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ORIGINAL RESEARCH

Ventilation monitoring during moderate sedation in GI patients

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Abstract Sedation in locations outside the operating room (OR) is common. Guidelines for safe patient monitoring have been updated by the American Society of Anesthesiology to include monitoring of ventilation and/or carbon dioxide (CO_2). Although technologies exist to monitor these variables, the quality and/or availability of these measurements in non-OR settings is not optimal. This quality improvement project assessed the value of impedance technology for monitoring minute ventilation (MV) compared to standard end-tidal monitoring of CO_2 ($ETCO_2$). Patients undergoing GI exams with moderate sedation provided by anesthesia providers were monitored for MV with a respiratory volume monitor (ExSpiron 1Xi, Respiratory Motion, Waltham, MA) and $ETCO_2$ via nasal cannula (NC). Calibration and baseline data were collected prior to sedation. Continuous MV and $ETCO_2$ data were collected and averaged, providing minute values after sedation medications throughout the procedure. Stable periods of reduced MV were averaged and used in comparison to $ETCO_2$. Data from 20 patients were evaluated. After sedation, the expected decrease in MV after sedation was observed in 18 of 20 patients (average −47.82 %), while an increase in $ETCO_2$ was observed in just 10 of 20 patients (average −5.17 mm Hg). The correlation coefficient between changes in MV and $ETCO_2$ in response to sedation administration was positive and not significant, $r = 0.223$. Ventilation monitoring may provide an element of safety for earlier and more reliable detection of reduced ventilation compared to a surrogate for hypoventilation, $ETCO_2$, in patients undergoing sedation for GI procedures outside of the OR.

Keywords End-tidal CO_2 · Minute ventilation · Conscious sedation · Monitored anesthesia care

1 Introduction

The American Society of Anesthesiology (ASA) has been a leader in setting practice standards for the provision of safe patient care during sedation and anesthesia, including standards for patient monitoring (electrocardiogram, blood pressure, pulse oximetry, temperature) during anesthesia care. These standards were updated in July 2011 to specifically enhance patient safety during sedation [1]. More and more minimally invasive procedures requiring sedation are being performed outside the operating room (OR) environment, with non-anesthesia personnel providing sedation for portions of these procedures. The ASA amendment states [1]:

> 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.

This new requirement has been challenging in practice because detecting exhaled carbon dioxide (CO_2) typically requires a nasal cannula (NC) device, continuous sampling

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during breathing, and sophisticated gas analysis. We have recently reported on some of the limitations inherent to nasal cannula monitoring of CO_2, including cannula positioning and design [2]. End-tidal CO_2 ($ETCO_2$) sensing is especially difficult during sedation in the gastroenterology (GI) clinic, where patient movement and scope placement may interfere with maintaining proper placement of the nasal prongs for breath detection.

The intent of the ASA guideline is to confirm the patient is ventilating adequately. $ETCO_2$ detection can reveal whether a breath has been taken if the nasal prongs are correctly positioned, but does not reveal whether the breath was small or large. Thus, $ETCO_2$ detection cannot inform the provider about hypoventilation unless the nasal prongs are precisely positioned and an appropriate rise in $ETCO_2$ is noted.

In this quality improvement (QI) project, we evaluated an alternative method to monitor ventilation, independent of CO_2. This was done with a non-invasive, thoracic impedance-based, respiratory volume monitor [3, 4]. Changes in impedance associated with airflow in the lungs are detected and minute ventilation (MV) is derived. Although this device does not meet precisely the requirements of the ASA amendment because it does not expressly measure $ETCO_2$, it certainly meets the spirit of this new safety guideline. The efficacy of this monitor for detecting ventilation during moderate sedation was evaluated in the GI clinic on patients undergoing moderate sedation for colonoscopy or esophagogastroduodenoscopy examinations. This project did not attempt to correlate $PaCO_2$ or "true $ETCO_2$" to nasal cannulae or MV devices; rather, it determined if the non-invasive devices provided directionally expected decreases in MV and increases in $ETCO_2$ during sedation.

