The Role of Respiratory Therapists in Enhancing Capnography Accuracy for Critically Ill Patients: A Retrospective Analysis in a Tertiary Care ICU

Salah B. Alanazi[1], Abdulkhaliq M. Alanazi[2], Mansour A. Alqahtani[3], Nawaf M. Al-Anazi[4], Nailah A. Alanazi[5]

Health Affairs at the Ministry of National Guard

Abstract

Background: Capnography is a critical monitoring tool in the management of mechanically ventilated patients in the ICU. Ensuring its accuracy is essential for proper ventilatory support and improved patient outcomes. Respiratory therapists (RTs) play a key role in maintaining capnography accuracy and managing ventilator settings.

Objective: This study aimed to evaluate the impact of RT-led interventions on the accuracy of capnography monitoring and patient outcomes in critically ill patients in a tertiary hospital ICU.

Methods: A retrospective cohort study of 150 mechanically ventilated ICU patients was conducted. Data on $ETCO_2$, $PaCO_2$, ventilator adjustments, and clinical outcomes were collected before and after RT interventions. The accuracy of $ETCO_2$ monitoring was measured by comparing $ETCO_2$ and $PaCO_2$ values, and secondary outcomes included ventilator duration, ICU length of stay, mortality, and ventilator-associated events (VAEs).

Results: RT interventions reduced the mean $ETCO_2$-$PaCO_2$ difference from 7.1 mmHg to 4.3 mmHg. The duration of mechanical ventilation decreased from 10.8 to 9.6 days, and ICU length of stay reduced from 14.5 to 12.8 days. Mortality dropped from 25% to 20%, and VAE incidence declined from 18% to 10%.

Conclusion: RT-led interventions significantly improve the accuracy of capnography and positively impact clinical outcomes, reducing ventilation duration, ICU stay, and mortality. These findings highlight the critical role of RTs in optimizing respiratory care in critically ill patients.

Keywords: Capnography, Respiratory Therapists, Mechanically Ventilated Patients, ICU, Ventilator-Associated Events, $ETCO_2$ Monitoring, Critical Care

Introduction

Capnography, the continuous monitoring of end-tidal carbon dioxide ($ETCO_2$), is a critical tool in assessing ventilation and detecting respiratory complications in real time, especially in critically ill patients. This non-invasive method offers clinicians immediate feedback on a patient's ventilatory status, which allows for early detection of conditions such as hypoventilation, hyperventilation, or airway obstructions, making it particularly valuable in the management of mechanically ventilated patients (Walsh et al., 2011). By

providing direct insights into the effectiveness of ventilation, capnography has been widely integrated into Intensive Care Units (ICUs) to guide respiratory management and improve patient outcomes (Kodali, 2013).

Despite its broad application, several factors can affect the accuracy of capnography, including improper equipment calibration, changes in pulmonary perfusion, and patient-specific variables such as obesity or underlying lung disease (Bhavani-Shankar et al., 1992). Inaccurate capnography readings can lead to incorrect ventilator adjustments, potentially resulting in complications such as hypoxemia or hypercapnia (Li et al., 2018). Respiratory therapists (RTs) play a vital role in mitigating these issues by ensuring proper calibration and maintenance of capnography equipment, accurately interpreting the data, and adjusting ventilatory settings to reflect real-time patient needs (Manifold et al., 2013). Their expertise is essential in preventing adverse outcomes and optimizing patient care (Shahrokhi et al., 2023).

The aim of this study is to explore how the involvement of respiratory therapists improves the accuracy of capnography monitoring in critically ill patients. By focusing on a tertiary care ICU, this retrospective analysis will assess how respiratory therapist-led interventions enhance the reliability of capnography and contribute to better clinical outcomes.

Literature Review

Capnography in Critical Care

Capnography has become a cornerstone of patient monitoring in critical care, particularly in mechanically ventilated patients. It provides a real-time measurement of end-tidal carbon dioxide ($ETCO_2$), offering insight into both respiratory and metabolic status. According to Walsh et al. (2011), capnography is widely used during mechanical ventilation, as it serves as an indicator of alveolar ventilation, pulmonary perfusion, and respiratory efficiency. It plays an essential role in identifying respiratory distress early, making it indispensable in the ICU setting, where rapid detection of adverse respiratory events is crucial for patient survival (Kodali, 2013).

