 0.58	36.00 ± 1.00	50.33 ± 0.58

Table 01: Indicated FiO_2 at varying flows O_2

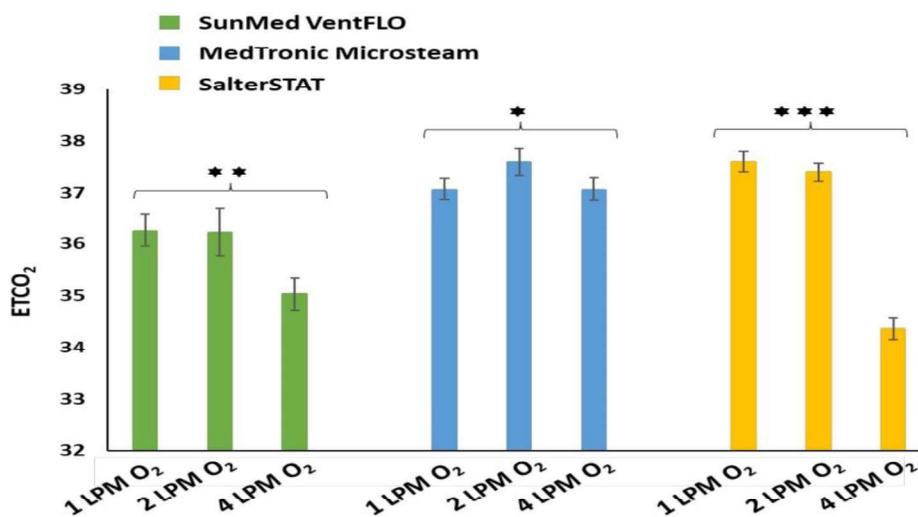


Figure 2- Indicated $ETCO_2$ (mm hg) at varying flows of O_2 ; data show significant differences; ANOVA: $P \leq 0.05$ (*), $P \leq 0.01$ (**), $P \leq 0.001$ (***)

Cannula	Oxygen Flow=1 l/min H ₂ CO ₂	Oxygen Flow=2 l/min H ₂ CO ₂	Oxygen Flow=4 l/min H ₂ CO ₂
VentFLO	36.27 ± 0.31	36.23 ± 0.46	35.00 ± 0.31
Microstream Advance	37.07 ± 0.21	37.60 ± 0.26	37.07 ± 0.23
SalterSTAT	37.60 ± 0.20	37.40 ± 0.17	34.37 ± 0.21

Table 02: Indicated EtCO₂ (mm hg) at varying flows of O₂

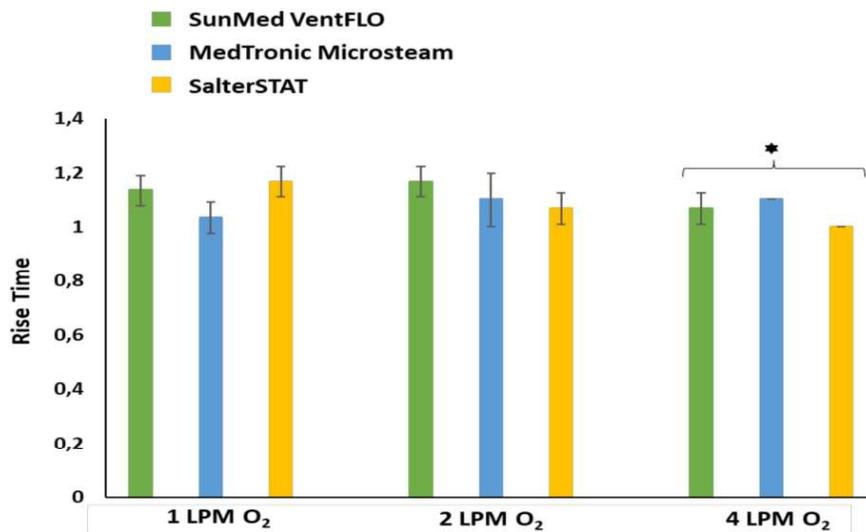


Figure 3- Indicated Rise Time, in seconds, at varying flows of O₂; data show significant differences; ANOVA: P ≤ 0.05 (*).

	Oxygen Flow=1l/min Second	Oxygen Flow=2l/min Second	Oxygen Flow=4 l/min Second
VentFLO	1.13 ± 0.06	1.17 ± 0.06	1.07 ± 0.06
Microstream Advance	1.03 ± 0.06	1.10 ± 0.10	1.10 ± 0.10
SalterSTAT	1.17 ± 0.06	1.07 ± 0.06	1.00 ± 0.00

Table 03: Indicated Rise time, in seconds, at varying flows of O₂

Discussion

Supplemental oxygen is frequently used in procedural sedation and pain management. The ability to deliver oxygen and monitor EtCO₂ has been shown to improve patient safety. Corbett evaluated the impact of capnography on the safety of procedural sedation. The primary endpoint was defined as the total incidence of respiratory and cardiac adverse events. Supplementary oxygen was used in 62% (n=864) of the procedures. Respiratory adverse events were defined as oxygen desaturation (75-90%) for < 60 seconds, and severe oxygen desaturation (<75 at any time). After implementing capnography, the incidence of adverse events dropped 43.2% (p<0.05). 147 adverse events occurred during 666 procedures without capnography compared with 93 adverse events that occurred during 735 procedures with capnography. (15) The SalterSTAT divided cannula delivered significantly higher FiO₂ at 4 LPM, which could make a difference in a respiratory-comprised patient. (12)