2 Methods

Patients at the Zablocki VA Medical Center in Milwaukee, Wisconsin, scheduled for GI procedures with anticipated MAC anesthesia (monitored anesthesia care) were monitored for ventilation with a respiratory volume monitor and carbon dioxide via a nasal cannula. These data were gathered as part of a QI Project, and for this type of study, formal consent is not required, although all patients provided their consent for the procedures they were undergoing as part of their clinical care.

The ExSpiron 1Xi (Respiratory Motion, Waltham MA) was used to collect MV. The non-invasive RVM (respiratory volume monitor) is based on thoracic electrical impedance. It has been shown to accurately monitor respiratory status in non-intubated patients, providing a real-time respiratory curve and measurements of MV, tidal volume (TV), and respiratory rate (RR) [3, 4]. Simultaneous measurements of MV, TV, and RR with the RVM and a Wright monitoring spirometer demonstrated a precision error of 7.2 and 7.1 % for MV and TV, and an accuracy error of 9.3 and 9.0 %, respectively. Throughout the range of four to 40 breaths per min (bpm), and during erratic breathing, RVM measurements were highly correlated with measurements made with a Morgan diagnostic spirometer ($r = 0.96$, 95 % CI 0.93–0.99) [3]. The ExSpiron system consists of two main components, a monitor and an electrode PadSet, which utilize three adhesive electrode patches placed on the thorax, similar to ECG monitoring electrodes [4]. The adhesive electrode array remains in place during patient movement from supine to lateral decubitus position.

Monitoring and recording of $ETCO_2$ from the nasal cannula and MV from the impedance device occurred prior to and during sedation, throughout the GI procedure. Simultaneous comparisons were made on 20 patients receiving sedation. Anesthesia personnel did not intervene with the nasal cannula or PadSet electrodes after initial placement and patient positioning. The ExSpiron monitor was calibrated in the "Quick View" setting using patient height and weight and a 30 s data collection of MV, TV, and RR. Using the "Quick View" mode allows the operator to skip the "Calibration" step and receive relative measurements for MV and TV as a fraction of the "Baseline" MV and TV measurements observed during the initialization of "Quick View." This mode does not involve a "Calibration" per se and as such has no impact on the RVMs calibration or performance.

Upon arrival in the procedure room, $ETCO_2$ was recorded from a nasal cannula with dual nasal prongs. Both $ETCO_2$ and MV data were averaged into minute intervals during the pre- and post-sedation throughout the GI procedure.

2.1 Statistical analysis

For each patient, the average baseline MV and CO_2 measurements were derived from data acquired just prior to initiation of sedation medications. Patient movement affected the quality of MV and $ETCO_2$ recordings. For comparative analysis, individual data were visually examined offline and 1-min epochs of MV and CO_2 data were averaged during 4–5 min of stable recordings after the administration of sedation drugs. The change (delta) between sedation and baseline was calculated for each patient, and a correlation between these delta values of $ETCO_2$ and MV was calculated in relation to this period of sedation administration.

3 Results

The 20 patients analyzed were male with an average age of 65 ± 9 years (mean ± SD; range 49–84), height of 177 ± 6 cm (mean ± SD; range 165–188), and weight of

92 ± 18 kg (mean ± SD; range 61–128). Seven were smokers, and eight had sleep apnea. Figure 1 depicts the average changes in MV and $ETCO_2$ during stable periods after sedation for each of the patients in the study. The group average shows a decrease in MV by −50.6 ± 32.0 % (mean ± SD; range, +32 % to −103 %) and an average decrease in $ETCO_2$ of −1.8 ± 6.5 mm Hg (mean ± SD; range +6 mm Hg to −16 mm Hg) (Fig. 2). Over the 20 sedation periods evaluated, the anticipated decrease in MV occurred in 90 % of the patients (18 of 20), while the anticipated increase in $ETCO_2$ occurred in only 50 % of the patients (10 of 20; 1 patient had no change) after sedation administration. A correlation between the change in MV and the change in $ETCO_2$ produced an r = +0.223, and was not significant.

Figures 3 and 4 are included to illustrate the potential inconsistencies in the nasal cannula measurement of the response of $ETCO_2$ to a MV change caused by sedation. Figure 3 displays the expected response of $ETCO_2$ to a change in MV, with the two parameters going in opposite directions, and Fig. 4, the unexpected response of $ETCO_2$ to an expected change in MV, with the two parameters directionally similar.