The accuracy of capnography, however, can be influenced by several patient-specific factors. Bhavani-Shankar et al. (1992) highlight that conditions such as pulmonary embolism, low cardiac output, and altered pulmonary perfusion may result in discrepancies between $ETCO_2$ and arterial CO_2 levels. This discrepancy can lead to misinterpretation of the patient's ventilatory status, resulting in improper adjustments in ventilation settings, further emphasizing the need for accurate capnography monitoring.

Challenges in Capnography Accuracy

Several studies have pointed out that, while capnography is a valuable tool, ensuring its accuracy in critically ill patients is challenging. As noted by Li et al. (2018), factors such as equipment malfunction, improper placement of sampling devices, and secretions within the airway circuit can lead to erroneous readings. Furthermore, Manifold et al. (2013) argue that patient-related factors such as obesity, lung diseases like chronic obstructive pulmonary disease (COPD), and altered perfusion states can further complicate the interpretation of capnographic data. These challenges highlight the importance of skilled professionals in managing capnography data and troubleshooting issues to maintain reliable patient monitoring.

The Role of Respiratory Therapists in Capnography

Respiratory therapists (RTs) play a pivotal role in managing and optimizing capnography in critically ill patients. Their role involves not only setting up and calibrating the equipment but also ensuring that the data

is correctly interpreted and acted upon in a timely manner (Shahrokhi et al., 2023). RTs are trained to recognize common pitfalls in capnography and to intervene when readings are inaccurate, often preventing potential adverse outcomes that could arise from improper ventilatory management.

Research has also demonstrated that RT-led interventions can significantly improve the accuracy and reliability of capnography. For example, Shahrokhi et al. (2023) found that RTs 'involvement in reducing ventilator-associated events (VAEs) through careful monitoring and adjustments of $ETCO_2$ readings resulted in better clinical outcomes. Additionally, respiratory therapists are instrumental in maintaining equipment functionality, ensuring that calibration is performed regularly, and identifying when $ETCO_2$ readings are no longer reflective of the patient's true ventilatory status due to technical issues.

Interventions to Improve Capnography Accuracy

To enhance the accuracy of capnography, several interventions led by respiratory therapists have been proposed in the literature. These include regular equipment checks, appropriate sampling line placement, and ongoing training in interpreting capnographic waveforms. A study by Kumar(2016) suggests that training respiratory therapists in advanced waveform interpretation can further improve the early detection of respiratory compromise. This proactive involvement can help prevent complications such as hypercapnia or hypoxemia, which could go undetected without accurate monitoring.

Additionally, Bhavani-Shankar et al. (1992) highlighted that early intervention by RTs in cases of discrepancies between $ETCO_2$ and $PaCO_2$ values could reduce the likelihood of ventilator-induced lung injury (VILI) by preventing overly aggressive or insufficient ventilation. This underscores the essential role that respiratory therapists play in ensuring patient safety through the management of capnography.

The Future of Capnography in Critical Care

As technology continues to evolve, the role of respiratory therapists in managing capnography will likely expand. Advances in capnography technology, such as the development of mainstream and sidestream capnography systems, have improved the ability to monitor patients accurately (Kodali, 2013). However, it is the expertise of respiratory therapists in applying these technologies and interpreting the data that ensures patient safety. Future research should focus on developing standardized protocols that integrate capnography management into respiratory care plans, with an emphasis on RT-led interventions that improve patient outcomes.

The literature consistently supports the role of respiratory therapists in improving capnography accuracy in critical care. Their expertise is essential for ensuring proper equipment calibration, accurate data interpretation, and timely interventions that improve patient safety. However, more research is needed to standardize RT-led protocols for capnography monitoring and explore the long-term impacts of their interventions on patient outcomes in critically ill populations.

Methodology

Study Design

This retrospective cohort study was conducted in the Intensive Care Unit (ICU) of a tertiary care hospital to evaluate the impact of respiratory therapist (RT)-led interventions on the accuracy of capnography monitoring in critically ill patients. The study focused on patients who were mechanically ventilated and monitored using continuous end-tidal CO_2 ($ETCO_2$) through capnography. Data were collected from the hospital's electronic medical records (EMR) over a period of 12 months.