If the patient has a normal respiratory function, the difference between EtCO₂ and PaCO₂ (partial pressure of CO₂) is 2 mmHg to 5 mmHg, and usually, the PaCO₂ is greater than the EtCO₂ value. However, the PaCO₂: EtCO₂ gradient increases in situations such as decreased lung perfusion, pulmonary embolism, dead space ventilation, and cardiac arrest. Even if the PaCO₂ : EtCO₂ gradient is wide, the EtCO₂ value can be used as a trending tool to monitor and alert clinicians of changes in the patient's ventilation status.

The SalterSTAT cannula has a divided facepiece, oxygen is delivered to one nare and CO₂ is sampled from the other nare. The Medtronic Advance and VentFlo deliver O₂ cloud outside the nares via small holes in the facepiece, while the 2 nasal prongs are used to sample CO₂. Similar to Ebert's (13) findings, the "blow-by" design had less impact on the EtCO₂ value as O₂ flow was increased. In this study, increasing the flow from 1 LPM to 2 LPM did not have a significant impact on the EtCO₂ value for all 3 cannulas. When the flow was increased to 4 LPM, the Microstream Advance and VentFlo cannulas had the most stable EtCO₂ values (37.60 ± 0.26 to 37.07 ± 0.23 and 36.27 ± 0.31 to 35.0 ± 0.31, respectively). The SalterSTAT EtCO₂ value dropped (37.60 ± 0.20 to 34.37 ± 0.21), although this was statistically significant, it is not considered clinically significant.

The CO₂ analyzer's response time, which includes the transit time and the rise time, must be sufficiently fast for accuracy. Rise time is defined as the time required to change from 10 % to 90 % of the final EtCO₂ value (Figure 1) (16) When the respiratory rate is high, faster rise times are recommended for accuracy. The rise time between the 3 cannulas was similar at all flow rate.

Study Limitation

This study has certain limitations. The first of these is that a bench trial does not capture the various clinical conditions that can impact the EtCO₂ value and waveform. Multiple factors can affect FiO₂, delivery and EtCO₂ values, specifically mouth breathing, nasal anatomy, tidal volume, and respiratory rate. These factors, in addition to V/Q mismatches and oxygen flow rate, have a direct impact on EtCO₂, values. The second is that only nasal EtCO₂, sampling was evaluated. EtCO₂ cannula with oral and nasal sampling have different results, especially simulating mouth breathing. Another limitation is that bench study was based on normal simulated breathing. Additional studies simulating different breathing patterns and disease states may have an impact on the results. A limited number of cannulas tested, and data points is another limitation of the study. Additional clinical trials on human subjects are recommended.

All three cannulas designed and studied had an adequate rise time and provided EtCO₂ monitoring that would alert clinicians to a decline in ventilation. The key difference in this study is the ability to deliver a higher FiO₂, at 4 LPM. According to Kuroe et al (5), hypoxemia is the most frequent respiratory compromise. In this clinical situation efficiency of O₂ delivery could make a difference.

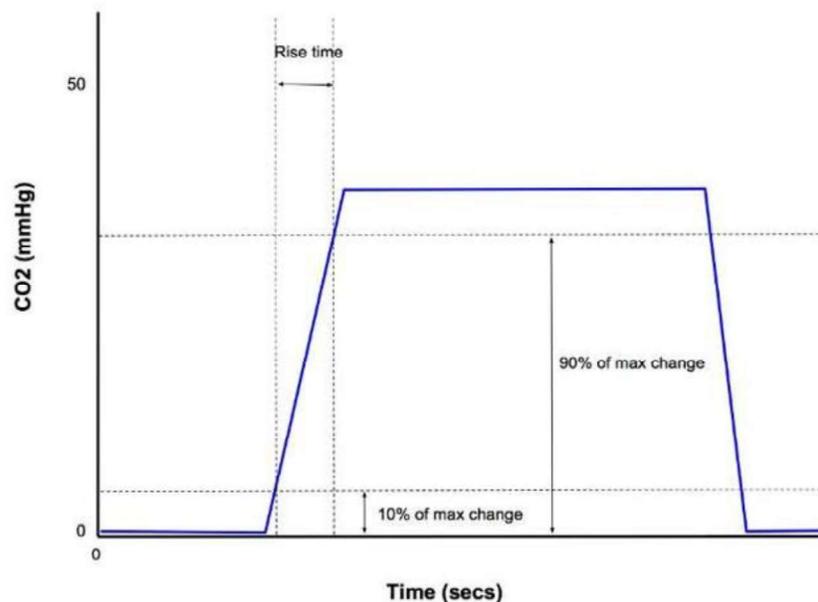


Figure 4. Rise time

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