4 Discussion

This QI evaluation examined the potential value of ventilation monitoring with an impedance-based monitor in patients receiving sedation for GI procedures, knowing the limitations of nasal cannula detection of expired CO_2 to monitor respiratory function [2]. Impedance-based ventilation monitoring provided a rapid and more reliable

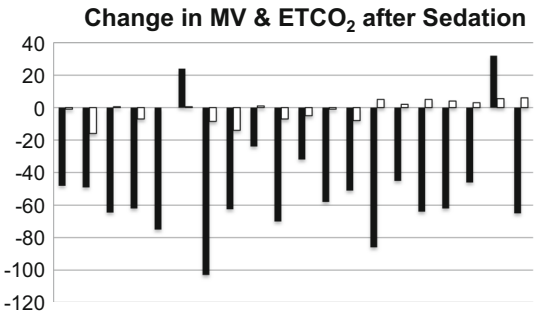

Fig. 1 Individual responses. This figure depicts the paired change in MV and CO_2 for each of the 20 patients after administration of sedation medications. Each pair of *red* and *blue bars* represents a single patient. The *red bar* represents the change in MV calculated as the difference between the average MV before and after sedation administration. The *blue bar* represents the change in $ETCO_2$ calculated as the difference between the average $ETCO_2$ before and after sedation administration. In the majority of cases, MV decreases as expected following sedation. The expected increase in CO_2 is much less consistently seen

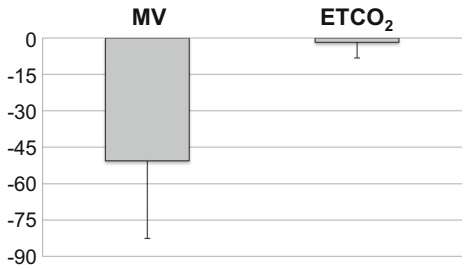

Fig. 2 Overall averages of post-sedation change in MV and CO_2. The average change in MV was −50.6 (−47.8 %), accompanied by a small average decrease in $ETCO_2$ (−1.8; −5.2 %)

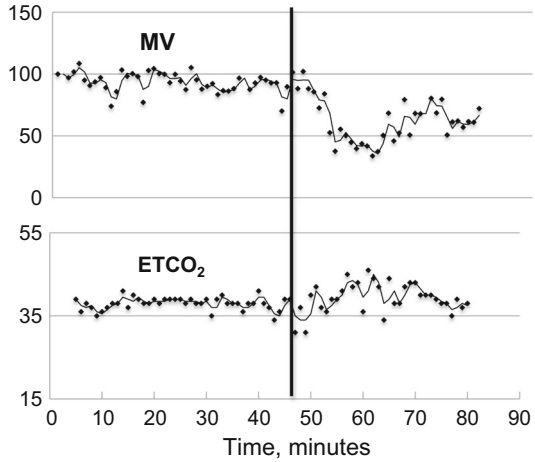

Fig. 3 Minute-to-minute data of the response to sedation administration. The *vertical bar* at minute 43 represents the time of the first sedation administration. The two *graphs* demonstrate an approximate 50 % decrease of MV accompanied by no change to a slight increase in CO_2 for a patient undergoing sedation

assessment of decreased ventilation from sedation than did $ETCO_2$ monitoring from a dual prong, CO_2 sensing, nasal cannula.

Sedation of patients in the GI suite is commonplace, but confirming the adequacy of ventilation can be challenging due to patient positioning and the necessity of maintaining nasal cannula positioning. Adequacy of ventilation can be monitored crudely by direct observation of abdominal and chest wall motion and by several surrogates for ventilation, e.g., pulse oximetry and $ETCO_2$. Decreases in oxygenation are typically not time sensitive measures due to existing reserves of lung oxygen referred to as functional residual capacity (FRC), and occasionally due to the passive exchange of oxygen from an open conduit between the nasal prongs and lungs. More rapid detection of apnea would be a safer approach to ventilation monitoring during sedation because of the rapid increase in $ETCO_2$ that occurs during apnea, averaging 3–5 mm Hg per min, and the subsequent untoward effects of hypercarbia on sedation and blood pressure. But the most important value of