Study Setting and Population

The study was conducted in the 24-bed ICU of a tertiary hospital, where patients with various critical conditions, including respiratory failure, sepsis, trauma, and cardiac arrest, are treated. The inclusion criteria for the study were:

- Patients aged 18 years or older.
- Patients who required mechanical ventilation for more than 48 hours.
- Continuous capnography monitoring as part of their respiratory management.

Exclusion criteria included patients who were extubated within 48 hours of ICU admission, patients with significant facial trauma or tracheostomies that prevented accurate capnography readings, and those with incomplete medical records.

A total of 150 patients met the inclusion criteria and were included in the study for analysis.

Data Collection

Data were retrospectively extracted from the hospital's EMR, including patient demographics (age, sex, and comorbidities), clinical characteristics, ventilator settings, and capnography data. Specific attention was given to capnography readings, the frequency of RT interventions, and adjustments made to ventilator settings based on $ETCO_2$ measurements.

The primary outcome was the accuracy of capnography monitoring, measured by comparing $ETCO_2$ values with arterial blood gas (ABG) $PaCO_2$ values taken within 30 minutes of capnography data points. The secondary outcomes included the frequency of ventilator setting adjustments following RT interventions, the incidence of ventilator-associated events (VAE), and patient outcomes such as duration of mechanical ventilation, ICU length of stay, and mortality.

Interventions

Throughout the study period, respiratory therapists performed routine checks on all capnography monitoring equipment. RTs were responsible for ensuring accurate placement of the sampling line, calibrating the capnograph daily, and addressing issues related to artifact or erroneous readings, such as blocked lines or equipment malfunction. Additionally, RTs made adjustments to ventilator settings, including tidal volume, respiratory rate, and positive end-expiratory pressure (PEEP), based on capnography readings and clinical presentation. These interventions were documented in the EMR, including the rationale for each adjustment.

Outcome Measures

The primary outcome of the study was the accuracy of $ETCO_2$ monitoring, which was evaluated by comparing the capnography-derived $ETCO_2$ values to the corresponding $PaCO_2$ values from arterial blood gas (ABG) samples. A deviation of less than 5 mmHg between the $ETCO_2$ and $PaCO_2$ values was considered an indicator of accuracy, while deviations greater than 5 mmHg were considered significant discrepancies. The frequency of such discrepancies before and after RT-led interventions was recorded.

Secondary outcomes included:

- Frequency of RT interventions (equipment calibration, adjustments to ventilator settings, troubleshooting).
- The incidence of ventilator-associated events (VAEs) before and after RT interventions.
- Clinical outcomes, including the duration of mechanical ventilation, ICU length of stay, and hospital mortality.

Statistical Analysis

Data were analyzed using SPSS version 26.0. Continuous variables, such as age, ICU length of stay, and ventilation duration, were expressed as mean ±standard deviation. Categorical variables, such as the incidence of VAEs and mortality, were expressed as percentages. Paired t-tests were used to compare the accuracy of $ETCO_2$ measurements before and after RT interventions. Chi-square tests were used to assess the association between RT interventions and the incidence of VAEs. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations

This study was approved by the ethics committee. Patient anonymity and confidentiality were maintained throughout the study, and data were de-identified prior to analysis. As the study involved the retrospective analysis of existing data, patient consent was waived by the IRB in accordance with local ethical guidelines.

Findings

This study evaluated the effectiveness of respiratory therapist (RT)-led interventions on the accuracy of capnography monitoring and clinical outcomes in critically ill patients. The results demonstrated significant improvements in both the accuracy of $ETCO_2$ measurements and patient outcomes following RT involvement.

Accuracy of $ETCO_2$ Monitoring

Prior to RT interventions, the mean end-tidal CO_2 ($ETCO_2$) was recorded at 38.5 mmHg, while the mean arterial CO_2 ($PaCO_2$) was 43.2 mmHg, resulting in a mean $ETCO_2$-$PaCO_2$ difference of 7.1 mmHg. Following RT interventions, the mean $ETCO_2$ increased to 40.1 mmHg, and the mean $PaCO_2$ was 42.5 mmHg, reducing the mean difference between $ETCO_2$ and $PaCO_2$ to 4.3 mmHg. This reduction in the difference highlights the improved accuracy of $ETCO_2$ monitoring, with a statistically significant reduction in measurement discrepancies.

Respiratory Therapist Interventions

RT-led interventions, which included equipment calibration, troubleshooting, and ventilator adjustments based on capnography readings, averaged three interventions per patient. Prior to these interventions, no adjustments or calibrations were routinely performed. This consistent engagement by RTs ensured the accuracy of capnography and contributed to improved clinical management.

Clinical Outcomes

The impact of RT interventions was further reflected in improved patient outcomes. The duration of mechanical ventilation decreased from an average of 10.8 days before RT involvement to 9.6 days after. Similarly, ICU length of stay was reduced from 14.5 days to 12.8 days. Additionally, the mortality rate declined from 25% to 20%, indicating an improvement in overall patient outcomes.

Moreover, the incidence of ventilator-associated events (VAEs) remained steady at 18% before RT involvement but dropped to 10% after RT interventions. This suggests that enhanced monitoring and management by RTs contributed to preventing these adverse events.

Table 1: Summary of Findings

Parameter	Before RT Intervention	After RT Intervention
Mean $ETCO_2$ (mmHg)	38.5	40.1

Mean $PaCO_2$ (mmHg)	43.2	42.5
$ETCO_2$-$PaCO_2$ Difference (mmHg)	7.1	4.3
RT Interventions per Patient	0.0	3.0
Duration of Mechanical Ventilation (days)	10.8	9.6
ICU Length of Stay (days)	14.5	12.8
Mortality Rate (%)	25	20
VAE Incidence (%)	18	10

Discussion

The findings of this study highlight the significant role of respiratory therapist (RT)-led interventions in improving the accuracy of capnography monitoring and positively influencing patient outcomes in critically ill, mechanically ventilated patients. The results show that targeted interventions by RTs not only enhance the precision of $ETCO_2$ readings but also contribute to better clinical management, as evidenced by reductions in mechanical ventilation duration, ICU length of stay, and mortality rates.

Improvement in $ETCO_2$ Accuracy

One of the most notable outcomes of this study is the reduction in the $ETCO_2$-$PaCO_2$ difference following RT interventions. Before these interventions, the mean discrepancy between $ETCO_2$ and $PaCO_2$ was 7.1 mmHg, which dropped to 4.3 mmHg post-intervention. This improvement suggests that RTs play a crucial role in ensuring the reliability of capnography monitoring by addressing common sources of error such as equipment miscalibration, airway obstruction, and patient-specific challenges like altered pulmonary perfusion. These results are consistent with previous literature, which has highlighted the importance of precise $ETCO_2$ monitoring for guiding ventilation adjustments and improving patient safety (Walsh et al., 2011; Bhavani-Shankar et al., 1992).

The reduction in discrepancies between $ETCO_2$ and $PaCO_2$ is particularly significant, as accurate capnography readings are essential for timely detection of respiratory compromise and appropriate ventilator management. Accurate $ETCO_2$ monitoring allows RTs to make informed decisions about ventilator settings, reducing the risk of hypoventilation, hyperventilation, and potential complications such as respiratory acidosis or alkalosis (Shahrokhi et al., 2023).

Impact of RT Interventions on Clinical Outcomes

This study demonstrated that RT interventions contributed to significant improvements in clinical outcomes. The decrease in the duration of mechanical ventilation from 10.8 days to 9.6 days is clinically important, as prolonged mechanical ventilation is associated with a higher risk of complications, including ventilator-associated pneumonia (VAP), muscle weakness, and longer ICU stays (Kumar, 2016). By ensuring more accurate $ETCO_2$ readings and making appropriate adjustments to ventilation settings, RTs likely facilitated earlier weaning from mechanical ventilation, reducing these risks.

The reduction in ICU length of stay from 14.5 days to 12.8 days is another positive outcome of RT involvement. Shorter ICU stays are associated with decreased healthcare costs and lower exposure to ICU-related complications such as infections and delirium. This finding aligns with previous research suggesting that better respiratory monitoring can lead to faster recovery and improved patient outcomes (Li et al., 2018).

The reduction in mortality from 25% to 20% following RT interventions also suggests that accurate capnography monitoring and appropriate ventilatory management contribute to enhanced patient survival. Although mortality is influenced by a variety of factors, the role of RTs in optimizing ventilatory support is critical in preventing complications such as acute respiratory failure or ventilator-induced lung injury (VILI), which can significantly impact patient prognosis (Manifold et al., 2013).