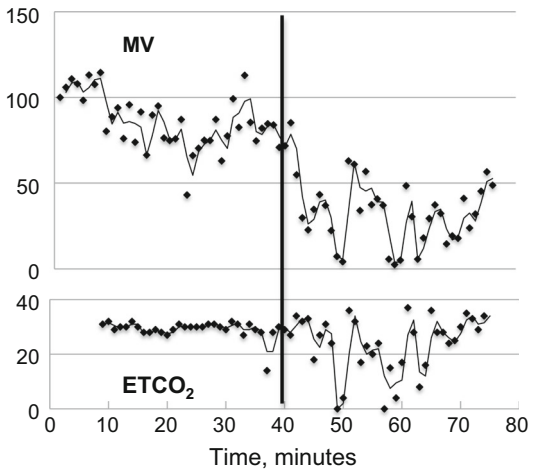

Fig. 4 Minute-to-minute data of an aberrant response to sedation administration. The *vertical bar* at minute 35 represents the time of the first sedation administration. Comparison of the MV and CO_2 graphs (*top* and *bottom*) suggests that while MV accurately depicts a decrease in ventilation after sedation, the CO_2 data were highly variable, and tended to trend down

monitoring for hypercarbia is the underlying hypoventilation that is driving the change, ultimately leading to poor oxygenation of patients. Early interventions to alleviate hypoventilation may be most important in patients with the least physiologic reserve, often referred to as the frail patient.

While in the ideal setting capnography can provide very early information on the adequacy of ventilation, these results are not reliable. In fact, a recent study has indicated that capnography had no statistically relevant effect on the incidence of hypoxemia during propofol sedation [5]. However, the use of capnography clearly can be helpful in the right setting. For example, its use during pediatric sedation in an ER setting resulted in fewer, but more timely interventions, translating to fewer episodes of hypoventilation and oxygen desaturation [6]. Notably, NC devices can be less reliable at detecting $ETCO_2$ because of NC design, positioning, depth of breathing, dilution, and obstruction of the nasal passages [2].

In the GI lab, a particular challenge with conventional $ETCO_2$ monitoring exists during sedation for upper GI procedures. The impedance-based ventilation monitor has been assessed in this setting and was more reliable at detecting poor ventilation than respiratory rate monitoring from a nasal cannula [7]. In the present study, we found that the predicted decrease in ventilation after sedation occurred in 18 of 20 patients, while an increase in CO_2 was observed in only 10 of 20 patients. The average change in MV by impedance following sedation was −48 %, and this was not accompanied by the expected increase in $ETCO_2$, but instead by an average decrease of 5 %. Representative tracings are displayed in Figs. 3 and 4 to demonstrate two phenomena that frame the weaknesses inherent with the use of the nasal cannula in GI sedation cases. Figure 3 depicts a patient with over a 50 % reduction in ventilation with little notable change in $ETCO_2$, although the trend for $ETCO_2$ to increase was appropriate. Figure 4 demonstrates a noteworthy amount of minute-to-minute changes in $ETCO_2$ that belie a true physiologic response. $ETCO_2$ values from 0 to 8 mmHg are interspersed with more likely values of 35–38 mmHg. Low $ETCO_2$ when expecting high $ETCO_2$ is likely a phenomenon of poor expiratory effort and the mixing of dead space gases with expired gases. This results in small, peaked waveforms rather than a squared waveform with the typical alveolar plateau.

MV monitoring via surface electrodes is not flawless. Electrode to skin interface deficiencies due to chest hair, skin adherence properties, and patient movement can disrupt the continuous signal detection, much like a poorly adhering ECG electrode.

5 Conclusion

Non-invasive ventilation monitoring is commercially available and makes use of bio-impedance technology to detect air movement within the thorax. We believe that ventilation monitoring may provide an element of safety for early and more reliable detection of reduced ventilation in patients undergoing sedation for GI procedures in an out-of-OR setting.

Financial disclosure The authors received no financial assistance for this study. As a quality assurance study, the Clement J. Zablocki VA Medical Center provided the electrodes for the ExSpiron monitor.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to report.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent These data were gathered as part of a QI Project, and for this type of study, formal consent is not required.

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