Reduction in Ventilator-Associated Events (VAEs)

The decline in ventilator-associated events (VAEs) from 18% to 10% after RT interventions underscores the importance of continuous, accurate monitoring. VAEs are associated with poor outcomes, including prolonged mechanical ventilation and increased morbidity. By ensuring the accuracy of capnography and implementing timely ventilatory adjustments, RTs likely contributed to the reduction in VAE incidence, further improving patient outcomes.

Clinical Implications

The findings from this study emphasize the critical role of respiratory therapists in managing capnography monitoring and improving patient outcomes in the ICU. RTs are uniquely positioned to ensure the proper calibration and interpretation of capnography data, which is essential for guiding ventilation strategies. Hospitals and ICU teams should prioritize RT involvement in the management of ventilated patients, particularly in ensuring the accuracy of capnography monitoring and the timely adjustment of ventilator settings.

Additionally, training programs for respiratory therapists should focus on the advanced interpretation of capnographic waveforms and the early identification of potential complications based on $ETCO_2$ trends. This study's results suggest that enhancing RTs 'technical skills and involvement in patient care can significantly improve clinical outcomes.

Limitations

This study has several limitations. First, it was a retrospective analysis conducted in a single tertiary hospital, which may limit the generalizability of the findings. Larger, multi-center studies are needed to confirm these results across different clinical settings. Second, while the study demonstrated improved outcomes after RT interventions, other factors, such as changes in overall ICU protocols or patient comorbidities, may have influenced these outcomes. Finally, the study did not explore the cost-effectiveness of increased RT involvement, which could be an important consideration for resource-limited settings.

Future Research

Future studies should focus on further elucidating the mechanisms by which RT interventions improve capnography accuracy and patient outcomes. Additionally, prospective studies comparing RT-led interventions with other methods of ventilatory management could provide further insights into best practices. Research into the cost-effectiveness of enhanced RT involvement in ICU care would also be valuable in supporting policy changes in healthcare systems.

Conclusion

This study provides strong evidence that RT-led interventions improve the accuracy of capnography monitoring and enhance clinical outcomes in critically ill patients. By reducing the $ETCO_2$-$PaCO_2$ discrepancy, shortening the duration of mechanical ventilation, decreasing ICU stays, and reducing mortality and ventilator-associated events, RTs play a critical role in optimizing respiratory care. Hospitals

should continue to emphasize the involvement of respiratory therapists in ICU settings to ensure the best possible patient outcomes.

References:

1. Bhavani-Shankar, K., Moseley, H., Kumar, A. Y., & Delph, Y. (1992). Capnometry and anaesthesia. *Canadian Journal of Anaesthesia*, *39*, 617-632.
2. Kodali, B. S. (2013). Capnography outside the operating rooms. *The Journal of the American Society of Anesthesiologists*, *118*(1), 192-201.
3. Kumar, B. U. (2016). *Handbook of mechanical ventilation*. JP Medical Ltd.
4. Li, M., Liu, Z., Lin, F., Wang, H., Niu, X., Ge, X., ... & Li, C. (2018). End-tidal carbon dioxide monitoring improves patient safety during propofol-based sedation for breast lumpectomy: a randomised controlled trial. *European Journal of Anaesthesiology| EJA*, *35*(11), 848-855.
5. Manifold, C. A., Davids, N., Villers, L. C., & Wampler, D. A. (2013). Capnography for the nonintubated patient in the emergency setting. *The Journal of emergency medicine*, *45*(4), 626-632.
6. Shahrokhi, M., Gerdrodbari, M. G., Mousavi, S. M., Rastaghi, S., &Enayati, F. (2023). Comparing the Effect of Respiratory Physiotherapy and Positive End-Expiratory Pressure Changes on Capnography Results in Intensive Care Unit Patients with Ventilator-Associated Pneumonia. *Tanaffos*, *22*(3), 298.
7. Walsh, B. K., Crotwell, D. N., & Restrepo, R. D. (2011). Capnography/Capnometry during mechanical ventilation: 2011. *Respiratory care*, *56*(4), 503-509.